Multi-hazard risk assessment

Distance education course

Guide book

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Table of contents:

Introduction

The world is confronted with a rapidly growing impact of disasters, due to many factors that cause an increase in the vulnerability of society combined with an increase in (hydrometeorological) hazard events related to climatic change. The possible impacts of hazardous events are large, especially in developing countries and governments have to incorporate risk reduction strategies in development planning at different levels. The evaluation of the expected losses due to hazardous events requires a spatial analysis, as all components of a risk assessment differ in space and time. Therefore risk assessment can only be carried out effectively when it is based on extensive, multidisciplinary studies on the basis of spatial information, derived from Remote Sensing and other sources. There is an urgent need to include the concepts of disaster geo-information management into emergency preparedness planning, spatial planning and environmental impact assessment. This requires capacity building and training of disaster management experts and professionals, such as planners, engineers, architects, geographers, environmental specialists, university teachers etc. The Hyogo framework of action 2005-2015 of the UN-ISDR indicates risk assessment and education as two of the key areas for the development of action in the coming years.

A number of organizations are specialized in providing short training courses on disaster risk management related issues. Some organizations have also prepared training materials that are accessible through the internet (see examples in box left). Most of these however are concentrating on community-based methods. Disaster risk management courses at BSc or MSc level are now available in many Universities in all continents.

Relatively few training materials are available on multi-hazard risk assessment. Good textbooks on the subject are still not available. Online training materials can be obtained for example from the websites of FEMA and EMA. The development of innovative forms of learning and teaching oriented towards building new curricula in the field of natural risk has attracted attention in European initiatives such as DEBRIS and NAHRIS.

As far as GIS-related material related to multi-hazard risk assessment is concerned, the HAZUS methodology developed in the US can be considered the standard. This comprehensive loss estimation software which runs under ARCGIS is a very good tool for carrying out loss estimations for earthquakes, flooding and windstorms (FEMA), but is restricted to use in the USA, due to constraints in the data and the classifications used for elements at risk and fragility curves. The manuals of Hazus, however, provide a very good overview of the entire process of multi-hazard risk assessment. Courses on the use of HAZUS can be followed online from the ESRI Virtual Campus. However, complete GIS based training packages on spatial hazard and risk assessment using low-cost or free GIS software are still very scarce, to the knowledge of the author. One example is a training package in English and Spanish developed for Central America in the framework of the UNESCO RAPCA project (ITC).

Hyogo framework for action 2005-2015.

Priorities for action:
1. Ensure that disaster risk reduction is a national and a local priority with a strong institutional basis for implementation
2. Identify, assess and monitor disaster risks and enhance early warning
3. Use knowledge, innovation and education to build a culture of safety and resilience at all levels
4. Reduce the underlying risk factors
5. Strengthen disaster preparedness for effective response at all levels
:
http://www.unisdr.org/eng/hfa/hfa.htm

Some organizations that offer training courses on Geoinformation for Disaster Risk Management

Asian Disaster Preparedness Center
http://www.adpc.net
Provention consortium
http://www.proventionconsortium.org/
Worldbank on-line courses
http://go.worldbank.org/RUY76WGVO1
Pacific Disaster Center
http://www.pdc.org/iweb/pdchome.html
ESRI
http://training.esri.com/Courses/
FEMA
http://www.fema.gov/plan/mitplanning/planning_resources.shtm
UNU ESD
http://www.unu.edu/esd/
ITC UNU-ITC DGIM
http://www.itc.nl/unu/dgim/
IIRS, India
http://www.iirs-nrsa.gov.in/
UGM, Indonesia
http://geo.ugm.ac.id/en/
AIT-GIC, Thailand
http://www.geoinfo.ait.ac.th/
CIGA, UNAM, Mexico
http://www.ciga.unam.mx/
CLAS, Bolivia
http://www.clas.umss.edu.bo/

This course intends to fill this gap and provide you with practical hands-on experience on how you can use spatial information for hazard, vulnerability and risk assessment.

Objectives

This course deals with the procedures to collect, analyse and evaluate spatial information for risk assessment from natural and human-induced hazards (such as geological hazards, hydrometeorological hazards, environonmetal hazards and technological hazards). The course will guide you through the entire process of risk assessment, on the basis of a case study of a city exposed to multiple hazards, in a developing country (RiskCity).

At the end of this course you will be able to:

1. understand the concepts of hazard assessment, elements at risk mapping, vulnerability assessment, and risk assessment;
2. formulate the spatial data requirements for risk assessment;
3. generate an elements at risk data base using GIS;
4. formulate the requirements of hazard data and methods;
5. apply various methods for vulnerability assessment;
6. generate risk maps using qualitative and quantitative methods;
7. have insight in how a risk assessment could be carried out in your own situation;

This course is designed for all those who have to carry out risk assessment and need knowledge and skills on the procedures to do that using a GIS. These include professionals working in NGOs and governmental organisations related with disaster risk management, but also professionals, planners, engineers, architects, geographers, environmental specialists, university teachers. Some basic background in Geographic Information Systems is desirable, although not strictly required, as the course follows a step-by-step approach which allows participants to rapidly acquire the basic skills in handling GIS software. If you lack the basic GIS skills it might be better to follow the course in a classroom environment, where more direct support on the software can be given. Courses on multi-hazard risk assessment are offered annually in the Netherlands, Mexico, Bolivia, and Thailand, and frequently also in India and China.

Partner organizations involved in the development of this package:

http://www.itc.nl/unu/dgim/ http://www.ehs.unu.edu/ http://www.unu.edu/esd/

http://www.geohp.com/lab http://www.adpc.net

http://www.geoinfo.ait.ac.th/ http://www.clas.umss.edu.bo/ http://www.ciga.unam.mx/

Course structure

The course is composed of a number of sessions. Below is a summary of the sessions and detailed content.

Session 0: Getting started

Theory: Introduction to the course, objectives, structure, and set-up. Explanation of the available materials.

Activities: Set up Blackboard account, install ILWIS software, getting to know the tutors and fellow students.

Session 1: Introduction to disaster risk management

Theory: Introduction to disaster risk management and risk assessment.

Exercise: Generation of a hazard profile using disaster databases; Introduction to ILWIS, and introduction to the RiskCity dataset. Learn the various hazard problems by evaluating high resolution images

Session 2: Obtaining spatial data for risk assessment

Theory: Presentation of data requirements for the various types of hazards. Sources of spatial data.

Exercises: Defining spatial data requirements for risk assessment; Internet search for information on risk assessment; acquiring free and low cost data; generating three dimensional image data using Google Earth; stereo image interpretation

Session 3: Hazard Assessment

Theory: Hazard types; Main concepts of hazard assessment; Frequency magnitude – relationships

Exercises: Frequency assessment; Selection of hazard assessment example (flooding, landslides, earthquakes, technological hazards, volcanic hazards etc)

Session 4: Elements at risk assessment

Theory: Types of elements at risk; classification of buildings, infrastructure, lifelines, critical facilities; population information; collection of elements at risk information.

Exercise: Generating an elements at risk database from scratch; Generating an elements at risk database using available data (building footprint map, census data and LiDAR)

Session 5: Vulnerability assessment

Theory: Types of vulnerability; social vulnerability; physical vulnerability; methods for vulnerability assessment; participatory GIS; Spatial Multi Criteria Evaluation

Exercises: Defining vulnerability curves; Spatial Multi-criteria evaluation for vulnerability assessment

Session 6: Risk estimation

Theory: Loss estimation models; HAZUS; qualitative risk assessment; QRA; basics of flood risk, seismic risk, landslide and technological risk assessment;

Exercises: Creating risk curves; Selection of risk assessment method: flooding, earthquakes, landslides, technological.

Session 7: Risk management

Theory: Risk evaluation; risk governance; risk communication; cost benefit analysis; Using risk information for emergency planning; spatial planning, and Environmental Impact Assessment

Exercises Multi-hazard risk assessment for buildings; assessing economic losses; Cost benefit analysis

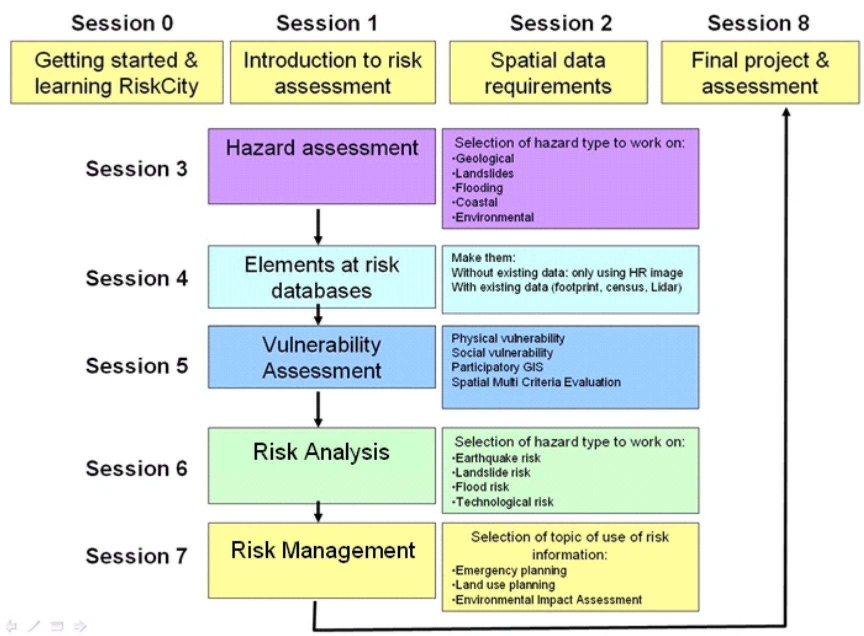
Session 8: Final project and examination

Discussion: How to do such a study in your area?

Final project: Selection of project topic related to risk assessment and its use in risk management

Examination: multiple choice exam.

The figure below illustrates the course structure:



The table below gives an overview of the sessions and related RiskCity exercises.

Session		RiskCity exercise
1. Introduction to Risk Assessment		Exercise 1: Introduction to ILWIS and the Riskcity dataset
2. Spatial data for risk assessment		Exercise 2: Creating and interpreting multi-temporal images
3. Hazard assessment		Exercise 3a: Frequency assessment
	Choice: flooding	Exercise 3F1: Flood hazard assessment using 2D flood propagation model outputs
		Exercise 3F2: Flood hazard monitoring using multi- temporal SPOT-XS imagery
	Choice landslides	Exercise 3L1. Landslide susceptibility assessment using statistical method
		Exercise 3L2. Deterministic landslide hazard assessment
	Choice: Volcanics	Exercise 3V: Modeling erosion from pyroclastic flow deposits on Mount Pinatubo
	Choice: Earthquakes	Exercise 3E: Earthquake hazard assessment
	Choice: Coastal	Exercise 3C1: Hazard analysis of cyclone flooding in Bangladesh
		Exercise 3C2: Analysis of coastal areas vulnerable to Enhanced Sea Level Rise
		Exercise 3C3: Modeling of Land Subsidence & Sea level rise in Semarang city, Indonesia
4. Elements at risk	Choice options	Exercise 4a: Generating a database of elements at risk from scratch
		Exercise 4b: Generating a database of elements at risk using existing data
		Exercise 4c: Participatory GIS for risk assessment.
5. Vulnerability assessment		Exercise 5a. Generating vulnerability curves
		Exercise 5b. Spatial Multi Criteria Evaluation for vulerability and qualitative risk assessment
6. Risk Assessment	Choice options	Exercise 6F: Flood risk assessment
		Exercise 6L: Landslide risk assessment
		Exercise 6S: Seismic risk assessment
		Exercise 6T: Technological risk assessment
		Exercise 6M : Multi-hazard risk assessment
7. Risk Management		Exercise 7b: Risk information for emergency preparedness & response
		Exercise 7a. Analysis of costs & benefits of risk reduction scenarios
8. Final project		Select a topic from a list and carry out your own analysis

Software

The course uses standard software like Adobe Acrobat Reader (Click here to download it if you don't have it yet), Microsoft Excell, Windows Media Player

The course is based on the use of Open-Source software. Open Source software has a number of criteria (http://www.opensource.org/docs/definition.php), some of which are:

- Freely distributed, downloadable from the Internet
- Access to the source code of the software
- Allows modifications or additions to the programme
- No discrimination against persons

ILWIS

The main software that will be used for all the GIS exercises that are part of this course written for the ILWIS software. ILWIS is an acronym for the Integrated Land and Water Information System. It is a Geographic Information System (GIS) with image processing capabilities. ILWIS has been developed by the International Institute for Geoinformation Science and Earth Observation (ITC), Enschede, The Netherlands.

ILWIS is a remote sensing and GIS software which integrates image, vector and thematic data in one unique and powerful package on the desktop. ILWIS delivers a wide range of features including import/export, digitizing, editing, analysis and display of data, as well as production of quality maps. ILWIS software is renowned for its functionality, and user-friendliness, and has established a wide user community over the years of its development. Even after its last commercial release in 2005, its user community has remained active, both within and outside ITC.
ILWIS is an open source software, and can be downloaded from the following web-site: http://52north.org/ilwis

ILWIS 3.4 Open is included on your course DVD in the ...Software\ILWIS 3.4 Open\ folder.

To install the software, run the ILWIS34setup.exe program.

In the Software\ILWIS 3.4 Open\User's Guide folder you will find the ILWIS 3.0 Academic User's Guide in PDF format.

Installation of supporting software

The following tools are available on your CD-ROM:

Acrobat Reader:	to open PDF files. Many files of the course material are in PDF format.
MediaPlayer:	used for Video-lectures and other multimedia.
Flash Player:	used to open the animations attached to the e-lectures
ShockWave-PlugIn:	used for playing video animations related to web sites.

! Some functions of the e-lectures need Microsoft Internet Explorer. Please make it sure that you use this browser as the default when running the e-lectures.

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We would like to thank the following persons for their permission to use certain parts of the materials:
Session 1:
Session 2:
Session 3:
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Session 6:
Session 7: Barend Köbben, Rob Lemmens, Emile Dopheide
RiskCity exercises : Manolo Barillas, Graciela Peters Guarin

Disclaimer:

This book is still a draft version. It still has to go through a reviewing phase, so there may be quite some mistakes in it. We would appreciate it if you could report any mistakes to us. This can be done by sending an e-mail to **westen@itc.nl**, in which you indicate the page number and the problem.

In this book we have tried our best to indicate the sources of information. If you feel that we have omitted to indicate the source properly, please inform us.

Structure of the training materials

The training materials will consist of:

A guide book,

consisting of 8 chapters and an introduction, following the same structure as the sessions explained above. The guide book will contain for each session:

- **Theoretical background**, which guide you through the session and which contain theoretical parts, highlighting the main theoretical aspects, mixed with short assignments and questions, and links to relevant internet sites.
- **Tasks:** mixed with the theory of the guide book you will find a number of taks where you are asked to carry out certain small assignments, which will make you understand the theory better, and apply it to your own situation. The answers to the tasks don't have to be submitted for the course
- **Selftests:** each session has a selftest.

A RiskCity exercise book

RiskCity exercise descriptions. The exercises are written in such a way that whenever students have to carry out an action with GIS this is written in a light green box. Normally the exercise instructions are given completely (so-called "cook book style") so that it is easier to carry out the instructions also for people with no experience in ILWIS. There are also additional optional exercises which require more knowledge on the software, and which are indicated as "Optional exercise for experienced ILWIS users". These instructions are not in "cook book style", and require more knowledge on how to solve a particular problem with ILWIS. Non experienced ILWIS users might like to skip these exercises in the beginning.

A DVD

Digital datasets of RiskCity for each exercise. Each exercise has its own data, which are stored in a separate subdirectory. Results from one exercise that are needed for the next, are provided in the dataset of the next exercise, so you start each exercise with a "clean slate"

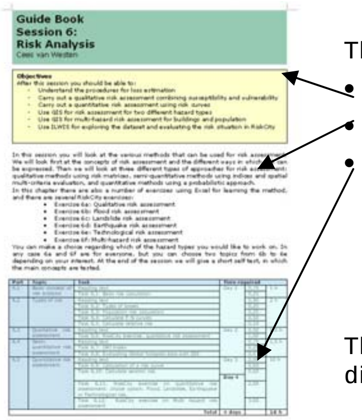
- An introduction video for the course.
- The ILWIS software with its users guide.
- Some other generic software needed to follow the course (Acrobar reader etc.)
- The Guide Book chapters as PDF files
- The RiskCity exercise descriptions as PDF files.
- The data for the RiskCity exercises.

Blackboard

The course has also an internet site with educational support software (Blackboard), which can be reached through: bb.itc.nl It containing all materials and the tools for communication, and uploading of results

- All Guide book chapters, and RiskCity exercises as PDF files
- The answers to the selftests of the Guide Book
- Answer sheets for the RiskCity exercises
- Discussion board for the answers of the tasks.

How to use the Guide Book



The Guide Book contains 8 sessions. Each session starts with:

- The objectives of the session
- A description of the contents of the session
- A table with an overview of the sessions, it different sections and the tasks within each section. Also for each section and tasks the time required is indicated. Also the total time needed for the session is indicated in number of days, assuming that on average you will spend 4 hours a day on the course.

The Guide book contains different types of information. They are indicated in different colours.

Definitions and equations are always presented in such boxes with yellow color and red outline.

Task 1.1: Question (duration 5 minutes)

Each session contains a number of tasks that are related to the theory. Tasks are always indicated in these green boxes. For each task the time required is indicated. Each task is numbered. The task will be discussed on the Blackboard where you can discuss the answers with the other participants and with the staff.

Task 1.10: RiskCity exercise (duration 1 hour)

If the task refers to a RiskCity GIS exercise it is indicated in such types of boxes. In this case you have to look for the RiskCity exercise in the exercise book, and follow the instructions there. Once you finish the exercise, you proceed in the Guide Book. The answers to the exercise are available in Blackboard as answer sheets.

T
h
e

The Guide Book is the main source for the course. It is your guide and it indicates which tasks and GIS exercises should be done when. It also has a number of choices. These are particularly in session 3 on Hazard Assessment, where you can choose after session 3.3 one of the following topics (linked to sections of the guide book and separate Riskcity exercises):

- Landslide hazard
- Flood hazard
- Earthquake hazard
- Volcanic hazard
- Coastal hazards.

Also in session 4 there are two choices to make a RiskCity exercise: Generation of an elements at risk database from scratch", or "Generation of elements at risk database using existing data".

Finally also in session 6 (Risk Analysis) you can make a selection to do a quantitative risk assessment either for flooding, landslides, earthquakes or technological hazards.

Each session of the Guide Book ends with a selftest (you can find the answers on Blackboard) and literature references.

How to use the RiskCity exercise descriptions

The exercise descriptions contain different parts.

Information

Information written in normal text without colours are related to the explanation on the various procedures used throughout the manual.

ILWIS instructions

The exercises are written in such a way that whenever you have to carry out an action with GIS this is written in a light green box. Normally the exercise instructions are given completely (so-called "cook book style") so that it is easier to carry out the instructions also for people with no experience in ILWIS.

☞

- This is an example of a box containing the actual instructions on using the ILWIS software

Additional information

This is a textbox that contains additional information, e.g. on the specific aspects of the software or the GIS operations that are carried out. They sometimes refer also to the ILWIS Help or to other links

This is a an example of such a text box

ILWIS instructions for advanced users.

There are also additional exercises which require more knowledge on the software, and which are indicated as "Optional exercise for experienced ILWIS users". These instructions are not in "cook book style", and require more knowledge on how to solve a particular problem with ILWIS. If you are not an experienced ILWIS user you might like to skip these exercises in the beginning.

Answers

In many cases you are asked to provide the answer to a specific problem, and write these down in a table, indicated in Blue colour. These are also the answers that you should submit in the small report for uploading to the Blackboard after completing the exercise.

Below is an example of such an answer table.

Which signs can you see of a recent disaster in the area?	X	Y

Answer sheets

We have made an answer sheet for each exercise. This will help you in checking the results of your work. The answer sheets contains:

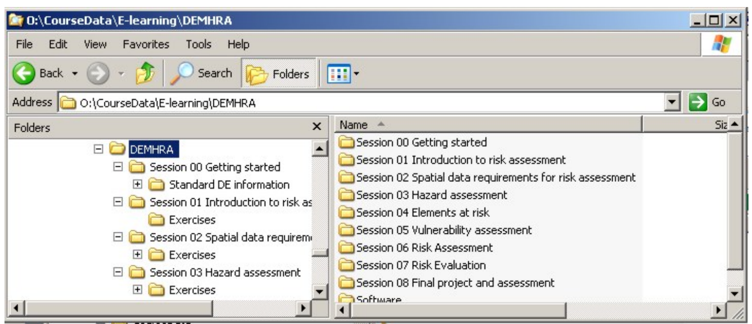
- The answers of the questions that are asked in the text.
- Screen shots of main result maps that have to be produced as part of the exercise, together with some additional explanation
- The procedure and answers of the Optional exercises for advanced ILWIS users.

Exercise data

The GIS data for the exercises has been prepared carefully, in order to avoid confusion during your work.

IMPORTANT:

- Each exercise has its own data, which are stored in a separate subdirectory. Results from one exercise that are needed for the next, are provided in the dataset of the next exercise, so you start each exercise with a "clean slate"
- Copy the exercise data in the same directory structure to your harddisk
- Work in the same subdirectory with the data for the specific exercise
- Do not copy the data from one directory to the other.



Guide book
Session 1:
Introduction to Disaster Risk Assessment

Cees van Westen

Objectives
After this session you should be able to:

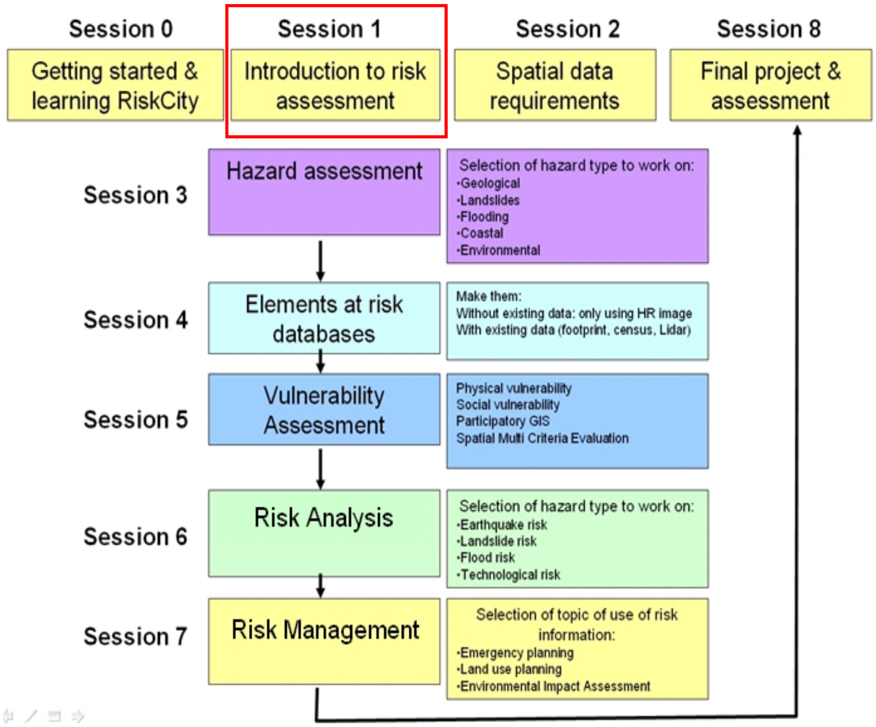
- Indicate the causal factors for disasters;
- Evaluate disaster databases and make a profile for your country;
- Find relevant information on disasters on the internet
- Understand the principles of disaster risk reduction;
- Indicate the components that make up a risk assessment
- Understand the main concepts of Risk City;
- Use WebGIS for exploring the data types needed for risk assessment
- Understand the main concepts of ILWIS;
- Use ILWIS for exploring the dataset and evaluating the risk situation in Risk City.

You will do this by using the following materials:
- The first part of the guidance notes deals with an introduction to disasters, disaster statistics, disaster management and risk assessment.
- The second part of the guidance notes deals with a brief introduction to the tools: WebGIS and the ILWIS software.
- RiskCity exercise 1: Introducing ILWIS and the dataset.
- Assignments: at the end of this session you are requested to carry out the following assignments and evaluations.
- As an overall task you are asked to make a disaster profile of a particular country (preferably you own country) in which you describe the main hazard types, areal extend, and losses due to disasters, using the various resources that will be treated in this chapter.

This table below gives an indication of the sections, tasks and the required time.

Section	Topic	Task	Time required		
1.1	Introduction to disasters		Day 1	1 h	2.8 h
		Task 1.1: Recent disaster		0.1 h	
		Task 1.2: what is a disaster		0.1 h	
		Task 1.3: Natural disaster?		0.1 h	
		Task 1.4: Nathan internet search		0.25 h	
		Task 1.5: Disaster databases		1.00 h	
		Task 1.6: Real time information		0.25 h	
		Tasks 1.7: Disaster profile		1.00 h	
1.2	Disaster Risk Management			0.5 h	0.65
		Task 1.8: video		0.15 h	
1.3	Risk Assessment		Day 2	0.5 h	0.65
		Task 1.9: Exposure		0.15 h	
1.4	RiskCity case study			0.5 h	0.5
1.5	The Tools: WebGIS and GIS			0.5 h	3.5 or 1.5
		Task 1.10: WebGIS exercise (optional)		1 h	
		Task 1.11: RiskCity exercise 1: Introduction to ILWIS and RiskCity		3 h	
				Total	**8.1 h**

1.1 Introduction to disasters



This chapter is the first of a total of 8 chapters that will guide you through the process of spatial multi-hazard risk assessment. This chapter will introduce the concepts of disasters, the types of disasters, their causes and statistics. After that a section deals with disaster risk management, before going to the concept of risk. An introduction is given of risk and risk assessment. The last part of the chapter has a description of the case study RiskCity and the OpenSource ILWIS software.

1.1.1 What are disasters?

Disasters appear on the headlines of the news almost every day. Most happen in far- away places, and are rapidly forgotten by the media. Others keep the attention of the world media for a large period of time. The events that receive maximum media attention are those that hit instantaneously and cause widespread losses and human suffering, such as earthquakes, floods and hurricanes. Recent examples are the Indian Ocean tsunami (2004), the earthquakes in Pakistan (2005), Indonesia (2006) and China (2008) and the hurricanes in the Caribbean and the USA (2005, 2008). On the other hand there are very serious slow onset geomorphologic hazards, such as soil erosion, land degradation, desertification, glacial retreat in mountains etc. that may cause much larger impacts on the long run but receive less media attention.

Task 1.1: Internet assignment (duration 10 minutes)
Know any recent disaster ?
Go to the internet page of your favorite newspaper or press agency and check for items related to disasters for the past few days. Alternatively if you don't have good internet access you may also consult your local newspaper for that.
Which events are reported ?

There are many ways in which you could define disasters:

Definitions of disaster:

- A serious disruption of the functioning of a community or a society causing widespread human, material, economic or environmental losses which exceed the ability of the affected community or society to cope using its own resources.

(Source: http://www.unisdr.org/eng/library/lib-terminology-eng%20home.htm)

- An extreme event within the earth's system (lithosphere, hydrosphere, biosphere or atmosphere) which differs substantially from the mean, resulting in death or injury to humans, and damage or loss of 'goods', such as buildings, communication systems, agricultural land, forest, and natural environment (Alexander, 1993)
- A disaster occurs when a significant number of vulnerable people experience a hazard and suffer severe damage and/or disruption of their livelihood system in such a way that recovery is unlikely without external aid. (Blaikie 1994)

When considering all definitions we can 'characterize' a disaster as:

- an extreme phenomenon (of different origins),
- of large intensity (e.g. a measurable quantity such as earthquake intensity, water depth)
- and limited duration (which can vary from seconds to months, but should be defined in time);
- occurring at a certain location (this spatial component will be very important in this course);
- involving a complex interplay between physical and human systems;
- causing loss of lives and threats to public health, as well as physical damage
- and disruption of livelihood systems and society;
- exceeding local capacities and resources;
- requiring outside assistance to cope with.

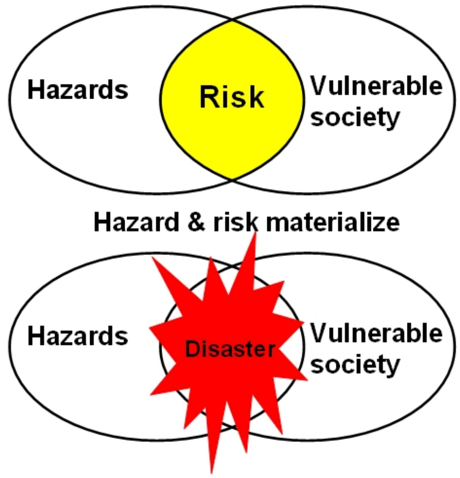


Figure 1.1: A disaster occurs when the threat of a hazard become reality, and impacts on a vulnerable society.

Task 1.2: Question (duration 5 minutes)
What is a disaster ?
To illustrate the above mentioned aspects, consider for yourself whether you would indicate the following situations a 'disaster':

1. *When you become ill, and cannot work anymore?*
2. *When a famous football player is injured and misses the most important match, and his team loses the word championship?*
3. *When does a car accident become a disaster? The annual financial cost of car accidents in the US is estimated to be around 230 Billion dollars, with 2.9 million injuries and around 43,000 casualties.*
4. *The death of 2,974 people in the attack on the Twin Towers on 9/11/2001?*
5. *The financial crises that hit the world in 2008?*
6. *Is HIV/AIDS a disaster?*

You can comment on these situations on the discussion forum in Blackboard. You can also come up with other examples that illustrate that the definition of 'disaster' is not a very straightforward one and can also been seen at the level (e.g. of an individual, family community, society)

It is important to distinguish between the terms *disaster* and *hazard*. A disaster is a function of the risk process. Risk results from the combination of hazards, conditions of vulnerability and insufficient capacity or measures to reduce the potential negative consequences of risk.

Hazards can include latent conditions that may represent future threats. When the threat becomes a reality, or when it materializes, the risk becomes a disaster. For example, a certain area might be located in a region where earthquakes might occur. There is a certain hazard. There is only risk if within the earthquake hazard area there is a vulnerable society. There is a risk that a future earthquake might cause considerable casualties and losses. When the hazard materializes, the earthquake actually takes place, causing the losses and casualties to the vulnerable society, and creating the disaster. An event such as an earthquake by itself is not considered a disaster when it occurs in uninhabited areas. It is called a disaster when it occurs in a populated area, and brings damage, loss or destruction to the socio-economic system.

Definitions of hazard :

- A potentially damaging physical event, phenomenon or human activity that may cause the loss of life or injury, property damage, social and economic disruption or environmental degradation.

  (Source: http://www.unisdr.org/eng/library/lib-terminology-eng%20home.htm)
- The probability of occurrence within a specified period of time and within a given area of a potentially damaging phenomenon" (UNDRO, 1991).

1.1.2 Disaster types

A hazard, and the disaster resulting from that, can have different origins: natural (geological, hydrometeorological and biological) or induced by human processes (environmental degradation and technological hazards). Hazards can be single, sequential or combined in their origin and effects. Each hazard is characterised by its location, intensity, frequency, probability, duration, area of extent, speed of onset, spatial dispersion and temporal spacing. We will look at this much more in later sessions. Hazards can be classified in several ways. A possible subdivision is between:

- *Natural hazards* are natural processes or phenomena within the earth's system (lithosphere, hydrosphere, biosphere or atmosphere) that may constitute a damaging event (such as earthquakes, volcanic eruptions, hurricanes);
- *Human-induced hazards* are modifications and of natural processes within the earth's system (lithosphere, hydrosphere, biosphere or atmosphere) caused by human activities which accelerate/aggravate damaging events (such as atmospheric pollution, industrial chemical accidents, major armed conflicts, nuclear accidents, oil spills);
- *Human-made hazards or technological hazards*: dangers originating from technological or industrial accidents, dangerous procedures, infrastructure failures or certain human activities, which may cause the loss of life or injury, property damage, social and economic disruption or environmental degradation (Some examples: industrial pollution, nuclear activities and radioactivity, toxic wastes, dam failures; transport, industrial or technological accidents (explosions, fires, spills).

A natural hazard may cause a disaster to a vulnerable society. However, one should be careful not to refer to these as 'natural disasters' as in disaster risk literature a lot of emphasis is place on the fact that disasters are relationships between hazards and vulnerable societies (O'Keefe, Westgate & Wisner, 1976). On the other hand, many use the terms 'natural disasters', 'human-induced disasters' and 'technological disasters' to indicate the origin of the cause of the extreme event.

Task 1.3: Question (duration 5 minute)

There are situations where one could speak about 'natural disasters' when the impact of the disaster is on the natural environment.
Can you give an example of that?

In the following pages you can find several examples of recent disasters with links to Youtube videos and a general description.

Example technological disasters: the 2000 Enschede fireworks explosion
Watch the You Tube video's such as:
http://uk.youtube.com/watch?v=MVqCWErj2Pc (overview, better turn sound off)
http://uk.youtube.com/watch?v=Ks5X0N8M_o8 (this is the shooting of the actual disaster how it unfolds). If you don't have a good internet connection you can also watch the video: **Enschede_Firework_disaster** which is on the course DVD.
The disaster happened on 13 May 2000 in Enschede, the Netherlands, at 300 meters from the location of the ITC building. The explosion took place in a company that makes fireworks during large events, such as rock concerts. On its premises it contained a bunker for fireworks, which was overloaded at the time. Also 23 large sea-containers with heavy fireworks were on the premises. The local government had given permission for the expansion and had not paid sufficient attention to provide licenses. The national organization for the checking of firework storage sites was also not operation very well. The firework storage area was in a location officially indicated for industrial purposes on the land regulation plan. However, on the other side of the street was a residential area. The local fire-brigade had no idea about the danger of the site, and had no prior knowledge of the firework amounts stored there. On 13 May the events started with a small fire (the origin of this was never discovered). The fire-brigade was extinguishing the fire with 3 fire trucks. Many people were watching as there was a constant display of firework. Suddenly the fire grew larger, and resulted in two major explosion. The second one detonated all firework containers and bunkers and caused a firestorm over the entire neighborhood, setting fire to many residential and industrial buildings.

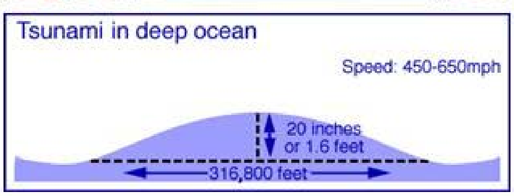
Size of the disaster area	**40 ha**
Number of inhabitants in most affected zone	**4163**
Number of completely destroyed houses	**205**
Number of completely damaged business and industrial buildings	**± 50**
Number of houses declared "inhabitable"	**293**
Number of damaged houses outside mostly affected zone	**ca. 1500**
Number of persons killed	**22**
Number of persons injured	**947**
Number of homeless persons	**1250**
Number of persons that had to be evacuated	**± 10.000**
Total material damage	**0.5 billion Euro**

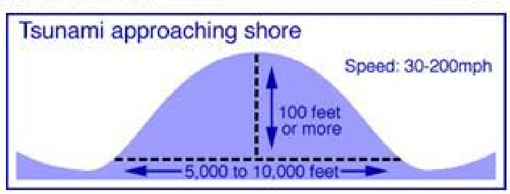

The image above shows the situation after the explosion. Almost an area of 1 square kilometer was devastated by the explosion. In fact all buildings visible on this image had to be demolished. In the top part you can see the large white building of the Grolsch Brewery. This building had a number of large ammonium tanks in the front part, which nearly caught fire. After the event the rules for firework storage changed dramatically, as well as the rules for building regulations which now also take into account the distance towards hazardous installations.
Also a Web-GIS with a risk map for the entire Netherlands was generated as a consequence of this disaster. See: www.risicokaart.nl (this will further treated in session 7)

Example Geological disasters: the 2004 tsunami
There are many examples of videos that depict this large tragedy on Youtube, for example:
http://uk.youtube.com/watch?v=R-jlyfzGP-o&NR=1
http://uk.youtube.com/watch?v=FCWfRs1frYE&feature=related
http://www.youtube.com/watch?v=FAtn4KSwxVQ
If you don't have internet access, you can also watch the video: **Tsunami_2004** on the DVD of the course.

The Indian Ocean tsunami occurred on December 26 2004. It was caused by an earthquake with a Magnitude of 9.3, occurring approximately 160 km north of Simeulue island, off the western coast of northern Sumatra, at a depth of 30 km. An estimated 1,600 km of faultline slipped about 15 m along the subduction zone where the India Plate slides under the Burma Plate. The tsunami which resulted from this hit the coasts of all countries surrounding the Indian Ocean, with main devastation in Indonesia, Sri Lanka, Malidives, India and Thailand.

Country where deaths occurred	Deaths		Injured	Missing	Displaced
	Confirmed	Estimated[1]			
Indonesia	130,736	167,736	—	37,063	500,000+
Sri Lanka[2]	35,322	21,411			516,150
India	12,405	18,045	—	5,640	647,599
Thailand	5,395[3]	8,212	8,457	2,817	7,000
Somalia	78	289	—	—	5,000
Myanmar (Burma)	61	400–600	45	200	3,200
Maldives	82	108	—	26	15,000+
Malaysia	68	75	299	6	—
Tanzania	10	13	—	—	—
Seychelles	3	3	57	—	200
Bangladesh	2	2	—	—	—
South Africa	2[4]	2	—	—	—
Yemen	2	2	—	—	—
Kenya	1	1	2	—	—
Madagascar	—	—	—	—	1,000+
Total	~184,168	~230,210	~125,000	~45,752	~1.69 million





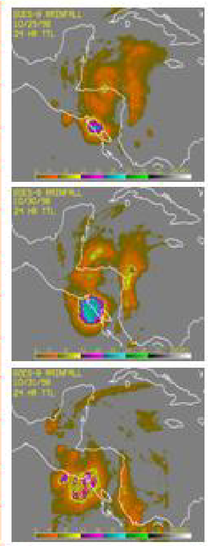
Example Hydro-meteorological disasters: Hurricane Mitch hitting Honduras

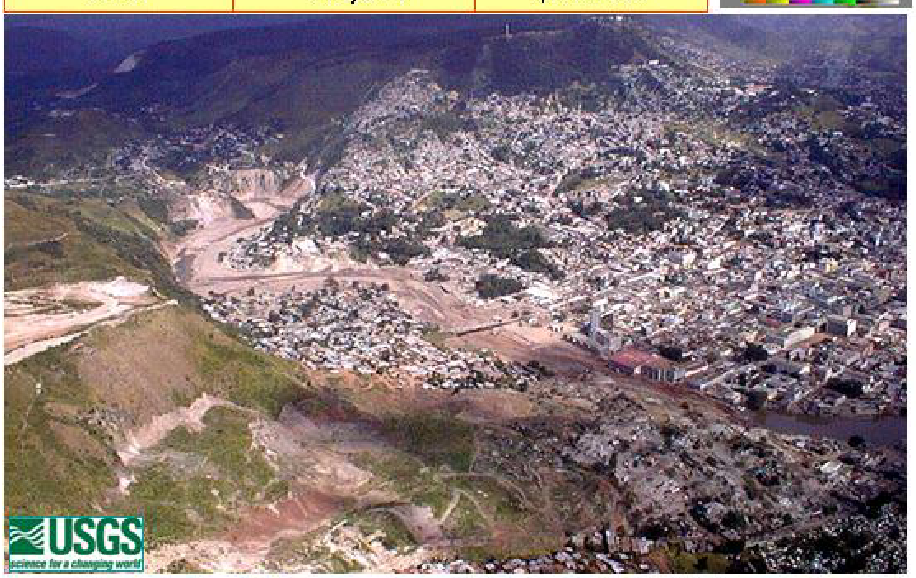
There are several videos on YouTube that give a good introduction to this event, e.g. http://uk.youtube.com/watch?v=0A4ufJ66TUs **(9 minutes focusing on the disaster in Tegucigalpa , the capital of Honduras)**

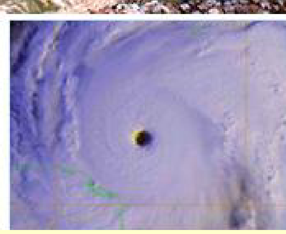
If you don't have internet access, you can also watch the video: **Honduras_Mitch** on the DVD of the course

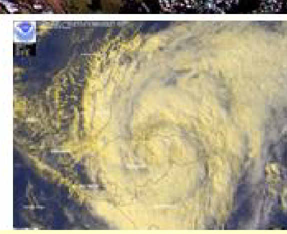
Mitch was one of the most catastrophic events in recent history in the Central American region. It hit several countries, but Honduras was one of the most affected with with over 7000 killed, 8000 missing and 12000 injured. Over 2 million people were evacuated. The capital of Honduras, Tegucigalpa suffered severe damage from landslides and flooding during Hurricane Mitch in October 1998 when the city received 281 mm of rain in 3 days. Due to river flooding, an old landslide was reactivated and an entire neighborhood on top of it was destroyed. The landslide caused the damming of the river and resulted in severe flooding in large parts of the city center for several weeks. The RiskCity case study is based on this example (See session 1.4)

Region	Direct deaths	Damage
Panama	3	Unknown
Costa Rica	7	$92 million
Jamaica	3	Unknown
Nicaragua	3,800	$1 billion
Honduras	7,000	$3.8 billion
Guatemala	268	$748 million
El Salvador	240	$400 million
Belize	11	Unknown
Mexico	9	Unknown
United States	2	$40 million
Offshore	31	*N/A*
Total	**~11,374**	**$6 billion**









Another subdivision relates to the main controlling factors leading to a disaster. These may be meteorological (too much or too little rainfall, high wind-speed), geomorphological/geological (resulting from anomalies in the earth's surface or subsurface), ecological (regarding flora and fauna), technological (human made), global environmental (affecting the environment on global scale) and extra terrestrial (See table 1.1).

Meteorological	**Geomor-phological & Geological**	**Ecological**	**Technological**	**Global environmental**	**Extra terrestrial**
Drought Dust storm Flood Lightning Windstorm Thunderstorm Hailstorm Tornado Cyclone Hurricane Heat wave Cold wave	Earthquake Tsunami Volcanic eruption Landslide Snow avalanche Glacial lake outburst Subsidence Coal fires Coastal erosion	Crop disease Animal disease Insect infestation Forest fire Mangrove decline Coral reef decline Pesticides	Armed conflict Land mines Major (air-, sea-, land-) Traffic accidents Nuclear / chemical accidents Oil spill Water / soil / air pollution Electrical power breakdown	Acid rain Atmospheric pollution Global warming Sealevel rise El Niño Ozone depletion	Asteroid impact Aurora borealis

Table 1.1: Classification of disasters according to the main controlling factor.

In literature sources several other classifications of disasters can be found, for instance by putting emphasis on the degree to which the origin of the disaster (the hazard event) is purely natural, human-induced or man-made. In this classification there will be several disaster types that are in different categories. Landslides, for instance, can be purely natural phenomena, but are also often human-induced. Other examples of events that can be both natural as well as human-induced are flooding, forest fires and snow avalanches. But also extreme meteorological events that may have an increased severity and frequency due to global warming, caused by human-induced CO2 emissions. The UN-ISDR (see also 1.2) uses another classification of disasters (http://www.unisdr.org/disaster-statistics/introduction.htm):

- Hydro-meteorological disasters: including floods and wave surges, storms, droughts and related disasters (extreme temperatures and forest/scrub fires), and landslides & avalanches;
- Geophysical disasters: divided into earthquakes & tsunamis and volcanic eruptions;
- Biological disasters: covering epidemics and insect infestations

1.1.3 Disaster location

Natural disasters occur in many parts of the world, although each type of disaster is restricted to certain regions. Figure 1.2 gives an indication of the geographical distribution of a number of major hazards, such as earthquakes, volcanoes, tropical storms and cyclones. It is clear from this figure that certain hazard occur in particular regions, such as:

- Earthquakes occur along active tectonic plate margins, and volcanos occur along subduction zones (e.g. around the margins of the Pacific plate, so-called 'Ring of Fire')
- Tsunamis occur in the neighborhood of active plate margins, but also at a considerable distance from these as tsunami waves can travel over large distances.
- Tropical cyclones (in North America called 'hurricanes' and in Asia called 'typhoons') occur in particular zones indicated with green areas in the map. Landslides occur in hilly and mountainous regions.

Task 1.4: Internet assignment (15 minutes)
NATHAN interactive search
Visit the website of NATHAN (Natural Hazard Analysis Network) of the Munich Re Insurance Company: http://mrnathan.munichre.com/
Use the Web-GIS application to view the hazard situation of your own country, and view the country profile

Münchener Rück
Munich Re Group
NATURAL HAZARD MAPS

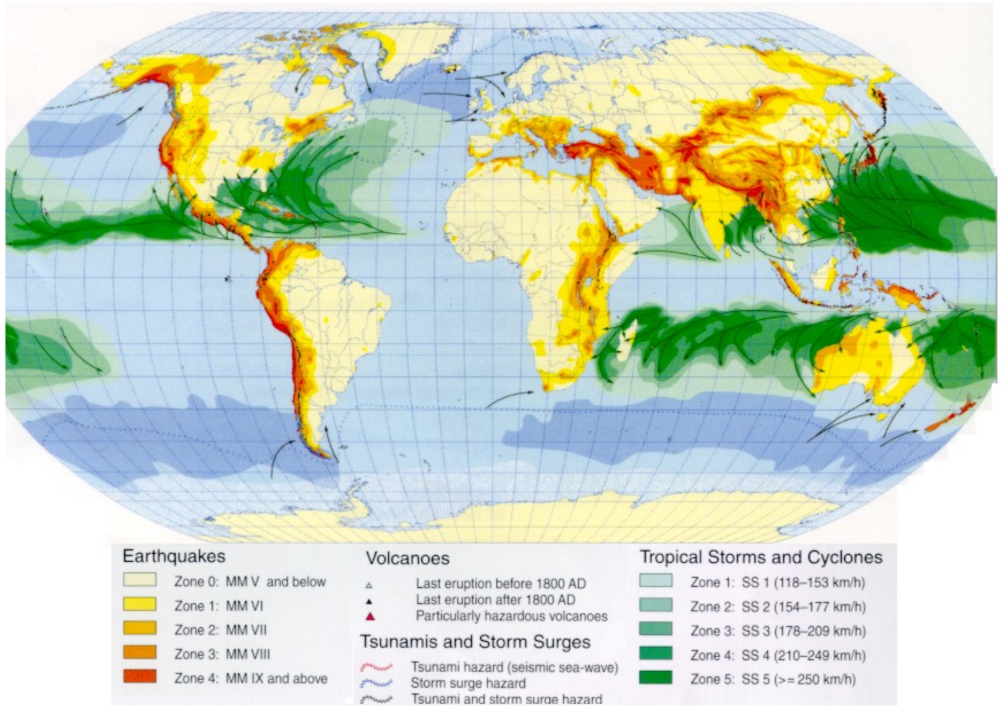


Figure 1.2: World map of natural hazards (Source: www.MunichRe.com)

The map below also gives an indication of the relative occurrence of main hazard types per continent.

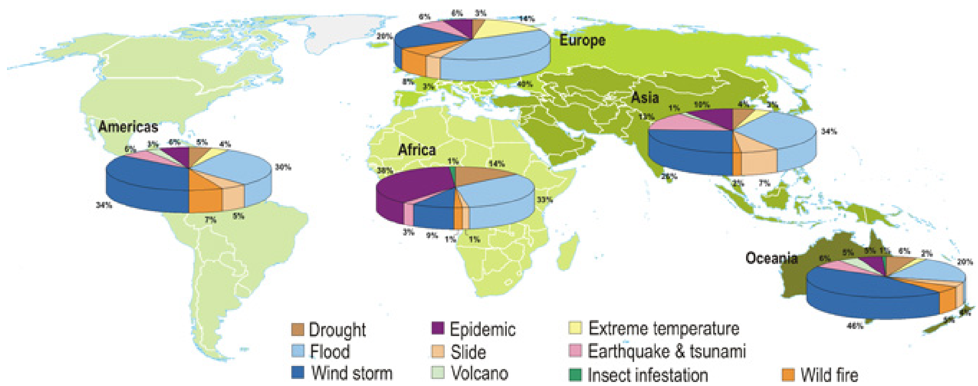


Figure 1.3 Relative importance of main hazard types per continent (source: www.unisdr.org/disaster-statistics/introduction.htm and www.emdat.be)

Recently a project on the "Identification of Global Natural Disaster Risk Hotspots" was carried out under the umbrella of the ProVention Consortium by World Bank staff from the HMU and the Development Economics Research Group (DECRG) and Columbia University. See also session 6.4.2.

1.1.4 Disaster statistics

Data on disaster occurrence, its effect upon people and its cost to countries are very important for disaster risk management. There are now a number of organizations that collect information on disasters, at different scales and with different objectives.

- Since 1988 the WHO Collaborating Centre for Research on the Epidemiology of Disasters (CRED) has been maintaining an Emergency Events Database - EM-DAT (www.em-dat.be). Disasters have to fulfill certain criteria in order to be included in the EMDAT database: they have to kill 10 people or more, 100 or more should be affected, it should result in a declaration of emergency or it should lead to a call for external assistance.

- Data on disaster impacts are also collected by reinsurance companies. (www.MunichRe.com; www.swissre.com). For instance the Munich Re data base for natural catastrophes NatCatSERVICE includes more than 23,000 entries on material and human loss events worldwide. However, these data are not publicly available. There is only a very general site where disaster information can be obtained: http://mrnathan.munichre.com/
- Recently the Asian Disaster Reduction Center (ADRC) has started a new disaster database, called Glidenumber. See www.glidenumber.net The database however is still very incomplete.
- Another useful source of disaster information for individual countries is the UNDP website: http://gridca.grid.unep.ch/undp/ Here you can also compare the disaster situation of two selected countries.
- At a local level disaster data has been collected by an initiative of NGO, called LaRed, initially in Latin America, but later on expanding also to other regions. They generated a tool called DesInventar, which allows local authorities, communities and NGO's to collect disaster information at a local level. Recently the DesInventar database has become available online: http://online.desinventar.org

Task 1.5: Internet assignment (duration 1 hour)
Evaluating disaster databases
The aim of this assignment is to evaluate the completeness of the disaster databases. Select either to search disasters for your own country or select some well known disaster events in other countries that you know about.

- *Start with making a query using the EMDAT database, via www.emdat.be You can either use the Advanced Search. Check also the Trends section to get an idea of the overall trends in hazards and disaster, which we will also discuss below. If you don't have a (good) internet connection you can also analyse the database in Excel format, entitled:* ***EMDAT_database****.*
- *Compare this with the data from Glidenumber, via: www.glidenumber.net for the same country or disaster.*
- *Finally go to the site http://online.desinventar.org and see if there are data available for your country or the disaster you have selected.*
- *Perhaps you know also local disaster databases for your own country. Google for them, and if you have found them, also report them.*

What can you conclude on the completeness of the disaster databases?

When we look at the number of reported disasters in the EMDAT database, there is a clear increase in hazardous events over the last decades. When we look at the data in the table below it is clear that this cannot be explained only by the better reporting methods for disasters, which probably made the number too low for the first part of the last century. The large increase is particularly for hydrometeorological events.

	1900 1909	1910 1919	1920 1929	1930 1939	1940 1949	1950 1959	1960 1969	1970 1979	1980 1989	1990 1999	2000 2005	Total
Hydrometeorological	28	72	56	72	120	232	463	776	1498	2034	2135	7486
Geological	40	28	33	37	52	60	88	124	232	325	233	1252
Biological	5	7	10	3	4	2	37	64	170	361	420	1083
total	73	107	99	112	176	294	588	964	1900	2720	2788	9821

Table 1.2: Statistics of great natural disasters for the last four decades (source: www.unisdr.org/disaster-statistics/introduction.htm and www.emdat.be)

This is confirmed by the databases of the reinsurance companies, although the figures are only reported for 'great' disasters. As a rule, this is the case when there are thousands of fatalities, when hundreds of thousands of people are left homeless. See figure 1.4.
The impact of natural disasters to the global environment is becoming more severe over time, as can be seen from table 1.3.
Earthquakes result in the largest amount of losses. Of the total losses it accounts for 35%, ahead of floods (30%), windstorms (28%) and others (7%). Earthquake is also the main cause in terms of the number of fatalities, which is estimated in the order of 1.4 million during the period 1950-2000 (47%), followed by windstorms (45%), floods (7%), and others (1%) (Sources: Munich Re., and EMDAT).

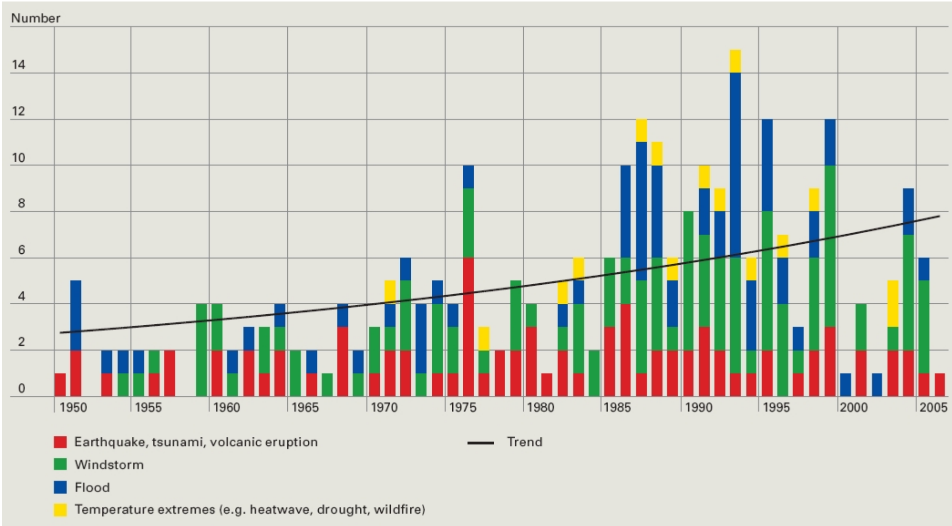


Figure 1.4: Number of 'great' natural disasters since 1950 (source: www.munichre.com)

	Decade 1960 - 1969 US $ billion	Decade 1970 -1979 US $ billion	Decade 1980 - 1989 US $ billion	Decade 1990 - 2000 US $ billion	Factor 90s: 60s
Number of large disasters	27	47	63	82	3.0
Economic losses	69.0	124.2	192.9	535.9	7.8
Insured losses	6.6	11.3	23.9	98.8	15.0

Table 1.2: Statistics of great natural disasters for the last four decades (source: www.MunichRe.com)

There are several problems in using the data from the EMDAT database. These are summarized by UNISDR and CRED as follows:

"Today key problems with disaster data remain the lack of standardised collection methodologies and definitions. The original information, collected from a variety of public sources, is not specifically gathered for statistical purposes. Even when the compilation is based on strict definitions for disaster events and parameters, the original suppliers of information may not follow rigorous criteria. Moreover, data are not always complete for each disaster. The degree of completion may vary according to the type of disaster or its country of occurrence.

- *Data on deaths are most of the time available because there is an immediate proxy for the severity of the disaster. However, the numbers put forward in the first few moments after a disaster may be significantly revised, even several months later.*
- *Data on the numbers of people affected by a disaster can be very useful for risk assessment, but are often poorly reported. Moreover, the definition of "affected" remains always open to interpretation, political or otherwise. Even in absence of manipulation data can be extrapolated from old census information, with assumptions being made about the percentage of an area's population affected.*
- *Data can also be skewed because of the rationale behind data gathering. Reinsurance companies, for instance, systematically gather data on disaster occurrence in order to assess insurance risk, but with a priority in areas of the world where disaster insurance is widespread. Their data may therefore miss out poor disaster-affected regions where insurance is unaffordable or unavailable.*
- *For natural disasters during the last decade, data on deaths are missing in about 10 per cent of the disasters; around 20 per cent lack information on the total number of people affected, and about 70 per cent do not cover economic damages. The figures therefore should be regarded as indicative. Relative changes and trends are more useful to look at than absolute, isolated figures.*
- *Dates can also be a source of ambiguity. For example, a declared date for a drought is both necessary and meaningless - drought does not occur in a single day. In such cases, the date the appropriate body declares an official emergency has been used.*
- *Changes in national boundaries also cause ambiguities in the data and may make long-term trends analysis more complicated.*

Information systems have improved vastly in the last 25 years and statistical data is now more easily available, intensified by an increasing sensitivity to disasters occurrence and consequences. However, despite efforts to verify and review data, the quality of disaster databases can only be as good as the reporting system. The lack of systematisation and standardisation of data collection reveals now its major weakness for long-term planning. Fortunately, due to increased pressures for accountability from various sources, many donors and development agencies have increased their attention on data collection and its methodologies" (source: http://www.unisdr.org/disaster-statistics/introduction.htm).

The strong increase in losses and people affected by natural disasters is partly due to the developments in communications, as hardly any disaster passes unnoticed by the mass media.

Task 1.6: Internet assignment (duration 15 minutes)
Getting real-time information on disasters
There are also many websites where you can get information about disasters that are happening now. Some of the most important ones are:

- ***ReliefWeb** is the world's leading on-line gateway to information (documents and maps) on humanitarian emergencies and disasters. ReliefWeb was launched in October 1996 and is administered by the UN Office for the Coordination of Humanitarian Affairs (OCHA). http://www.reliefweb.int/*
- *The Website of **AlertNet/Reuters**: www.alernet.org Here it might be also good to check out their maps section, as well as the Interactive map search using Microsoft Virtual Earth.*
- ***HEWSWEB** is a joint effort of several organization lead by the World Food Programme (WFP). The IASC Humanitarian Early Warning Service (HEWSweb) is an inter-agency partnership project aimed at establishing a common platform for humanitarian early warnings and forecasts for natural hazards. The main objective of HEWSweb is to bring together and make accessible in a simple manner the most credible early warning information available at the global level from multiple specialized institutions. Their website is particularly good in providing map information on hazard events: http://www.hewsweb.org/*

There are a number of factors responsible for the large increase in the number of disasters, which can be subdived in factors leading to a larger vulnerability and factors leading to a higher occurrence of hazardous events.
The **increased vulnerability** is due to:

- The rapid increase of the world population, which has doubled in size from 3 billion in the 1960s to 6 billion in 2000. Depending on the expected growth rates, world population is estimated to be between 7 and 10 billion by the year 2050 (*http://esa.un.org/unpp/*).
- However, the increase is disaster impact is higher than the increase in population, which indicates that there are other important factors involved that increase the overall world population.

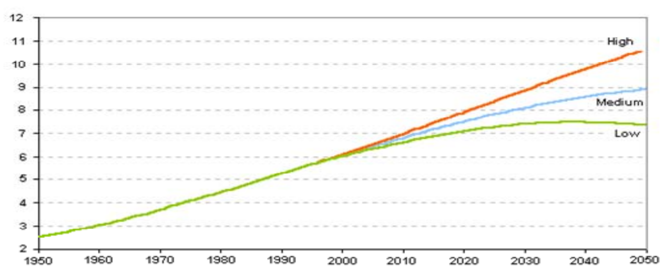


Figure 1.5: Population estimates according the UN. Source: http://esa.un.org/unpp/

- One of the main aspects is the large urbanization rate. According to UN figures (*http://esa.un.org/unpp/*) the worldwide urbanization percentage has increased from 29 to 50 % now and is expected to rise to 70 in 2050. Another factor related to the population pressure is that areas become settled that were previously avoided due to their susceptibility to natural hazards.
- Many of the largest cities in the world, the so-called 'Megacities' are located in hazardous regions, either in coastal zones, or in seismically active regions (see: http://www.megacities.uni-koeln.de/index.htm)
- The increasing impact of natural disasters is also related with the development of highly sensitive technologies and the growing susceptibility of modern industrial societies to

breakdowns in their infrastructure. Table 1.2 shows the distribution of economic and insured losses due to natural disasters during the last 4 decades.

- There is a rapid increase in the insured losses, which are mainly related to losses occurring in developed countries. Windstorms clearly dominate the category of insured losses (US $90 billion), followed by earthquakes (US $ 25 billion). Insured losses to flooding are remarkably less (US $ 10 billion), due to the fact that they are most sever in developing countries with lower insurance coverage (www.munichre.com).

However, it is not only the increased exposure of the population to hazards that can explain the increase in natural disasters. The **frequency of destructive events** related to atmospheric extremes (such as floods, drought, cyclones, and landslides) is also increasing. During the last 10 years a total of 3,750 windstorms and floods were recorded, accounting for two-thirds of all events. The number of catastrophes due to earthquakes and volcanic activity (about 100 per year) has remained constant. Although the time-span is still not long enough to indicate it with certainty, these data indicate that climate change is negatively related with the occurrence of natural disasters. There will be more on the relation between climate change and disasters in chapter 3.

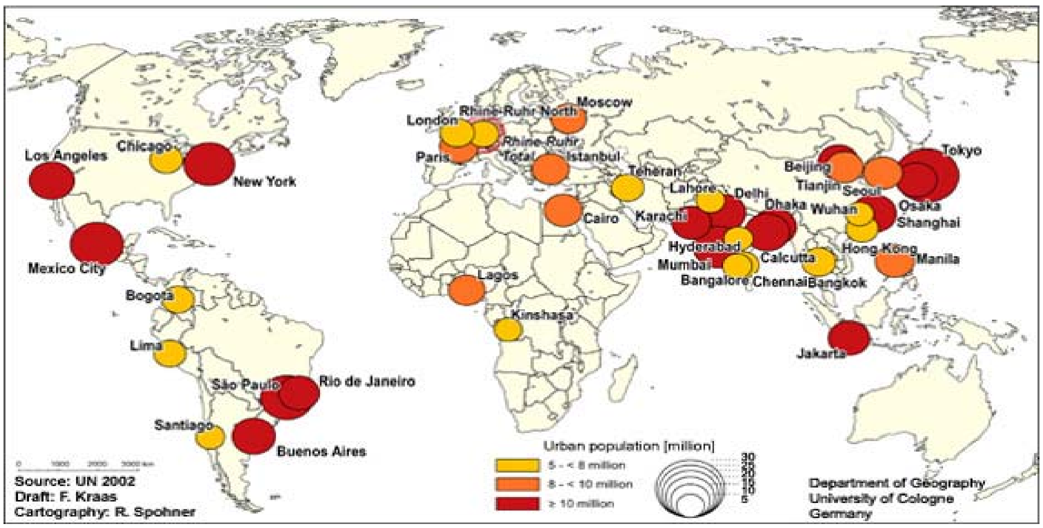


Figure 1.6: Megacities. Source: http://www.megacities.uni-koeln.de/index.htm)

1.1.5 Disasters and development

There is an inverse relationship between the level of development and loss of human lives in the case of a disaster. About 95 percent of the disaster related casualties occur in less developed countries, where more than 4.200 million people live. The greater loss of lives due to disasters in developing countries is due to several reasons:

- The buildings are often of lesser quality, due to lack of building codes or lack of enforcement of them, if they do exist. Therefore they have a higher chance of collapse, during a hazardous event.
- More buildings are constructed in hazardous areas due to lack of land use planning
- Lower awareness and disaster preparedness
- Less accurate or missing early warning systems
- Less accurate of missing evacuation planning
- Less adequate search-and-rescues and medical facilities after a disaster.

Disasters strike everywhere, in developing and developed countries (see figure 1.8). However, the effect of disasters on the economy is relatively much larger in developing countries.
Economic losses due to natural disaster can be very high in absolute terms, especially in developed countries. In the period 1991 – 2005 for instance, the USA had an estimated loss of 365 Billion US$, Japan 209, and China 173. However, economic losses attributable to natural hazards in less developed countries may represent as much as 100 % of their Gross Domestic Product. GDP is the total market value of all final goods and services produced in a country in a given year, equal to total consumer, investment and government spending, plus the value of

exports, minus the value of imports. See for instance the list of 50 events that caused the highest losses in terms of GDP on http://www.unisdr.org/disaster-statistics/top50.htm
Figure 1.9 gives a general indication of the relationship between the level of development and disaster losses. Economic losses in absolute terms (billions of dollars) are shown as a red line. They show an increase with the level of development, as the absolute value of elements at risk that might be damaged during a disaster increases with increasing level of development. However, in relative terms (percentage of GDP) the trend is reverse, as indicated by the dotted red line.

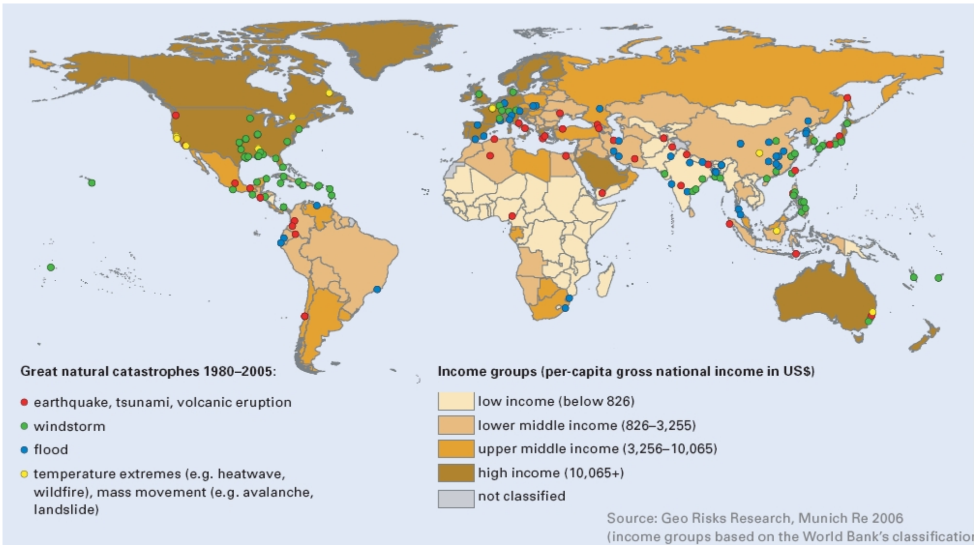


Figure 1.8: Overlay of great natural disasters and income (Source: www.MunichRe.com)

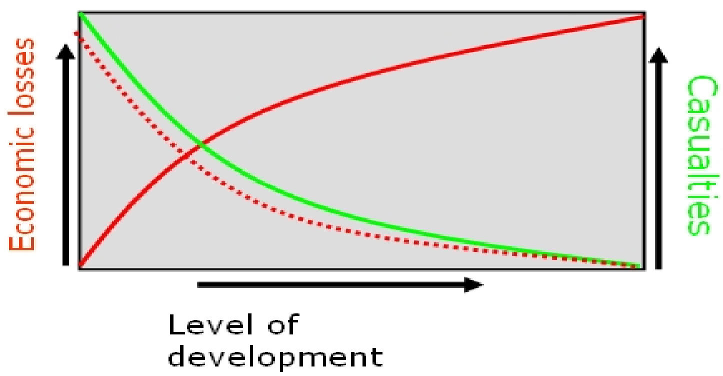


Figure 1.9: The figure indicates the relation between level of development, casualties and economic losses. When economic losses are indicated as percentage of GDP (dotted red line) the relation is opposite compared to the absolute economic losses.

Task 1.7: Making a disaster profile of a country (1 hour)

After the introductory session on disasters, we would like you to ultilize the information that was presented thus far in order to make a profile of your own country with respect to disasters. The aim of this assignment is to make a disaster profile of a particular country (preferably you own country) in which you describe the main hazard types, areal extend, and losses due to disasters, using the various resources that will be treated in this chapter.
Use internet resources, such as the ones indicated in this chapter to search for disaster statistics, hazard occurrences, and the effect disasters have on the economy.

Make a small report of maximum 5 pages which you submit through Blackboard or through e-mail to the course coordinator.

1.2 Disaster Risk Management

1.2.1 Introduction

The general framework of this book is based on the Disaster Risk Management (DRM) approach promoted by the United Nations through the International Strategy for Disaster Reduction – ISDR. One of the key premises in this approach is that disasters are not seen as events of nature by itself but the product of intricate relationships linking the natural and organizational structure of a society (UN-ISDR, 2005). Given the strength of the physical forces involved and the human socioeconomic interdependence on climate and the environment, it is unlikely that adverse impacts from climate events will ever be totally eliminated. Still, efforts to understand and dig in the root causes of disasters clearly indicate that there is considerable scope, both at a macro and household level, to handle the extent and nature of disaster occurrence.

Disasters could, in fact, be reduced, if not prevented, their impact on peoples and communities' mitigated, and human action or inaction to high risk and vulnerability to natural hazards could spell the difference (Birkmann, 2006). Human societies have, therefore, the responsibility to identify the risks and factors leading to disasters and decide on the appropriate interventions to control or manage them.

Risk assessment is then a central stage that, more than a purely scientific enterprise should be seen as a collaborative activity that brings together professionals, authorized disaster managers, local authorities and the people living in the exposed areas.

Disaster Risk Reduction (DRR) refers to the conceptual framework of elements considered with the possibilities to minimize vulnerabilities and disaster risks throughout a society, to avoid (prevention) or to limit (mitigation and preparedness) the adverse impacts of hazards, within the broad context of sustainable development

Disaster Risk Management (DRM) can be described as an array of measures involving public administration, decentralization, organizational and institutional development (or strengthening), community-based strategies, engineering, settlement development and land use planning. It also takes into consideration environmental issues as part of the risk mitigation and reduction strategies

1.2.2 Shift in paradigm

One way of dealing with natural disaster events is to ignore their threats. Until recently in many parts of the world, neither the population nor the authorities choose to take the danger of natural hazards seriously. The complacency may be due to the last major destructive event having happened in the distant past, or people may have moved in the area recently, without having knowledge about potential hazards. Alternatively, the risk due to natural hazards is often taken for granted, given the many dangers and problems confronted by people. Authorities sometimes may ignore hazards, because the media exposure and ensuing donor assistance after a disaster has much more impact on voters than the investment of funds for disaster mitigation.

International Decade for Natural Disaster Reduction: 1990 - 1999:

International Decade for Natural Disaster Reduction (1990-1999)

On 11 December 1987 at its 42nd session, the General Assembly of the United Nations designated the 1990's as the International Decade for Natural Disaster Reduction (IDNDR). The basic idea behind this proclamation of the Decade was and still remains to be the unacceptable and rising levels of losses which disasters continue to incur on the one hand, and the existence, on the other hand, of a wealth of scientific and engineering know-how which could be effectively used to reduce losses resulting from disasters.

The main objective was to minimize loss of life and property, economic and social disruption caused by the occurrence of natural disasters.

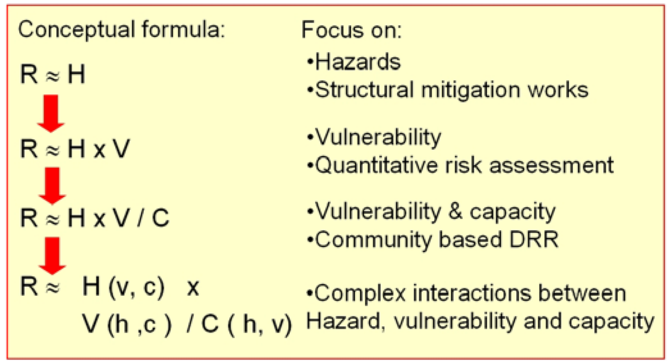


Figure 1.10: Shift in paradigm on disaster risk management. From a hazard centered approach to an approach that recognizes the complex interaction between hazards, vulnerability and capacity of communities at risk. (Source: Thea Hillhorst, Disaster Studies Wageningen.)

The past decades have witnessed a shift in focus from 'disaster recovery and response' to 'risk management and mitigation'. The change was also from an approach that was focused primarily on the hazard as the main causal factor for risk, and the reduction of the risk by physical protection measures to a focus on vulnerability of communities and ways to reduce those through preparedness and early warning. Later also the capacities of local communities and the local coping strategies were given more attention. The Yokohama conference in 1994 put socio-economic aspects as component of effective disaster prevention into perspective. It was recognized that social factors, such as cultural tradition, religious values, economic standing, and trust in political accountability are essential in the determination of societal vulnerability. In order to reduce societal vulnerability, and therewith decrease the consequences of natural disasters, these factors need to be addressed. The ability to address socio-economic factors requires knowledge and understanding of local conditions, which can – in most cases - only be provided by local actors.

From 1990-2000 the International Decade for Natural Disaster Reduction (IDNDR) and now its successor the International Strategy for Disaster Reduction (ISDR) stress the need to move from top-down management of disaster and a cycle that stresses rehabilitation and preparedness, towards a more comprehensive approach that tries to avoid or mitigate the risk before disasters occur and at the same time fosters more awareness, more public commitment, more knowledge sharing and partnerships to implement various risk reduction strategies at all levels (UN-ISDR, 2005). This more positive concept has been referred to as 'risk management cycle', or 'spiral', in which learning from a disaster can stimulate adaptation and modification in development planning rather than a simple reconstruction of pre-existing social and physical conditions (See figure 1.11).

The ISDR aims at building disaster resilient communities by promoting increased awareness of the importance of disaster reduction as an integral component of sustainable development, with the goal of reducing human, social, economic and environmental losses due to natural hazards and related technological and environmental disasters. The World Conference on Disaster Reduction was held in 2005 in Kobe, Hyogo, Japan, and adopted the present Framework for Action 2005-2015: Building the Resilience of Nations and Communities to Disasters. The main priorities for action are indicated below.

Hyogo framework for action 2005-2015.

ISDR Priorities for action:

1. Ensure that disaster risk reduction is a national and a local priority with a strong institutional basis for implementation;
2. Identify, assess and monitor disaster risks and enhance early warning;
3. Use knowledge, innovation and education to build a culture of safety and resilience at all levels;
4. Reduce the underlying risk factors;
5. Strengthen disaster preparedness for effective response at all levels.

Task 1.8: Video (duration 10 minutes)
Everybody's business: the video explaining the Hyogo Framework for Action.
Watch the video: http://www.youtube.com/watch?v=OR733gGIFdA
For more information:
http://www.unisdr.org/eng/hfa/hfa.htm
A summary of the Hyogo framework for action is also provided on the course DVD.

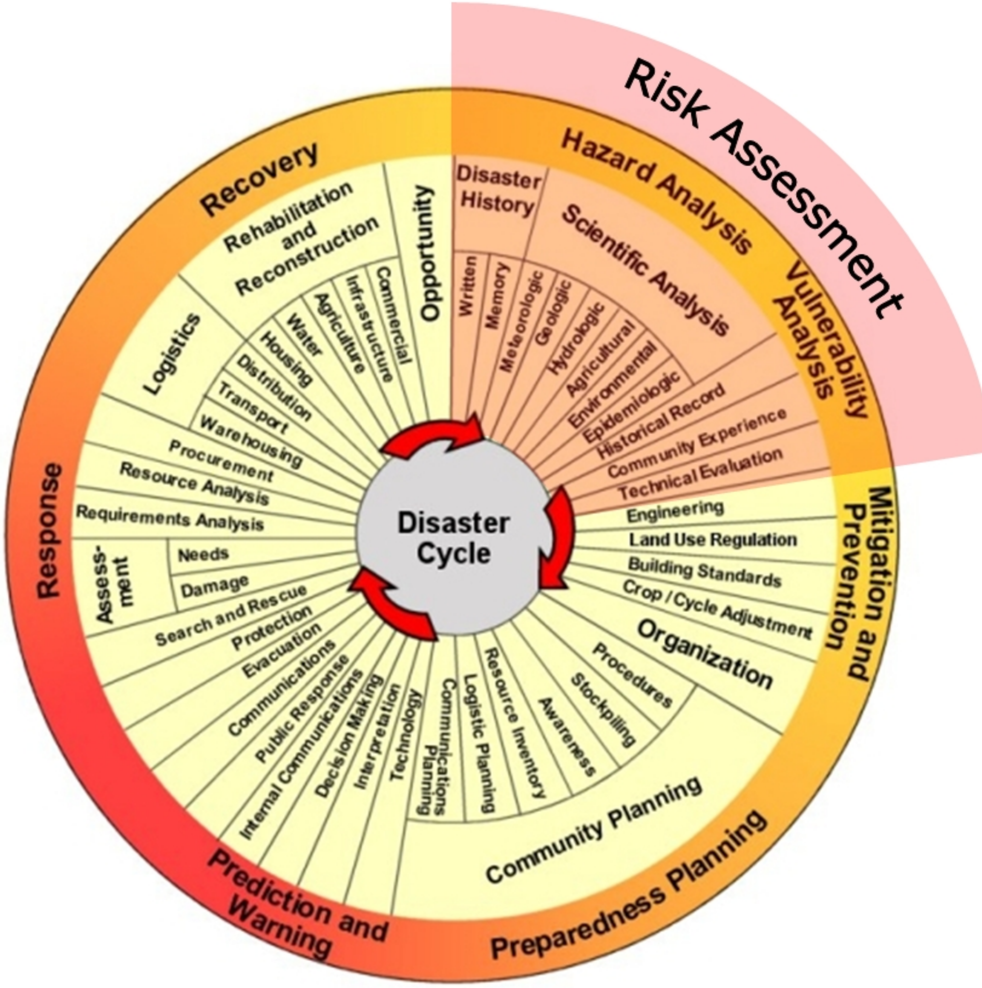


Figure 1.11: The "traditional" disaster cycle and the role of risk assessment.

A general strategy for disaster risk reduction must firstly establish the risk management context and criteria, and characterize the potential threats to a community and its environment (hazard); secondly it should analyse the social and physical vulnerability and determine the potential risks from several hazardous scenarios in order to, finally, implement measures to reduce them (see Figure 1.11). The final goal, reduction of disaster risk in the present and control of future disaster risk, should be achieved by combining structural and non-structural measures that foster risk management as an integrating concept and practice which are relevant and implemented during all stages of a community's development process and not just as a post-disaster response. Disaster risk management requires deep understanding of the root causes and underlying factors that lead to disasters in order to arrive at solutions that are practical, appropriate and sustainable for the community at risk (UN-ISDR, 2005).

Evidently, managing risk in this manner requires a consensual and collaborative approach. The UN-ISDR has widely advocated for new ways in which authorities, communities, experts and other stakeholders jointly diagnose problems, decide on plans of action and implement them. In other words, a new ethic of disaster risk management is emerging, based on 'informed consent' as opposed to paternalism. Risk assessment as the starting point for further risk management processes should in turn be a multifaceted activity aimed at integrating the likelihood and potential consequences of an event with subjective interpretations (perceptions) of interacting, heterogeneous actors.

1.3 Risk assessment

The term Risk is a rather new term. It is originally derived from the Arabic word "رزق", (rizk), which means 'to seek prosperity'. In the middle ages the word "risicum" was used in relation to sea trade and the legal problems of loss and damage. In the English language the word risk was used starting in the 17th century. According to Wikipedia (http://en.wikipedia.org/wiki/Risk) "*Scenario analysis matured during Cold War confrontations between major powers, notably the U.S. and the USSR. It became widespread in insurance circles in the 1970s when major oil tanker disasters forced a more comprehensive foresight. The scientific approach to risk entered finance in the 1980s when financial derivatives proliferated. It reached general professions in the 1990s when the power of personal computing allowed for widespread data collection and numbers crunching*."

Risk is a term that has become a part of our society and it is used in many different fields, such as:

- **Business and financial risk**: in finance, risk is the probability that an investment's actual return will be different than expected, something that we have experienced recently in the financial crisis of 2008/2009. Basically the stock market is a risk-increasing investment, where you invest money with the hope of a large return, but with the possibility (risk) of losing it. In contrast, putting money in a bank at a defined rate of interest is a risk-averse action that gives a guaranteed return of a small gain and precludes other investments with possibly higher gain.
- **Insurance**: insurance is a risk-reducing investment in which the buyer pays a small fixed amount to be protected from a potential large loss.
- **Health**: risk concepts are used extensively in human-health studies, particularly in the fields of toxicology and epidemology.
- **Engineering**: for instance in nuclear power or aircraft industries the concept of risk is extremely important. But also in all kinds of other engineering projects, for instance in construction engineering of large infrastructural works.
- **Natural hazards**: this is the field that we will look at mainly in this course.

The Risk Assessment approach adopted in RiskCity is based on the definitions from UN-ISDR.

Definition of risk

- the probability of harmful consequences, or expected losses (deaths, injuries, property, livelihoods, economic activity disrupted or environment damaged) resulting from interactions between (natural, human-induced or man-made) hazards and vulnerable conditions

Definition of risk assessment:

- A methodology to determine the nature and extent of risk by analyzing potential hazards and evaluating existing conditions of vulnerability that could pose a potential threat or harm to people, livelihoods and the environment on which they depend.

  (Source UN-ISDR: http://www.unisdr.org/eng/library/lib-terminology-eng%20home.htm)

  The process of conducting a risk assessment is based on a review of both technical features of hazards such as their location, intensity, frequency/probability and also the analysis of the physical, social, economic and environmental dimensions of vulnerability and exposure, while taking into account of the coping capacities pertinent to the risk

UN-ISDR defines risk in short as "the probability of losses". Risk can presented conceptually with the following basic equation (see also Table 1.? And Figure 1.?):

Risk = Hazard * Vulnerability * Amount of elements-at-risk [1]

and the more conceptual equation:

Risk = Hazard * Vulnerability / Capacity [2]

In the RiskCity training package both equations are used. Equation [2] is only conceptual, but allows incorporating the multi-dimensional aspects of vulnerability, and capacity, which are often integrated with hazard indicators using Spatial Multi-Criteria Evaluation. Equation [1], given above, is not only a conceptual one, but can also be actually calculated with spatial data in a GIS to quantify risk, with a focus on (direct) physical, population and economic losses.

Table 1.3: Summary of definitions used in the GIS-based risk assessment (based on IUGS, 1997; UN-ISDR, 2004).

Term	Definition
Natural hazard	A potentially damaging physical event, phenomenon or human activity that may cause the loss of life or injury, property damage, social and economic disruption or environmental degradation. This event has a probability of occurrence within a specified period of time and within a given area, and has a given intensity.
Elements-at-risk	Population, properties, economic activities, including public services, or any other defined values exposed to hazards in a given area". Also referred to as "assets". The amount of elements at risk can be quantified either in numbers (of buildings, people etc), in monetary value (replacement costs, market costs etc), area or perception (importance of elements-at-risk).
Exposure	Exposure indicates the degree to which the elements at risk are exposed to a particular hazard. The spatial interaction between the elements at risk and the hazard footprints are depicted in a GIS by simple map overlaying of the hazard map with the elements at risk map.
Vulnerability	The conditions determined by physical, social, economic and environmental factors or processes, which increase the susceptibility of a community to the impact of hazards. Can be subdivided in physical, social, economical, and environmental vulnerability.
Capacity	The positive managerial capabilities of individuals, households and communities to confront the threat of disasters (e.g. through awareness raising, early warning and preparedness planning).
Consequence	The expected losses in a given area as a result of a given hazard scenario.
Risk	The probability of harmful consequences, or expected losses (deaths, injuries, property, livelihoods, economic activity disrupted or environment damaged) resulting from interactions between (natural, human-induced or man-made) hazards and vulnerable conditions in a given area and time period.

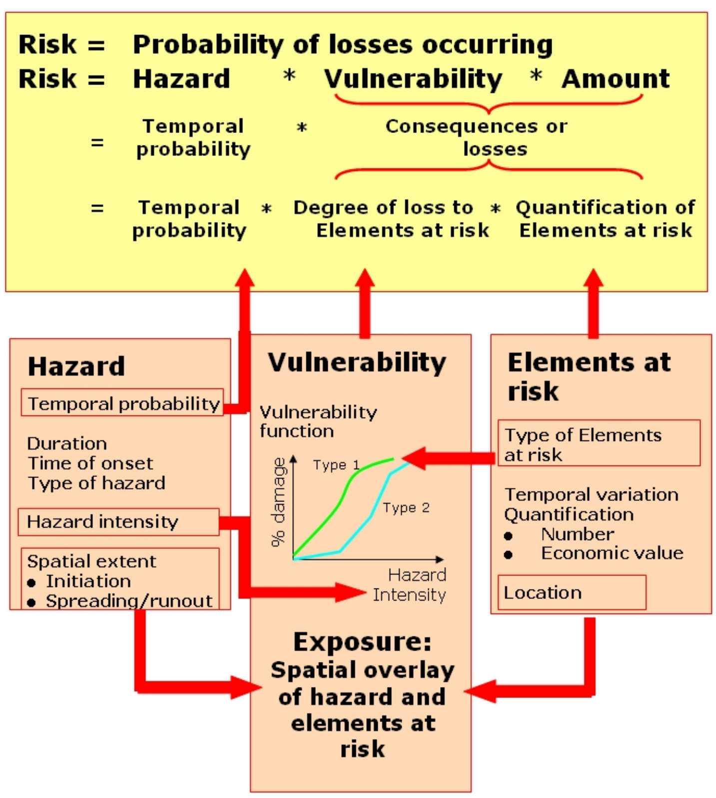


Figure 1.12: Basic function of risk, which can be divided into the components of hazard, the vulnerability, and the amount of elements at risk that are exposed to the hazard.

As illustrated in Figure 1.12 there are two important components, which also should be spatially represented: **hazards** and **elements at risk**. They are characterized by both spatial and non-spatial attributes. Chapter 2 explains the spatial data requirements for hazard and elements-at-risk data, and how available data from the internet can be used.
Hazards are characterized by their **temporal probability** and **magnitude** or **intensity** derived from frequency magnitude analysis (this will be treated in chapter 3). In this respect magnitude and intensity can be considered as synonymous terms that express the severity of the hazard. For instance flood depth, flow velocity, and duration in the case of flooding. For earthquakes the terms magnitude and intensity do have a different meaning, with magnitude expressing the energy level of the earthquake (on the Richter scale) and intensity expressing the local effects of the earthquake, that vary over a distance, becoming less further from the epicenter (and expressed in qualitative classes such as the Modified Mercalli Intensity). The hazard component in equation [1] actually refers to the probability of occurrence of a hazardous phenomenon with a given intensity within a specified period of time (e.g. annual probability). Hazards also have an important spatial component, both related to the initiation of the hazard (e.g. a volcano) and the spreading of the hazardous phenomena (e.g. the areas affected by volcanic products such as lava flows). Chapter 3 gives an overview of the approaches that can be used for the analysis of the temporal and spatial components of hazards.
Elements at risk are the population, properties, economic activities, including public services, or any other defined values exposed to hazards in a given area. They are also referred to as "**assets**". Elements at risk also have spatial and non-spatial characteristics. First of all there are many different types of elements at risk (which will be treated in chapter 4) and they can be classified in various ways. The way in which the amount of elements-at-risk are characterized (e.g. as number of buildings, number of people, economic value or the area of qualitative classes of importance) also defines the way in which the risk is presented.

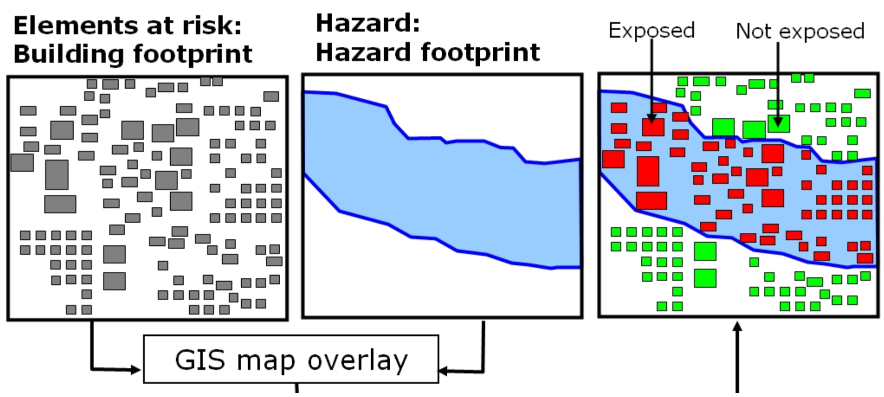


Figure 1.13: Spatial overlay of hazard footprints and elements at risk provides information on exposure.

The interaction of elements at risk and hazard defines the **exposure** and the **vulnerability** of the elements-at-risk. Exposure indicates the degree to which the elements at risk are exposed to a particular hazard. The spatial interaction between the elements at risk and the hazard footprints are depicted in a GIS by simple map overlaying of the hazard map with the elements at risk map.
Vulnerability refers to the conditions determined by physical, social, economic and environmental factors or processes, which increase the susceptibility of a community to the impact of hazards. Vulnerability can be subdivided in physical, social, economical, and environmental vulnerability. The vulnerability of communities and households can be based on a number of criteria, such as age, gender, source of income etc. which are analyzed using equation [2]. However, according to equation [1] vulnerability is evaluated as the interaction between the intensity of the hazard and the type of element-at-risk, making use of so-called **vulnerability curves**.
The concept of vulnerability and the generation of vulnerability curves will be treated in chapter 5, including the use of participatory methods for community-based risk assessment. The spatial interaction between elements-at-risk and hazard footprints, which is often referred to as "exposure" in other risk formulas, is an integral component of GIS-based risk assessment, and therefore the term exposure is not used as such in the risk equation. When we calculate the risk equation using a Geographic Information System (GIS) the elements

at risk that are exposed to the hazards are automatically obtained using map overlaying techniques. This is illustrated in Figure 1.13.

Task 1.9: Question (duration 5 minutes)
Check the figure 1.13. How much would be the risk using the equation [1] if we assume that:
- *the hazard event has a Return Period of 100 years*
- *the buildings in the hazard footprint zone would suffer 10 percent damage*
- *each building would cost 100.000 Euro?*

1.4 The RiskCity case study

The RiskCity training package focuses on demonstrating the procedures of risk assessment for natural and human-induced hazardous phenomena in an urban environment within a developing country. We have selected an urban area, because the elements at risk have a much higher density, the study areas are generally smaller and the scale of analysis larger as compared to a rural setting. This allows us to demonstrate which tools can be used for generating hazard as well as elements at risk databases, even in data poor environments, and to show how qualitative and quantitative techniques for risk assessment can be used, and in which situation. Also the combined effect of different hazard on the overall risk can be better demonstrated, as well as the effect of risk reduction measures. Figure 1.14 gives a schematic overview of the steps that will be followed in the Riskcity exercises. We will look at four different hazards: flooding, landslides, earthquakes and technological hazards. Future flood scenarios were modelled using two different models: HEC-RAS and SOBEK. Due to time limitations we will not be working with the actual models but use GIS for input and output. Landslide hazard assessment was carried out in the RiskCity case study using two different approaches: a combined statistical/heuristic analysis and physical modeling. Earthquake hazard assessment is done using empirical attenuation curves. Technological hazards are analyzed using effect distance formulae which are empirically derived.

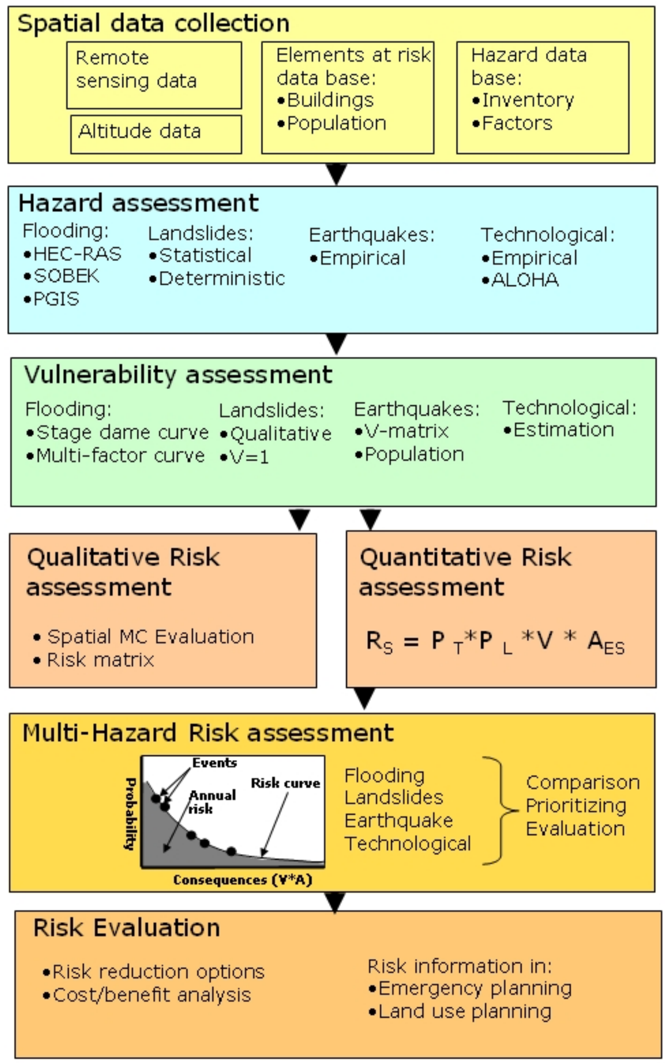


Figure 1.14: Overview of the steps used in the RiskCity case study for multi-hazard risk assessment. The abbreviations mentioned in the hazard assessment part are explained in session 3.

For each of the four hazard types the vulnerability will be analyzed using different approaches. Risk assessment will be done using a qualitative approach with spatial multi-criteria evaluation, and a quantiative approach using risk curves.

1.4.1 About the study area.

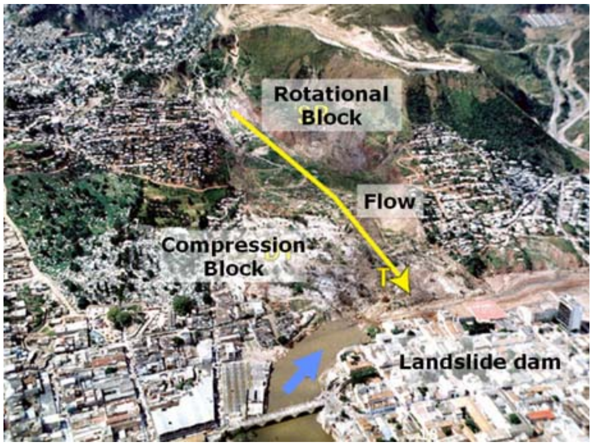


Figure 1.15: Overview of the hazard event with a landslide that dammed the river. Source: R. Peñalba

To illustrate some of the aspects discussed in this chapter for RiskCity, this section shows a number of examples related to landslides and flooding in RiskCity. As mentioned before the city of Tegucigalpa, Honduras was taken as the basis for RiskCity. It should be kept in mind that the material is for training purposes and has been adapted, and therefore is not a direct example for the city of Tegucigalpa. Therefore we will refer to it consistently as RiskCity from now on. Figure 1.15 shows an example of a large landslide, named El Berrinche, in the centre of the city of RiskCity. This landslide occurred in late October 1998, as a result of heavy rainfall and undercutting of the toe by the Choluteca River, during the passing of hurricane Mitch. RiskCity is located in a bowl shaped valley, underlain in the SE by a formation, consisting of red sandstone, siltstone and some conglomerates, and Tertiary volcanic deposits in the northwestern part. The highest parts of the area are plateaus underlain by ignimbrites with steep cliffs around their edges and a complex series of old landslides, which have not been dated till now. One of these is the El Berrinche landslide (see figure 1.15), which is approximately 700 meter long and 400 meter wide. The landslide has had several phases of activity over the last decades, which culminated in the massive failure on October 31 1998. The movement history can be reconstructed with the help of image interpretation, utilizing aerial photographs, satellite images and LiDAR data from different periods. On an airphoto from 1974, the paleo landslide can be clearly recognized, and a reactivation which occurred in the toe of the landslide in 1970 is evident. During this period also the houses on top of the old landslide were already constructed, road construction in the higher parts suggests that further development was planned, which was never implemented. A second reactivation took place in 1984, which produced considerable damage to roads and houses in the area. The first signs of what later would form into an earthflow can be identified on the aerial photo from 1990, as well as the depressions in the upper part of the landslide. After a geotechnical investigation the area was declared unsafe and further development was not considered appropriate. The main movement occurred in October 1998, and the aerial photo taken just after this clearly shows the different components of the landslide consisting of a rotational block in the upper part, an earthflow in the center and a compressional toe. The landslide had a volume of 6 million cubic meters, and most houses of the Colonia Soto were ruined as well as parts of the adjacent neighborhoods. The landslide dammed the Choluteca River leading to extensive flooding in the center of Tegucigalpa for a number of weeks. After the event the slope was flattened and a series of benches were constructed along the toe (See Figure 1.16).

In the case of RiskCity several types of remote sensing data were used. Aerial photographs for several periods, including the period of the major disaster event in 1998, and two sets of satellite data from 2001 and 2006 were the basis for landslide mapping. High resolution satellite data was used for mapping elements-at-risk, and medium resolution Aster data for generating a land use map of the area. Figure 1.16 gives an illustration of some of the remote sensing data used in the case study of RiskCity. Elements-at-risk data can be obtained at different levels of detail. In the RiskCity case study this is done at the urban level, where information needs to be as detailed as possible, preferably at the individual building level, or at a slightly more aggregated level of mapping units or building blocks with homogenous land use and building type. In the RiskCity case study two different situations with respect to the availability of input data were simulated: a situation where the database should be constructed from scratch and a situation in which already detailed spatial and attribute information is available.

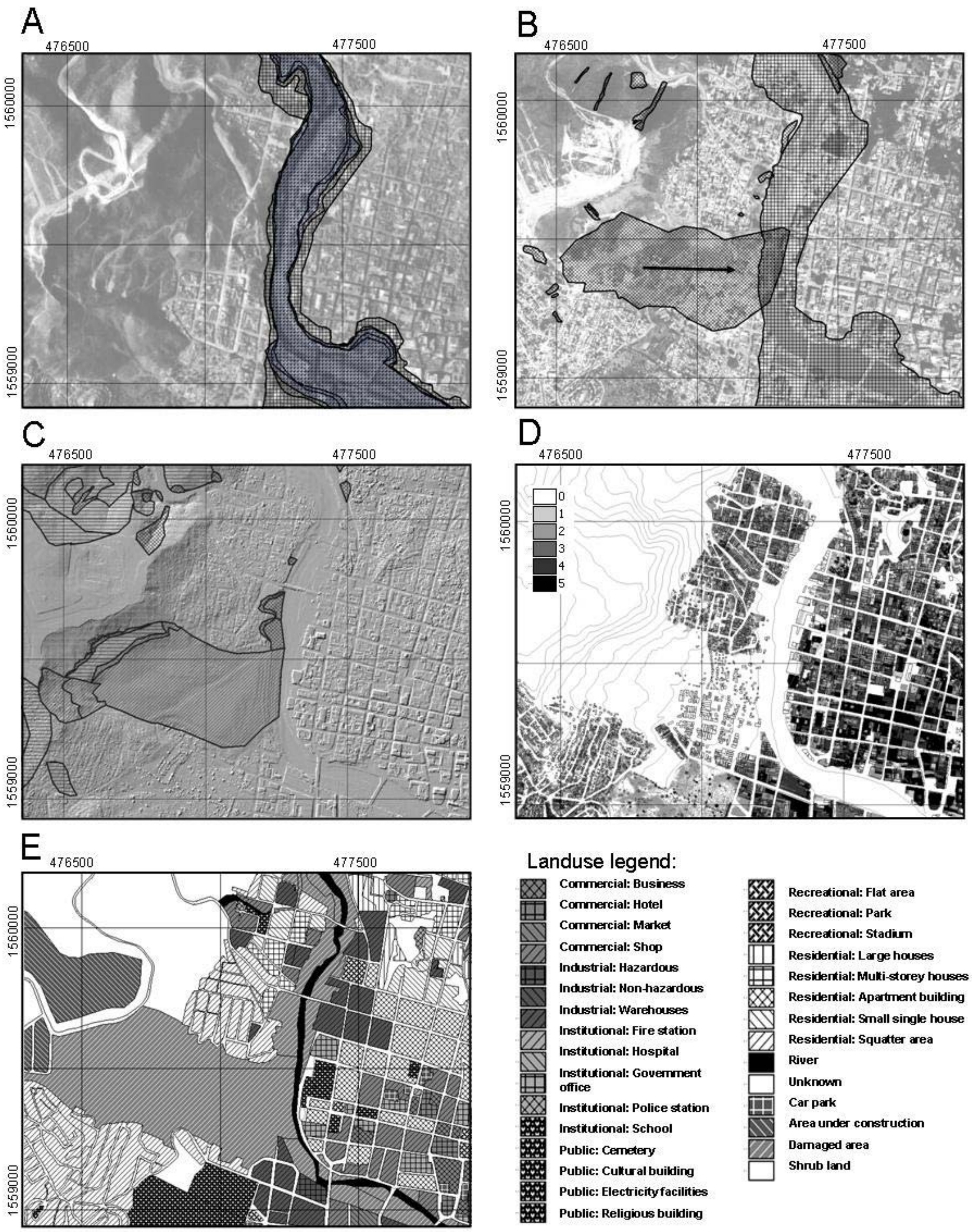


Figure 1.16: Different types of spatial information for risk assessment in the case study of RiskCity. A: Airphoto from 1977 with flood scenarios of different return periods, B: Post disaster airphoto of 1998 with flood and landslides, C: Hillshading of LiDAR DSM with landslide inventory, D: Building height, in number of stories, from LiDAR DSM and building footprint map E: Mapping units, representing zones of more or less homogeneous urban landuse and building types, with land use classification

This course aims at showing you how spatial data or geo-information can be used in a multi hazard risk assessment. The definition of geoinformation is:

> Geo-information science and earth observation consists of a combination of tools and methods for the collection (e.g through aerospace survey techniques), storage and processing of geo-spatial data, for the dissemination and use of these data and of services based on these data.

In order to be able to utilize geo-information for risk assessment, you will need specific tools. The next session deals with the tools that we will use in the course.

1.5 The tools: WebGIS and GIS

This course uses Geographical Information Systems for the multi-hazard risk assessment. During more than half of this course you will be working with GIS. However, this is not a GIS course. You also don't need to be a GIS expert in order to follow this course. Since we are using GIS tools that are easy to learn and use, we will focus entirely on what you can do with GIS for risk assessment and not on the tool as such.

> If you want to get more technical information on GIS we recommend you to follow the ITC distance education course on GIS. For information and registration please visit: http://www.itc.nl/education/courses.aspx

The course is designed in such a way that even non-GIS specialist can follow the course, since the instructions are describing the steps you need to take in a cook-book manner, at least in the initial phases. In the later part of the course, when you are more used to the ILWIS software there will be also exercises where you have to evaluate yourself the steps needed for an analysis.
The course is designed in such a way that you can also follow it if you are not able or willing to use the ILWIS GIS for the exercises. This may be the case if you are not that much interested in the particular steps to follow in a risk assessment, but want to know more about the overall procedure and the things you can do with the (intermediate) results. Therefore we have made the two following options with respect to the exercise part of the course:

- **The GIS version**. This is the standard option for using the course materials. You will be working with the Open Source GIS software ILWIS, and you will learn the individual steps to make a hazard assessment, elements at risk database, vulnerability assessment, qualitative and quantitative risk assessment, and how to use the risk information for (preparedness) planning. You follow the instructions in this theory book, and when the book contains a task (indicated in a green box that refers to one of the RiskCity GIS exercises) you then go to the exercise part of the book and follow the instructions there. You will use the GIS data for that particular exercise provided on the course DVD. The duration of the course will then be 6 weeks (distance education version) or 3-4 weeks (fulltime course), depending on the option for doing the final project in session 8.
- **The WebGIS version**. The WebGIS version allows you to evaluate the individual steps of the methodology without actually doing GIS analysis. You will not use ILWIS, but will use the WebGIS version that is also included on the course DVD. The WebGIS exercises will take much less time than the GIS version. They have separate exercise descriptions.

1.5.1 WebGIS

The aim of the WebGIS version of RiskCity is as follows:

- To illustrate the steps that will be carried out in each of the RiskCity exercises. The participants of the course can first follow the WebGIS version and see the main idea of the exercise before they actually do the exercise with ILWIS.
- In session 7 on risk management, we include one subchapter on WebGIS and its advantages, and then use the WebGIS version of RiskCity as an illustration of the possibilities of WebGIS for disaster risk assessment and management.
- The WebGIS version of RiskCity can also be used in short courses on Multi-hazard risk assessment focused on decision makers rather than technical staff. The decision makers do not have to know all individual steps of the procedure, and normally also do not have the time or background to do that. So we replace the RiskCity exercises by the WebGIS exercises for them. In this case we use 6 exercises that take about 2-3 hours each and that can be used in a short course of 1 week, together with a selection of the theory materials of RiskCity.

In addition to exercises offered by the RiskCity training package, a WebGIS version has been developed. The purpose is to offer the student an overview of the real benefits of this kind of instrument following the topics of the package and to give a general idea of data management results obtained in every exercise.

A WebGIS is an Internet GIS Application, a platform for sharing spatial and geographical data using the web. The traditional stand-alone GIS tools are fixed and gathered to the client by web, removing every need of software installation and setup. RiskCity database and browser are connected through some protocols: WebRiskCity network offers a series of webservices at server-side in which maps and spatial information are updated and organized to allow exploiting by users on the client-side. The solution used for WebRiskCity is built on OpenSource Cartoweb3, a ready-to-use WebGIS based on UMN Mapserver engine and released under GNU GPl License. The architecture of the platform is based on a core navigation interface (map and navigation) and other tools are activated by the user (map query, annotation and labeling, measuring, PDF creation and other export formats, help session support and expected activity text for every exercise).

A simplified version of RiskCity dataset is offered. Spatial data are available for different interactions: the user can personally evaluate the type and the resolution of result data archived for every exercise session, compare different kinds of information in a multi hazard-risk assessment, prepare queries according to exercise aims, download information tables for outside elaboration, create his personal layout with new shapes and labels directly drawn on map. WebRiskCity allows the users to learn different levels of risk assessment without actually executing all steps by themselves. The structure of the application is based on a complex hierarchy of layers, by which all users can compare different types of information and analyze a specific part of the City in several ways. All the maps are organized in sessions that can be accessed through switches at the bottom of the screen. Inside each one the activities and tasks required are made easier by using blocks, drop-down menus and exclusive options. Seven switches are used, following the same order of the sessions of this book.

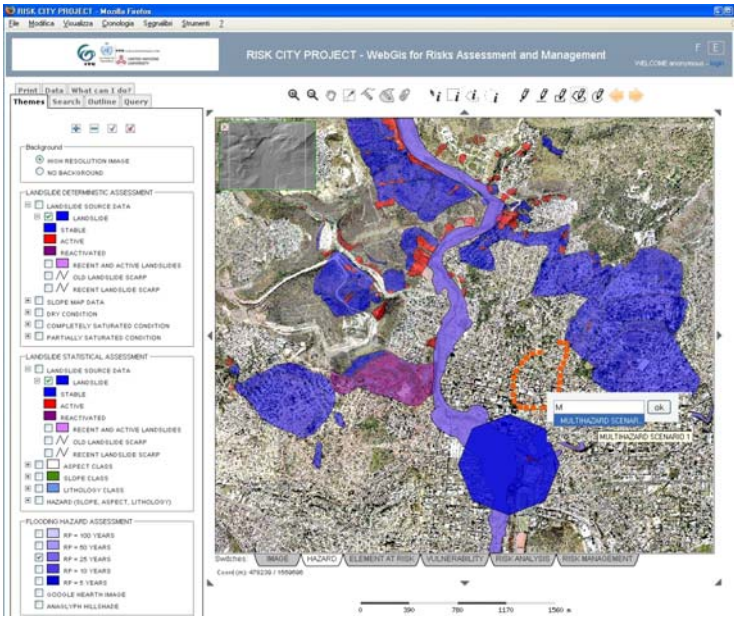


Figure 1.17: Overview of the WebRiskCity screen.

Besides a support for the RiskCity package, the platform is a direct user-friendly device for technicall staff and decision makers that normally do not have a background in Geoinformatics in Risk Analysis and Management. The instrument helps to identify the multirisk reality of the study area, to present the more "sensible" parts of the city that are prone to different kinds of hazards, to show the comparison between different maps and to understand the values and flaws of different kinds of approach on Risk management.

Task 1.10: WebGIS exercise: introduction to RiskCity (duration 1 hour)

Go to the WebRiskCity exercise 1 which deals with the introduction of the dataset, and follow the instructions.

If you also will do the GIS exercise (Task 1.11) you may also decide to skip this exercise now.

1.5.2 GIS

The other tool for handling geo-informatin that we will use extensively during this course is a Geographic Information System. The box on the next page gives a general introduction to GIS. If you are completely new to GIS you might find it rather difficult (although not impossible) to follow this course as it contains 50 percent of GIS related practicals. In that case you might have to use some more time for the practicals, and perhaps do less of them.

What is GIS?

- A Geographic Information Systems is a computerized system for collecting, storing, managing, analyzing and visualizing spatial information and related non-spatial data . The ultimate purpose of GIS is to provide support for decision making based on spatial data.

What is spatial information?

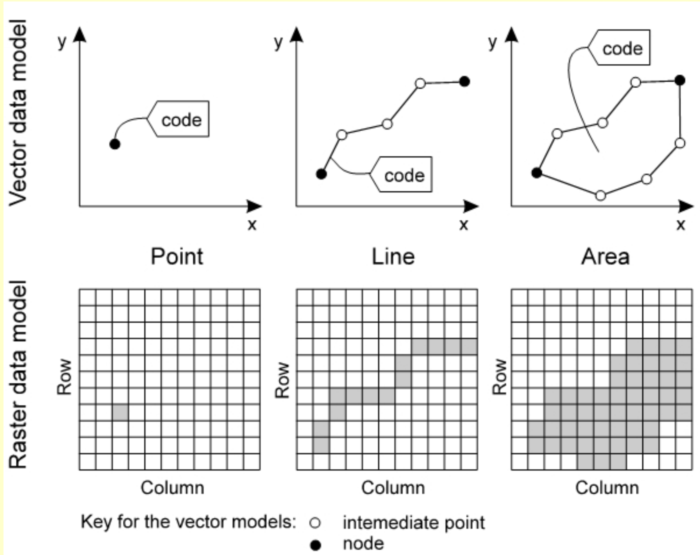
- Spatial information is information about a particular location on earth. It is information that has (X and Y) coordinates. Coordinates define where a point, line or area is on earth.

How are coordinates obtained?

- Coordinates are defined as either geographical coordinates or metric coordinates. Geographical coordinates are indicated in degrees, minutes and seconds. Metric coordinates are indicated in X,Y (and sometimes also altitude Z) in relation to a projection of the curved surface of the earth on a plane surface. Every country has its own projection system, but the Universal Transverse Mercator projection (UTM) is often used internationally. Coordinates can be obtained from existing maps, or through Global Positioning Systems (GPS).

Spatial data types:

- Spatial data can be stored in various ways. The main difference is between vector data (in which points, lines, and polygons are stored as points and connections of points with their X and Y and label) and raster data (in which the area is divided into regular cells called pixels with a certain size). Remote sensing data (satellite images) are always in raster format. Thematic data (e.g. contourlines, land use, geology) are digitized as vector data, but they can be converted to raster.



GIS components:

The general purpose geographic information systems essentially perform six processor tasks:

- **Input** . The entry of spatial data is through scanning of maps or images (the data is then in raster format), conversion from other digital formats, or digitizing (normally a map is first scanned and digitizing is done on the screen)
- **Manipulation**: data needs to be georeferenced (attaching the right coordinates to it), properly edited, and linked to non-spatial data (which are normally in the form of tables).
- Management: the data needs to be properly managed, documented (using Metadata which describe what the data is), updated and shared with other users (e.g. through an internet based Spatial Data Infrastructure)
- **Query:** querying is consulting the spatial data in order to find information on a specific location (what is?) or find the locations that meet a certain criteria (where are..?). A query allows the users to consult different types of data simultaneously.
- **Analysis**: Analysis is the process of inferring new meaning from data. Data analysis is the core of a GIS. It allows to use the spatial and non-spatial data for problem solving. Analysis in GIS can also be carried out using a series of operations such as measurement (calculating how large, how long how many), overlay operations (combination of two or more maps e.g. through joint frequency or cross tables), and neighboirhood operations (which calculate things based on the characteristics of neighboring areas). GIS analysis can be linked to models either inside GIS or with external models that use GIS for input and output.
- **Output and Visualization**: the results of the analysis should be properly visualized using cartographic tools of a GIS (combining thematic data with topographic data, adding legends, scale bars, etc) or using WebGIS which allows visualizing data through internet.

GIS software

- There are many different software packages available for GIS analysis. The standard is ARCGIS, which is a commercial software. Non-commercial software is also widely available such as ILWIS or GRASS.

As mentioned in Session 0 we are using an Open Source GIS software in this course. ILWIS is an Open source GIS and image processing software developed by ITC. There are many more Open Source GIS software packages available. For a list of these please visit: http://opensourcegis.org/

There is one software we would like to mention specifically : PCRaster. The PCRaster Environmental Modelling language is a computer language for construction of iterative spatio-temporal environmental models. It runs in the PCRaster interactive raster GIS environment that supports immediate pre- or post-modelling visualisation of spatio-temporal data. The software was developed by the University of Utrecht (The Netherlands). It can be downloaded from: http://pcraster.geo.uu.nl/. PCRaster is often used in combination with ILWIS for advanced modeling applications.

Task 1.11: GIS exercise: introduction to ILWIS and RiskCity (duration 3 hours)

Now that you have had the introduction on the method, the riskcity case study and ILWIS, it is time to start working with it.
Find the exercise description of exercise 01: Introduction to RickCity and follow the materials using the spatial data that is provided on the DVD.

- *You can find the GIS data in a Zipped file in the directory:* ***:\RiskCity exercises\01 Intro RiskCity\Data***
- *Make a directory on your harddisk:* ***\Riskcity data\01 intro***
- *Unzip the data into this directory.*
- *Go to the exercise text and follow it from there by starting up ILWIS.*

Table: overview of the session and related RiskCity exercises.

Session		RiskCity exercise
1. Introduction to Risk Assessment		Exercise 1: Introduction to ILWIS and the Riskcity dataset
2. Spatial data for risk assessment		Exercise 2: Creating and interpreting multi-temporal images
3. Hazard assessment		Exercise 3a: Frequency assessment
	Choice: flooding	Exercise 3F1: Flood hazard assessment using 2D flood propagation model outputs
		Exercise 3F2: Flood hazard monitoring using multi- temporal SPOT-XS imagery
	Choice landslides	Exercise 3L1. Landslide susceptibility assessment using statistical method
		Exercise 3L2. Deterministic landslide hazard assessment
	Choice: Volcanics	Exercise 3V: Modeling erosion from pyroclastic flow deposits on Mount Pinatubo
	Choice: Earthquakes	Exercise 3E: Earthquake hazard assessment
	Choice: Coastal	Exercise 3C1: Hazard analysis of cyclone flooding in Bangladesh
		Exercise 3C2: Analysis of coastal areas vulnerable to Enhanced Sea Level Rise
		Exercise 3C3: Modeling of Land Subsidence & Sea level rise in Semarang city, Indonesia
4. Elements at risk	Choice options	Exercise 4a: Generating a database of elements at risk from scratch
		Exercise 4b: Generating a database of elements at risk using existing data
		Exercise 4c: Participatory GIS for risk assessment.
5. Vulnerability assessment		Exercise 5a. Generating vulnerability curves
		Exercise 5b. Spatial Multi Criteria Evaluation for vulerability and qualitative risk assessment
6. Risk Assessment	Choice options	Exercise 6F: Flood risk assessment
		Exercise 6L: Landslide risk assessment
		Exercise 6S: Seismic risk assessment
		Exercise 6T: Technological risk assessment
		Exercise 6M : Multi-hazard risk assessment
7. Risk Management		Exercise 7b: Risk information for emergency preparedness & response
		Exercise 7a. Analysis of costs & benefits of risk reduction scenarios
8. Final project		Select a topic from a list and carry out your own analysis

Selftest

Self test
In order to evaluate whether you have understood the concepts that were presented in this session. Please make the following test, and check the answers in Blackboard.

Question 1.1: Disaster occurrence
Disaster losses have shown an increase over the last 60 years with a factor of 7 and the number of disasters an increase with a factor of 2.5. This is caused mainly by:
A) Better reporting of disasters in the media, and an increase in technological disasters due to climatic change.
B) Population increase, combined with an increase of geological events due to increased tectonic activity.
C) Increased vulnerability of societies and population growth, combined with an increase in hydro-meteorological extreme events.
D) Economic decrease and technological development combined with a better risk management.

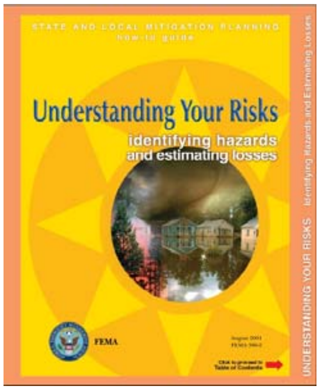
Question 1.2: Risk definition
Which definition of risk is **not** correct?
A) The term risk refers to the expected losses from a given hazard to a given set of elements at risk, over a specified future time period.
B) Risk can be expressed mathematically as the probability that a hazard impact will occur multiplied by the consequences of that impact.
C) Risk is the expected number of lives lost, persons injured, damage to property, or disruption of economic activity due to natural or man induced phenomena.
D) Risk is a serious disruption of the functioning of a community or society causing widespread human, physical, economic and environmental losses, that exceed the capacity of that community or society to cope using its own resources.

Question 1.3: Disaster risk management
Hazard and risk maps are used in the following phase of disaster risk management:
A) Disaster prevention.
B) Disaster preparedness.
C) Disaster response.
D) All of the above.

Question 1.4: Climate change and risk
Which of the following statements is true?
The effects of climate change on risk are expected to be highest in these areas because of:
A) Pacific islands because of changes in local risk of extremes
B) Desert areas because of changes in average climate
C) Desert areas because of changes in local risk of extremes
D) Pacific islands because of changes in average climate

Question 1.4: disaster statistics
The official CRED disaster database often does not contain the correct information on all types of disasters, because:
A) Disasters that happen in remote locations are often not well known and therefore mostly overestimated.
B) Many small and frequent events may not pass the thresholds for inclusion in the database.
C) The losses from spectacular disasters, that attract more media, are often overestimated.
D) Disaster losses are often not properly recorded during holidays or weekends.

Further reading:



FEMA guide

There is a very useful guide prepared by FEMA called "Understanding your risks" that guides you through the various phases of a risk assessment. This guide is not ment for the use of GIS, but it is a very useful background reading document. The guide is also in the background materials of the course. You can also access it on: http://www.fema.gov/plan/mitplanning/howto2.shtm

Relevant background documents on Disaster Risk Reduction are:

Alexander, D. 1993. Natural disasters. UCL Press Ltd., University College, London.

Baas, S., S. Ramasamy, et al. (2008). Disaster Risk Management Systems Analysis A guide book.

Birkmann, Jörn (UNU-EHS): Measuring vulnerability Measuring Vulnerability to Natural Hazards Towards Disaster Resilient Societies. http://www.ehs.unu.edu/article:279

Blaikie, P. (1994). At risk : natural hazards, people's vulnerability and disasters. London etc., Routledge.

O'Keefe, P., Westgate, K. and Wisner, B. (1976). Taking the naturalness out of natural disasters. Nature 260, 566-567.

United Nations-International Strategy for Disaster Reduction (UN-ISDR) (2005). United Nations. Bureau for Crisis Prevention and Recovery. Reducing Disaster Risk: A Challenge for Development. http://www.undp.org/bcpr/disred/rdr.htm

UN (2004). Living with Risk, United Nation

Relevant literature used in developing the materials for RiskCity, based on the orginial situation in Tegucigalpa, Honduras.

JICA, Japanese International Cooperative Agency, 2002, The study on flood control and landslide prevention in the Tegucigalpa metropolitan area of the Republic of Honduras: Japan International Cooperation Agency (JICA) Interim Report, 148 p.

Gutierrez, R. Gibeaut, J.C., Smyth, R.C., Hepner, T.L. and Andrews, J.R. 2001. Precise Airborne Lidar Surveying For Coastal Research and Geohazards Applications. International Archives on Photogrammetry and Remote Sensing, Volume XXXIV-3W4, Annapolis, MD, 22-24 Oct. 2001. 185-192

Harp, E.L., Castañeda, M.R., and Held, M.D., 2002a, Landslides triggered by Hurricane Mitch in Tegucigalpa, Honduras: U.S. Geological Survey Open-File Report 02-33, 11 p., 1 plate.

Harp, Edwin L., Held, Matthew D., Castañeda, Mario, McKenna, Jonathan, P., and Jibson, Randall W., 2002b, Landslide hazard map of Tegucigalpa, Honduras: U.S. Geological Survey Open-File Report 02-219, 9 p., 2 plates.

Mastin, M.C., 2002, Flood-hazard mapping in Honduras in response to Hurricane Mitch: U.S. Geological Survey Water-Resources Investigations Report 01-4277, 46 p.

Olsen, R.S. and Villanueva, E., 2007. Geotechnical Evaluation of the massive El Berrinche landslide in Honduras. In: V.L. Schaefer, R.L. Schuster and A.K. Turner (eds), Proceedings First North American Landslide Conference, Vail, Colorado, USA, June 2007, 738-748.

Peñalba, R.F., Kung, G.T.C. and Juang, C.H., 2007. El Berrinche landslide in Honduras. In: V.L. Schaefer, R.L. Schuster and A.K. Turner (eds), Proceedings First North American Landslide Conference, Vail, Colorado, USA, June 2007, 730-737.

Rogers, R.D. y E.A. O'Conner, 1993, Mapa Geológico de Honduras: Hoja de Tegucigalpa (segunda edicion), Instituto Geográfico Nacional, Tegucigalpa, Honduras, escala 1:50,000.

Guidance notes
Session 2: Obtaining spatial data for risk assessment

Norman Kerle & Michiel Damen

Objectives

After this session you should be able to:

- Understand that a vast range of spatial data exist that may be useful for risk assessment
- Understand that different hazard types call for data with different spatial, spectral and temporal characteristics, and what we have to consider when trying to decide what to use
- Evaluate the different spatial, spectral and temporal characteristics of different data types
- Evaluate additional constraints that may influence which data set(s) we use in our risk assessment
- Know where to search for and obtain some key thematic and image data types
- Understand the basic concepts of 3-D vision
- List the most used remote sensing systems to create 3-D for hazard studies
- Create a 3-D vision yourself using the ILWIS software

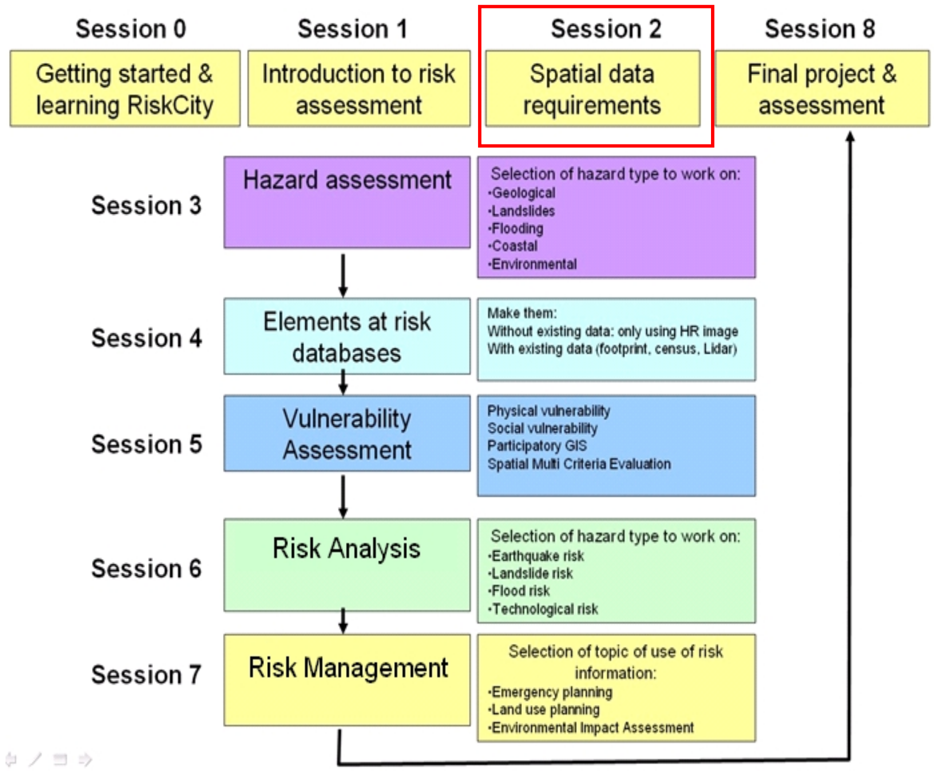
You will do this by using the following materials:

- These guidance notes, which contain the theory, tasks and exercises, specifically:
    - o Theory with main aspects related to this topic.
    - o A background box summarizing the main aspects of remote sensing theory, as well as main components of image processing and visualization, and a box with background information on digital elevation models (DEMs).
    - o A variety of short tasks. The overall purpose of the exercises is for you to practice how to decide on which data are suitable for a risk assessment, here focusing mostly on the hazards aspect.
    - o A comprehensive overview of the most important sources for thematic and image data.
    - o Background information with relevant literature.

Section	Topic	Task	Time required		
2.A.3	Which data are useful for risk assessment?	2. 1 Identify a hazard of interest		0.1 h	0.4 h
		2.2 Identify spatial types you already know		0.15 h	
		2. 3 Inventorise already available data for the chosen hazard type		0.15 h	
2.A.4	How to decide which data are suitable?	2. 4 Identification of suitable data		0.25 h	0.25 h
2.A.5	Spatial data for risk assessment	2. 5 Finding population data for your country		0.5 h	3.5 h
		2. 6 Use Google Earth to check the available data situation for your country		0.5 h	
		2.7 Explore two of the spatial data sources introduced		0.75 h	
		2. 8 Preparation of a summary for the given tasks		0.75 h	
2.B.1	Introduction	2.9 Have stereo vision yourself with the provided anaglyph glasses		0.15 h	0.15 h
2.B.3	Lidar	2.10 Study the text on the Actual Height Model of the Netherlands and look at Lidar animations		0.75 h	0.75 h
2.B.4	SRTM	2.11 Download of SRTM data from WWW		1.5 h	1.5 h
2.B.5	Optical systems for 3-D generation	2.12 Explore internet sites with examples of Aster and SPOT		0.5 h	0.5 h
2.B.8	Summary and Final Assignment	2.13Risk City Exercise 2		2.5 h	2.5 h
				Total	**9.55 h**

2.1 Spatial data requirements for risk assessment & sources of spatial data

2.1.1. Introduction



This is a course on geoinformatic-based risk assessment, and in Session 1 it was already explained that spatial data are uniquely suited to study and assess multi-hazard risk. All aspects of risk that we need to consider – the different natural or manmade hazards, the areas they might affect, the elements exposed during such events and their vulnerability – are spatial in nature. By that we mean that they have a certain location and extent, thus can be put in relation with one another, and can be associated with attributes that are linked to a geographic place or area (Figure 2.A.5). The course explains how the different aspects of risk can be analyzed and mapped with a variety of spatial data. In session 2 we want to look at what spatial data types exist, how they can be used in risk assessment, and how we decide which data set(s) to use, and where to get them.

2.1.2 Types of spatial data

In geoinformatics, also called geoinformation science, we can consider any data type that can be linked to a geographic place, which is easiest achieved through coordinates. The classic data type is a map, a more modern one could be a satellite image (for an introduction on remote sensing see box). However, we need to consider that our work is largely done digitally on a computer, and that we might want to use data that are actually quite variable in nature. When we think about disasters or risk, we may want to include (i) tabular data or statistics (e.g. on the number of hazard or disaster events of a certain type and in a given time period), (ii) thematic data (e.g. a road or river network, soil types, or digital elevation models [DEMs]), (iii) topographic maps, (iv) model results (e.g. for flood hazard or slope instability), or (v) images (e.g. aerial photos or satellite images). Even within those major data types there are large variations.

Remote Sensing

Remote sensing (RS) can be described as the process of making measurements or observations without direct contact with the object being measured or observed. Thus, while in the geoinformatics context satellites often come to mind, even amateur photography is a form of RS. It usually results in images, but also includes other measurements, such as of temperatures or gravity.

- ***Sensors and platforms.*** For remote sensing we normally require a **sensor** (i.e. a camera or scanner), but also something that carries the device. Such **platforms** can be airplanes or satellites, but also other instruments that allow us to place the sensor so that the area or object of interest is exposed, such as balloons or kites. The choice of platform directly affects what we can observe and how. Airplanes and helicopters are flexible in their operation, and by flying relatively low provide good spatial detail. However, such surveys can be expensive and regular imaging of the same area thus costly. Satellites fly on a fixed **orbit**, and are thus less flexible, but can provide data at regular intervals (think of trains on a track). We distinguish between so-called **polar orbiters**, whereby the satellites continuously circle the Earth at an altitude of some 500-900km, passing over or near the poles. Normally only a relatively narrow strip of Earth underneath the sensor is observed. Modern satellites can also point the sensor sideways for greater flexibility. The other class of satellites is positioned in **geostationary orbit**. This means that the satellite is always directly above a designated place on the equator, moving with the rotating Earth at an altitude of 36,000 km. At that height the sensor can usually observe an entire hemisphere (the side of the Earth facing it), and provide data at any desired frequency. Many weather and communication satellites fall in this category, while most Earth observation satellites are polar orbiters.

- ***Collecting information.*** The data we obtain depend primarily on the sensor type, just like you might take color or black/white photos with your camera. The secret to taking such different photos lies in the **electromagnetic energy**, which is what our sensors can detect. The most common source of energy is reflected sunlight, which, as you probably know, contains visible light, but also ultraviolet (UV), infrared (IR), thermal and other energy (Figure 2.1). Which part of this continuous energy band we capture depends on the sensor. Your camera might only capture visible light, while others can "see" UV, IR or thermal energy.

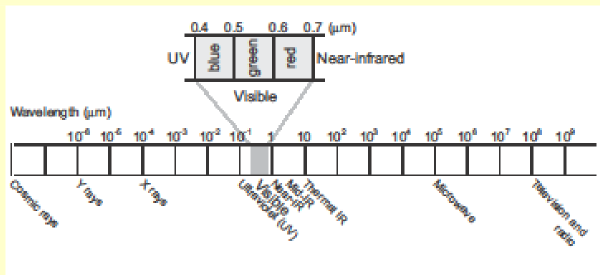


Figure 2.1: The electromagnetic (EM) spectrum

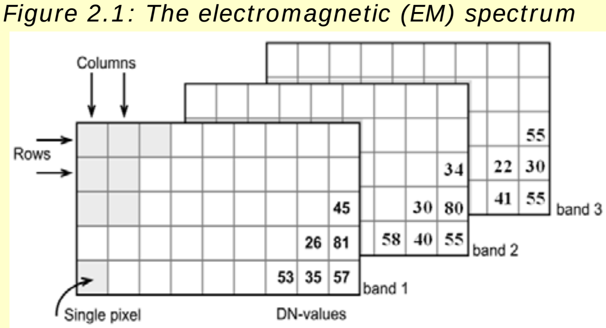


Figure 2.2: Grid structure of a multi-band image

- ***The data.*** The data our sensors record typically have the form of a grid, or raster (Figure 2.3). Rows and columns in that grid are populated by cells. These cells contain the information recorded by the sensor. A sensor can also have several **bands**, meaning that different sections of the electromagnetic spectrum are observed. Thus for the area observed we will have an image that contains several bands, and the cell corresponding to a small part on the ground will have one data value for each band. The most important point to understand here is that different materials on the ground reflect energy in a characteristic spectral pattern. For example, vegetation is characterized by high energy in the near infrared (NIR), while for water the energy is very low. In figure 2.2 this would result in high values (digital numbers [DN]) for vegetation and low values for water in the band corresponding to the NIR.

- ***Other factors influencing our data.*** RS data come in many forms, often described by **sensor type**, as well as **spatial**, **temporal** and **spectral resolution**. Sensors recording reflected sunlight or energy emitted by the earth are called **passive sensors**. However, we also have sensors that emit their own energy, which is reflected by the earth, just like you use a flash on your camera. These are **active sensors**, well-known examples being radar (see Figure 2.10) or laser scanning. The **spatial** resolution describes the size of the ground area represented in a single pixel. This largely depends on the distance between the sensor and the object. While aerial photos may have a resolution of a few cm, data from polar orbiters range between about 50 cm and 1 km per cell. Sensors on geostationary satellites, being very far away, record data at resolutions of a few km. The **temporal** resolution describes the possible frequency of repeat observations. For aerial surveys this can be years. Depending on the type of polar orbiter and sensor, their temporal resolution varies between approx. 1 and 44 days, while geostationary sensors record data up to every 15 minutes. The **spectral** resolution describes how narrow a slice of the EM spectrum a sensor band records.

In the following part we also provide a short background on some basic image display and enhancement methods that you will encounter in this course

- **Displaying an image.** Once we have our data we can either display them directly on our monitor (if they are already digital), or first scan them. A monitor works with 3 different color channels (blue, green, red), and is able to generate any color (including black and white) with a combination of those 3 colors. Thus we can take an image with only 1 or with several bands and display 1 band at a time, thus as a **pan-chromatic** image (Figure 2.3 A). We can also use 3 bands and display them as a so-called **true-color composite** (B), which looks like the scene would look to us from space. However, we can essentially assign any of the image bands to one of the 3 colors. A typical combination, called a **false-color composite**, is shown in C, where the information from the NIR band is displayed in red. Recall that vegetation leads to high DN values in the NIR, hence the high vegetation signal leads to a dominant red color wherever there is vigorous vegetation. Image D shows another form for false-color composite.

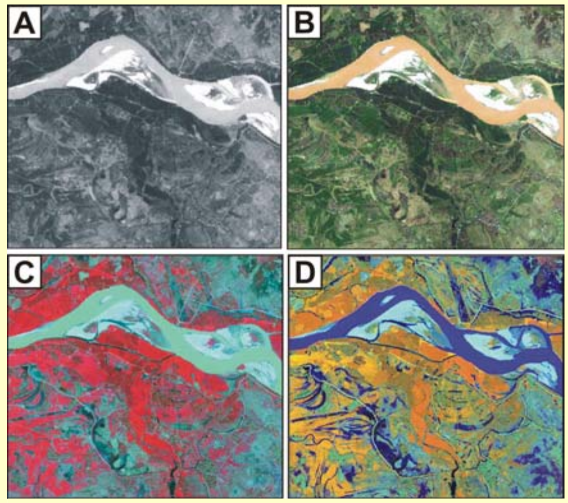


Figure 2.3: A – panchromatic, B- true-color, C and D – false color composites

- **Enhancing an image.** Sometime, for information to be made more visible, we have to enhance the image. One typical form is **stretching**. Our displays are typically able to display 256 brightness levels for each color, corresponding to 8bit. However, very often the image data only have a limited range, say with DNs between 50 and 150, where are not very bright or very dark features on the ground. To achieve a display with a richer contrast we can stretch the data over the entire available range (0-255). The same concept applies to other data types you will work with, for example elevation. The elevation file for our test area ranges between approximately 900 and 1350m. By default they will be stretched over the available display range. However, we can also stretch a small value range, say 950-1000, to highlight more details. Another common enhancing method is **filtering** (Figure 2.4). This is a so-called neighborhood analysis, often used to smoothen an image or to highlight edges. In the example the average of all cells shown in grey in the input image is calculated and written to a new file, before the filter template moves to the next pixel (hatched box). Many filter types have been developed, which you will also use in the ILWIS exercises (for example shadow and smoothing filters).

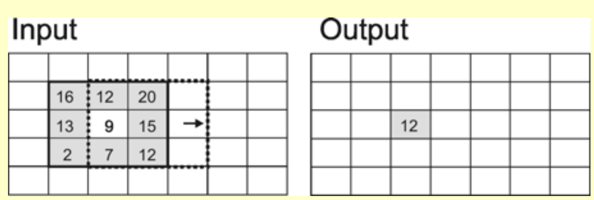


Figure 2.4: Principle of filtering

For example, you might find statistics presented in a table with either coordinates or grouped per administrative area, or illustrated as a chart or graphic. It can also happen that field photographs are available. Associating those with the other data, and integrating the information you think is useful in those photos with the rest of the analysis, can be challenging. Also consider that many maps or aerial photographs are available only as paper hardcopies. To use them in our work we first have to convert them to a digital format. This can be done by digitizing relevant information, or by scanning and subsequently georeferencing the maps or images.

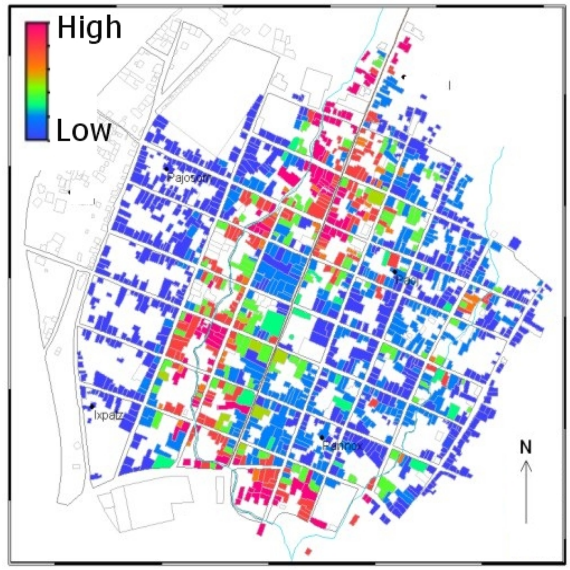


Figure 2.5: Example of a risk map for an urban area subjected to flooding (Source: Peters Guarin, ITC)

2.1.3 Which data are useful for risk assessment?

To determine which data are actually of use requires a detailed understanding of hazard and risk theory, which is an integral part of this course. In this session we want to focus on the practical considerations that are necessary to make the decision, and where those data are actually available. When you think about different hazard types you quickly realize why we have to adjust the data types we can use in the risk assessment. Consider Figure 2.6: as is illustrated, different hazard types, such as earthquakes or hurricanes, have different (i) **spatial**, (ii) **spectral** and (iii) **temporal** characteristics (see Remote Sensing box). (i) A hazard can be very local and spatially confined (e.g. an unstable slope), it can be very extensive (e.g. flooding or drought), or there can be a large distance between the actual source of the hazard and the area in question. Examples of that can be earthquakes, where the responsible fault may be a long distance away from areas that may still experience strong shaking during an event, or the breaking of a dam that may lead to flooding far downstream. We also have to consider the dimensions of the hazard: a dam or a hill slope are quite small in extent, while an area possibly exposed to a hurricane or a tsunami may be vast. The data we choose in the analysis need to reflect those dimensions and the details we need to see. Recall that it is largely the **platform** type that determines how large an area can be observed.

(ii) Remote sensing is very sensitive to the surface characteristics of the object or area under investigation, resulting from the different spectral characteristics of different materials, and different sensors have been built that are especially suitable for specific surface materials. For example, a near infrared band, common to most **passive** satellite sensors, is well suited to map vegetation health or water. It is thus suitable, at times in combination with other spectral bands, to track vegetation health (e.g. to monitor drought hazard), or to map flood or other surface water. In areas or situations where clouds, smoke, or night-time conditions prevent a clear view on the surface, we can resort to **active** sensors, such as radar. However, here it is particularly important to understand that radar data more strongly reflect the surface physics (structure/roughness, moisture, topography) than surface chemistry (mineral type, chlorophyll in leaves, etc.). Hence using radar is only of use if it not only penetrates difficult observing conditions, but still provides the information we require (compare Figures 2.9 and 2.10).

(iii) Hazard events can be sudden and of short duration (e.g. earthquakes or landslides), sudden but of long duration (e.g. a dam break leading to prolonged flooding), but can also show precursory signs (e.g. volcanic activity or hurricanes). Some events, such as earthquakes, may also show a repetitive pattern, where violent aftershocks may affect areas already destabilized by the primary event. Some effects may also be delayed, such as disease outbreak after a flood or earthquake. This is also a good example of one hazard type event leading to secondary effects. Other examples of that phenomenon are slope or dam instability caused by earthquakes.

Task 2.1: Question (duration 5 minutes)
Identify the hazard type you are most interested in, and write down for yourself how it can be characterized in terms of its spatial and temporal properties, as well as possibly its spectral characteristics.

Thus we see that we need to have a good understanding of the spatial, spectral and temporal characteristics of the hazard(s) under consideration, before deciding on a specific analysis type and data requirements. Figure 2.6 further illustrates that also our spatial data sources have spatial and temporal characteristics, in case of image data also in the spectral domain. Those need to be matched with the hazard characteristics, but, for risk assessment, also with those of the elements at risk. For example, while we may use a satellite image that shows a large area, such as the catchment from which a flood might originate, we may need very detailed imagery to map buildings and other structural elements that may be affected by a flood. This is difficult, as there is a largely inverse relationship between coverage and detail; very similar to a zoom lens on a camera we can either see a large area (wide angle) or detail (when zooming in; see Figure 2.7). Hence we may have to combine different data sets to cover both requirements.

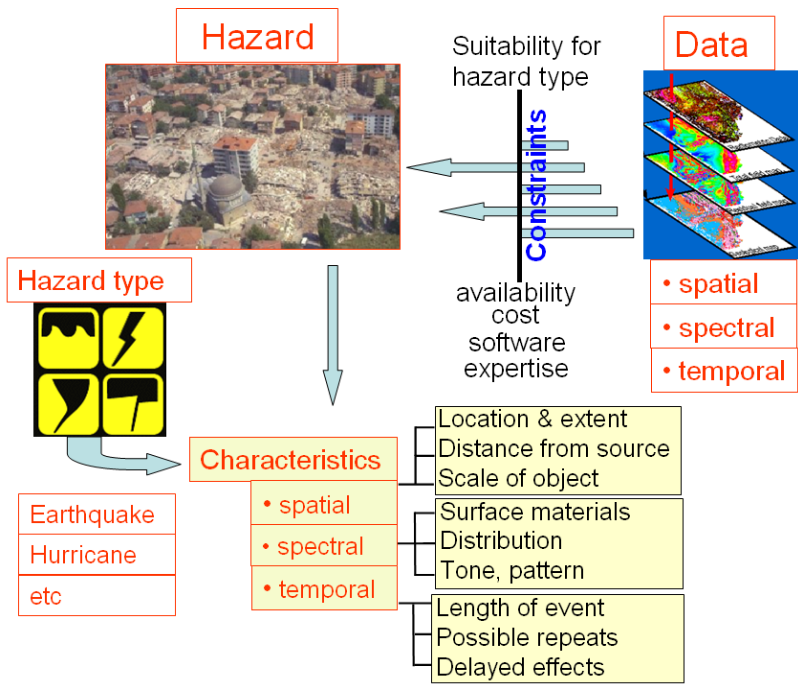


Figure 2.6: The hazard type dependency of spatial data suitability

Task 2.2: Question (duration 10 minutes)
Which spatial data types that you know already (both images and thematic data) do you think are useful to observe the hazard you selected in task 2.1? What relevant information can they provide?

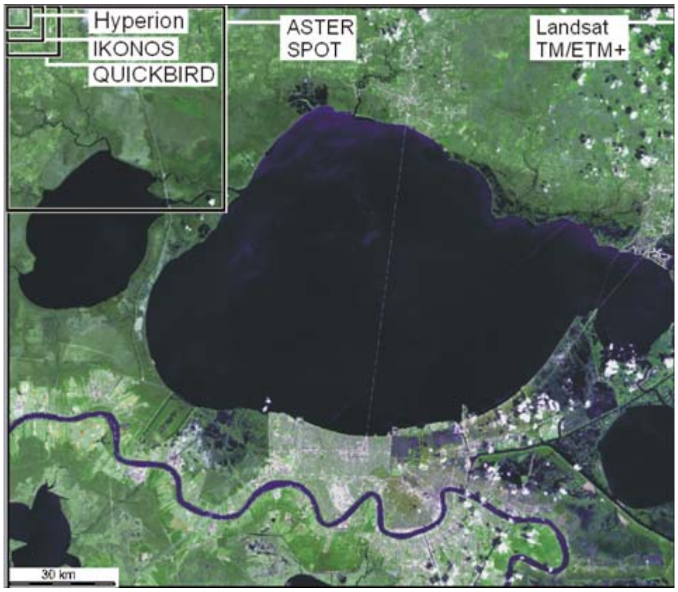


Figure 2.7: Ground coverage of different common satellite sensors

Once we have clarified the suitability of a given data type, or combination of types, there are a few other important considerations that typically act as constraints: **availability**, **cost**, **software**, **expertise**. There can be a large difference between suitable and actually **available data**. For example, we may want to use statistics on hazard events or census data for a certain area, only to find that no current data have been compiled. Some datasets may also be proprietary, meaning that they are not available outside a company or organization. Some countries, such as India, may even prohibit the sale or export of imagery of their territory for security reasons, while others degrade data quality on purpose, such as the US did for the global SRTM DEM (see below). Yet other data, such as census data, may only be available in aggregated form, which may limit their utility. For satellite images we further have to consider the difference between geostationary satellites and polar orbiters. The former are always positioned on the same spot above the Earth surface, thus being able to observe the same area with high frequency, as is the case for weather satellites. The highest current temporal resolution is achieved by Meteosat Second Generation (MSG), which provides data every 15 minutes. However, the satellite has to be placed in geostationary orbit, at about 36,000 km above the Earth, resulting in data between 1 and 3 km in resolution. An alternative are polar orbiters, circling at some 500-900 km above the surface. This means that the image detail the latter provide can be much higher (at the moment up to 50cm from GeoEye-1), but their revisit time ranges between 1 day and more than 1 month. Hence, if we need data very quickly, such as after a sudden disaster, no suitable images may exist. Also recall the tradeoff between coverage and detail (Figure 2.7); while MSG can see almost all of Africa, Europe and parts of the Middle East every 15 minutes, GeoEye can only image an area some 15 km across, and only every 3 days.

Satellite images also have a reputation for being **expensive**. That is still partly true, in particular for imagery from commercial satellite companies such as GeoEye or DigitalGlobe, but also for data from some governmental operations, such as from ENVISAT (operated by the European Space Agency), ALOS (Japanese Space Agency) or RADARSAT (Canadian Space Agency). However, there have been very interesting developments that work in our favour. First, geodata are now very commonly used in many aspects of science, industry or even recreation. Think of GPS as an example – cheap devises are now being used by hikers, and we take it for granted. Similarly, many people use Google Earth on a routine basis, and free of charge. While those images may be of limited utility for rigorous quantitative risk assessment, this wide use of spatial data has served as a catalyst. The more such products are being used, the better the chance that continuous development will take place, assuring that we will still have such data in the future, but it also tends to lead to lower prices. Later in this session we will look specifically at sources of free and low cost data, but also list some commercial providers.

Working with digital data requires a **software** environment to process them. While a simple PC with basic software is enough perhaps to browse the internet and view images, processing spatial data tends to be more complicated. As we said before, we are dealing with data that use a reference framework (coordinates) and projections, meaning that usually some type of geographic information system (GIS) or image analysis software is used. Just like with the data, there are expensive software types, but also free or open source packages, such as the ILWIS software we use in this course. A rule of thumb is that software developed for very specific data types (e.g. radar or laser scanning data), or incorporating sophisticated model, tends to be expensive. Conversely, for more basic GIS and image analysis functions there are many free or low cost packages available.

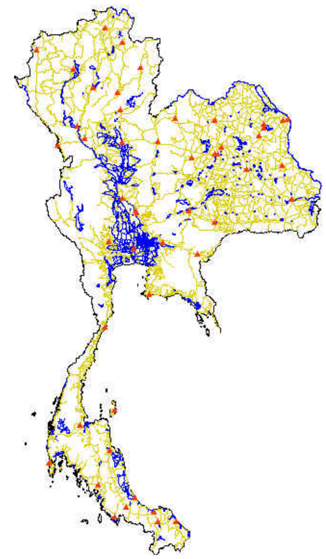


Figure 2.8. Thematic data of Thailand (points, lines, polygons), from the Digital Chart of the World.

Lastly, to process spatial data requires a certain amount of **expertise**. While the skills required for some basic or routine steps are quite easily obtained, doing more advanced data processing or integrating, as well as modeling, may require expertise that is not always available.

The above means for us that, even if we understand the characteristics of a hazard or risk situation, not all suitable data may be available and we may not always have the software tools or expertise needed. Therefore, geoinformatics-based risk assessment requires much flexibility, as we have to strive for data interchangeability or workarounds when we hit an obstacle.

Task 2.3: Question (duration 10 minutes)
Continuing with the hazard type you considered in the previous questions, inventorize the data you currently have ready access to, but also which computing requirements (hardware and software) are available in your office, and what expertise can be made use of.

2.1.4 How to decide which data are suitable?

The preceding text should make it clear that there are different ways to do risk assessment with geodata, and that our requirements or chosen methodology can shift quickly, depending on the specific hazard situation, types of elements at risk, or secondary hazards. The following checklist can help you decide what data you need.

(i) Identify data type(s) needed (e.g. thematic layers [Figure 2.8], images [Figure 2.9], maps)

As explained above, understanding the risk components, and how we can assess and map hazards, elements at risk and their vulnerabilities, is a prerequisite. Once we understand the system we are dealing with, we can decide on the data needed for the job.

(ii) Date of (image data) acquisition (archived, current, future)

Most risk assessment work requires different data, often including historic data (e.g. statistics on a given hazard phenomenon), recent and older imagery (to detect changes of time), and we might also need data that have not yet been acquired. Also remember that the natural environment looks different throughout the year. If you want to map vegetation changes, looking at a winter image may be of little use. Thus we need to determine the types of data and their dates.

(iii) Number of datasets/images needed

How many datasets and images do we need? To assess changes we need at least two, to cover a larger areas also several images may be required. Some relevant statistics or thematic data may also be housed in several different databases or datasets.

(iv) Identify possible cost, check budget

While some data may be free of charge, others are very expensive. Once we have our list of needed data, check how much they cost and if the available budget supports the choice. If not, some data may have to be replaced with lower-cost alternatives.

(v) Identify relevant source and search for appropriate data

Once you have settled on a final data list, identify the sources for the different data types, and search for the data you need. Pay particular attention to the suitability of data that you find, for example with respect to coverage and extent, but also cloud cover.

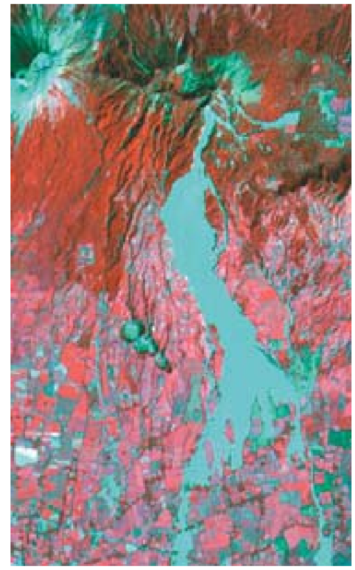


Figure 2.9. SPOT satellite optical image of a volcanic mudflow in Nicaragua (20m resolution).

(vi) Order data, or download directly

Task 2.4: Exercise (duration 15 minutes)
Without yet having learnt in detail how to assess risk with geodata, try to fill in the checklist for steps (i)-(iii).
Hazard type chosen:
(i)

(ii)

(iii)

In the past most data, in particular image data, had to be ordered and were shipped on tape or CD. Increasingly the data can now be downloaded directly. However, if your internet bandwidth is insufficient, you typically can still order data on a CD or DVD. There are also increasing numbers of repositories for other relevant data, such as on populations, thematic data, or disaster statistics. Those are introduced further below.

The steps outlined above are not always easy, for a number of reasons:

- Databases housing suitable information are often fragmented, e.g. every organisation or data provider organizes their own distribution method. It is still quite rare that a single portal provides access to a range of datasets.
- Obtaining data for routine observations is quite straightforward. For more specific questions or small, specific areas, this is harder. For example, getting weather data for all of Africa is easy (from MSG), but getting a good soil or transport network map for a specific municipality in countries such as Kenya or Indonesia may not be successful.

- Also remember that there are many organisations collecting data, and many sensors taking images on a routine basis, all generating a massive amount of data. For example, ENVISAT alone produces >500GB of data, every day! Finding the needed data is often not easy.

Even within the cost-step there are many aspects to consider, all influencing the overall data cost:

- Data type and extent of study area
- Number of datasets (e.g. need for repeat datasets)
- Need for raw or processed (value-added) data
- Availability of reference data (e.g. existing GIS databases)
- Need for commercial image data (Landsat, Ikonos, Quickbird, etc.)
- Need for rapid custom image acquisition
- Need for ground crews for collection of additional information
- Need for outside special resources (experts, databases, etc.)

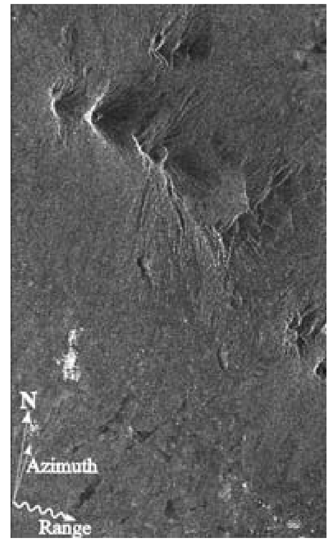


Figure 2.10. ERS-2 radar image of the same volcanic site as in figure 2.9. Note that the landslide is not visible.

Similarly, identifying relevant data sources may not always be easy, with many issues affecting both data availability and cost, and the need for specific software or expertise:

- We can distinguish between raw image data vs. thematic data (e.g. vegetation indices), which tend to be housed in separate catalogues
- There are global vs. regional vs. local data – the more local, the harder to find
- Image data can be obtained by different sensor types, e.g. satellite vs. airborne vs. ground-based; in principle the more global the easier the data are to get
- Do we need vector data or raster (image) data? (compare Figures 2.8 and 2.9)
- Do we need specific data types, such as laser scanning data or digital elevation models (DEMs)?

We can thus conclude that there are indeed many spatial datasets available, be it in form of tables, charts, statistics, or as maps, photos, model outputs or raster images. Where, then, do we find what we need? In the next section we introduce the main data repositories of interest for disaster risk management.

2.1.5 Spatial data for risk assessment

As there is a large range of spatial data that may be of use for risk assessment, below we only introduce the ones that are most widely used. Remember that it gets increasingly difficult to find data the more local your study area is, or the more specific your data needs are. Many other data sets can easily be found be searching the internet. Note that one very important data type – statistical disaster data – was already introduced in session 1 and is not repeated here.

Statistical data

If you require **population data**, organized on a per country or grid basis, try sources such as the global population database at Columbia University (http://sedac.ciesin.columbia.edu). Also census datasets are available, though they are usually provided by the governments of the respective countries, so you would have to search there.

For many specific hazards (not disasters), detailed databases also exist, which can be used to find out the approximate frequency of events for a given area and time frame. For example, for geophysical hazards check out NOAA's National Geophysical Data Center (http://www.ngdc.noaa.gov/hazard/), or specifically for seismic events, the USGS's Earthquake Hazard Program (http://neic.usgs.gov/neis/sopar/).

Task 2.5: Exercise (duration 30 minutes)
Go to the website of Columbia University listed above, and try to find population data for your country. Which data exist, and how detailed are they? Can you find more detailed data elsewhere, such as from your national census bureau? And which of the data you found are readily usable digitally and in a mapping framework (i.e. have a spatial reference system)?

Free or low cost thematic data

In this section we review commonly used thematic data that cover the world or large regions. As you will see below, there are more sources for image data than thematic databases with global or regional coverage.

(i) Digital Chart of the World (DCW)

An example of this dataset was already shown in Figure 2.8. The DCW is a global basemap of coastlines, international boundaries, cities, airports, elevations, roads, railroads, water features, cultural landmarks, etc. It was originally developed in 1991/1992, and national boundaries reflect political reality as of that time, thus in parts it is outdated. However, it still forms a widely used dataset that is free and easily obtained. On http://www.maproom.psu.edu/dcw/ you can search by country, and decide which data layers you need. The data are prepared for you immediately and can be downloaded. As it is originally an ESRI dataset, the data come in ArcInterchange format that can be read by most geoinformatics programs.

(ii) FAO/Geonetwork

The Food and Agricultural Organisation (FAO) of the UN has prepared a number of useful geo-tools, including the Geonetwork (http://www.fao.org/geonetwork/srv/en/main.home). Here you can search globally or by region, use existing maps or create your own. The available data comprise base layers (e.g. boundaries, roads, rivers), thematic layers (e.g. protected areas), or a backdrop image (e.g. World Forest 2000). Also try AgroMetShell, a specific software tool box for crop yield forecasting, or Dynamic Atlas (http://www.fao.org/gtos/atlas.html), designed for the integration of spatial (map), tabular (spreadsheet), and unstructured (document) data and metadata. Using dynamic Web Map Server technology it allows data from various sources to be integrated and customised online maps to be produced.

(iii) Geocommunity

Another useful source is Geocommunity (http://data.geocomm.com/). It is another source for DCW data, but also some DEMs, geology polygons, and some satellite imagery).

(iv) Mountain Environment and Natural Resources' Information Systems (MENRIS)

If you have an interest in the Himalayan countries (Figure 2.11), check out the Mountain Environment and Natural Resources' Information Systems (http://arcsde.icimod.org.np:8080/geonetwork/srv/en/main.home).

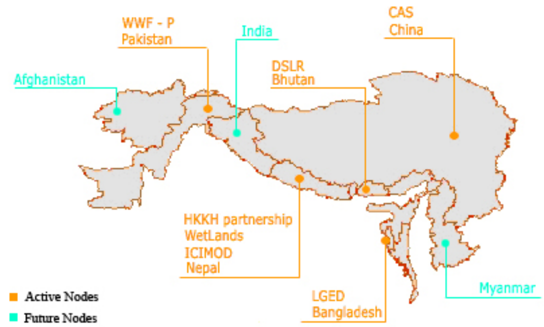


Figure 2.11: Countries covered by the MENRIS database.

Free or low cost image data

There are many sources for image data. As was pointed out before, it is much easier to find data from sensors that have global coverage (including those polar orbiters that only image a small part of the Earth at a time, but in time visit nearly the whole globe), than data from dedicated campaigns, for example for aerial photography. We also need to distinguish between the actual image data, and a picture. Many satellite images comprise several spectral bands that contain valuable information, such as the near infrared band for vegetation mapping that was already mentioned. If we convert such an image to a picture, such as a *.jpg or *.tif, the individual bands get merged, and the actual quantitative information lost. We can still use those pictures, but must be aware of the reduced information content. Note that there will be a separate exercise on finding and downloading of satellite data, thus this is not done here.

(i) Google Earth

The best example for the satellite imagery that has been converted to pictures is Google Earth. What you see there are typically the highest resolution and most recently available satellite images, but only shown as raster pictures. We cannot change bands, or enhance or otherwise manipulate the imagery. However, we can put many other available data layers on top, create our own or load those we get from other sources as *.klm files, and we also have an underlying DEM for 3D viewing. With Google Earth Pro (license cost of some 400 Euro) it is possible to save the high resolution pictures. We can then integrate them with other spatial data in a GIS. This can be very valuable when performing detailed elements at risk mapping, or for change detection when we have another, for example older image, available.

Task 2.6: Exercise (duration 30 minutes)

Open Google Earth (or install it if you don't have it yet). Review carefully the data coverage for your country, keeping in mind the hazards that are present, in particular the one you selected earlier. Evaluate how useful those data can be (also considering the 3D data) to study the hazards or elements at risk. What are the limitations?

(ii) Global DEMs

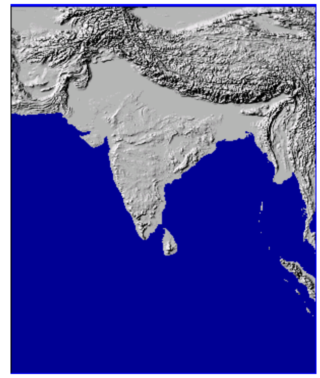


Figure 2.12: One of the tiles of the GTOP30 DEM.

There are two main sources for global DEMs: the older GTOPO30, or the more recent SRTM-based DEM. The GTOPO30 (http://edcdaac.usgs.gov/gtopo30/ gtopo30.html) is a coarse, global DEM, with grid cells of 1km across. The global dataset has been tiled, and individual tiles (Figure 2.12) can be downloaded from the site given above. The data are georeferenced, providing a good backdrop for large areas where fine detail is not necessary.

A more detailed source for DEMs is the dataset collected in 2000 during the Shuttle Radar Topography Mission (SRTM). A radar pair mounted on a space shuttle mapped nearly the entire globe at 30m resolution (http://www.jpl.nasa.gov/srtm/). Note though that the data outside the US are degraded to 90m. However, the data are free, and still a substantial improvement over the GTOPO30. The link gets you to the Seamless Data Distribution Centre, where you can specify the area needed. Be aware that, due to the high resolution, the files to be downloaded can be quite large.

(iii) Advanced Very High Resolution Radiometer (AVHRR)

The AVHRR is an older satellite mission, having already flown, with continuously replaced instruments, for over 20 years. It provides better than daily coverage, at a resolution of 1.1km per cell at nadir, meaning that because of the wide swath the coverage towards the edge of the image is closer to 4km. It is an excellent tool for frequent mapping at regional scale (Figure 2.13). The data can be downloaded at http://www.class.noaa.gov/ (see Figure 2.14). Because of the frequent observations a very large archive exists.

(iv) Advanced Spaceborne Thermal Emission and Reflection Radiometer (ASTER)

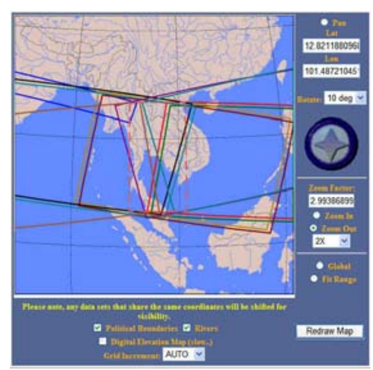


Figure 2.13: Example of AVHRR coverage for Thailand.

ASTER has become a very widely used satellite image source. Launched in 1999, the sensor carries a spectacular 15 channels, with 4 bands at 15 m resolution, 6 at 60m, and 5 at 90m. The spatial and spectral details are thus excellent, and, in addition, the data can be used to create DEMs. The best way to search for ASTER data is via the Earth Observing System Data Gateway (http://edcimswww.cr.usgs.gov/pub/imswelcome/), where also other data from NASA or NOAA-operated satellites can be found. You can register (for free), or search as a guest. Be aware that there are many different data products (Figure 2.14). It is advisable to read up on how these products were generated and what they are useful for (see http://asterweb.jpl.nasa.gov/). An even quicker way to check for available data is via the USGS'S Global Visualization Viewer (GLOVIS)'s (http://glovis.usgs.gov/), which gives a nice graphical overview. Aster data used to be free of charge for the first few years. Now they cost a nominal modest fee of 80US$ per scene. However, educational organizations such as universities can apply for free data (see http://lpdaac.usgs.gov/aster/afd/index.php).

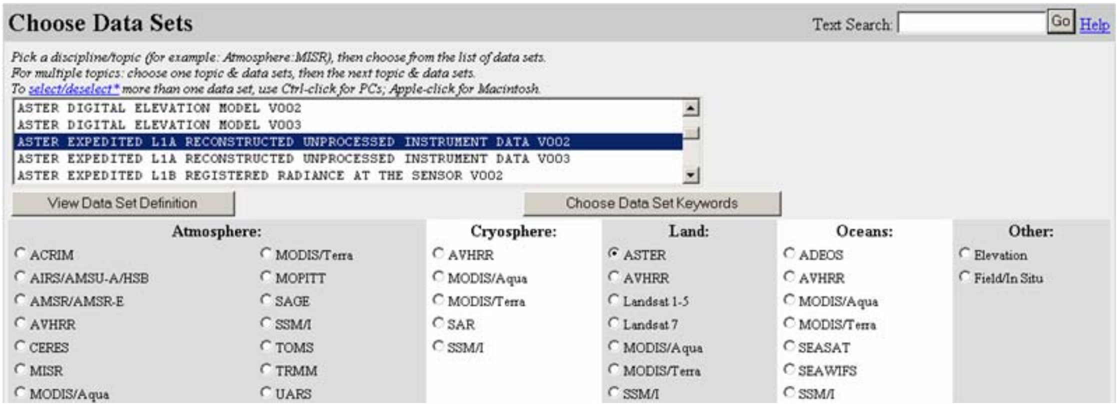


Figure 2.14: Screen capture of the data selection at NASA's Earth Observing System Data Gateway.

(v) Moderate Resolution Imaging Spectroradiometer (MODIS)

MODIS data are often considered together with ASTER, as the sensor is also NASA operated and compliments ASTER. There are actually MODIS sensors on two different satellites, acquiring data at moderate resolution in a remarkable 36 channels. Like ASTER, the resolution is variable, with some bands at 250m, some at 500, and some at 1,000m. The coverage of MODIS is 2,230km, thus very large regions can be monitored daily. The data are particularly suited for vegetation studies, see http://modis-land.gsfc.nasa.gov (select the Products category), http://edcdaac.usgs.gov/modis/dataproducts.asp. The data are free, but as with ASTER it is important to be careful in the product selection. As MODIS also contains bands that record information in the infrared and thermal parts of the spectrum, it is very sensitive to strong thermal emission, such as originating from wild fires or magmatic activity at volcanoes. At the University of Hawaii an automatic system was set up that uses MODIS data to map volcanic hotspots, see http://modis.higp.hawaii.edu/.

(vi) Landsat MSS/TM data

One of the oldest and best known satellites missions is Landsat, which has been providing Earth surface data since 1972. Initially the data had a resolution of 60 m, which was later improved to 30m (lower in the thermal bands). Despite its pioneering qualities, there have also been setbacks, with Landsat 6 failing to reach orbit in 1993, and the most current one, Landsat 7, suffering from some image quality problems. However, the latter also includes a 15m panchromatic band, and a thermal band that provides 60m data. For many years the data were also commercially sold, and at several thousand dollars per scene very expensive. Only recently the US government decided to make all Landsat data, including the entire archive, available free of charge. Data can be searched and downloaded using the GLOVIS tool already mentioned. There is also a source for free orthorectified Landsat data: http://www.landsat.org/ortho/index.htm. Good places to search are also the Global Landcover Facility (http://glcf.umiacs.umd.edu/index.shtml), or http://earthexplorer.usgs.gov. Be aware that Landsat datasets, even when compressed, can easily reach several hundred MB in size, which can make their download difficult (Figure 2.15). As with the other datasets mentioned above though, the files have geographic reference information and can easily be imported into a GIS or similar program.

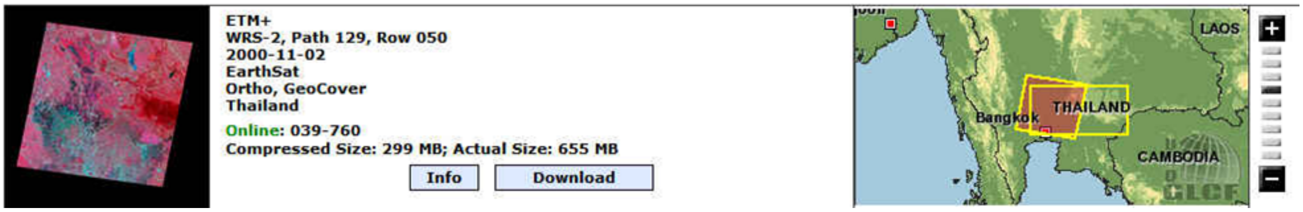


Figure 2.15: Landsat data ready for download at the Global Landcover Facility.

(vii) SPOT Vegetation

The SPOT satellites were initiated by the French Space Agency, but are now operated by Spot Imaging, a commercial company. The regular images are expensive, but the latest Spot satellite includes a vegetation mapper which collects data that are available for free if they are older than 3 months. They are distributed by VITO in Belgium (http://free.vgt.vito.be/). The resolution of the vegetation data is comparable to AVHRR at about 1.1 km (see Figure 2.16).

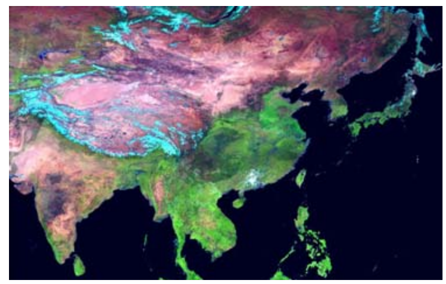


Figure 2.16: Example of Spot Vegetation data.

> **Task 2.7: Exercise (duration 45 minutes)**
> *Select 2 of the above data sources, and go to the internet pages provided. Familiarise yourself with the interface. In case of the NASA portal you can register or use it as a guest. Select a dataset that you know, and have a try to seeing what data for your area and a given time period exist. How easy is it to find data? Are those many data types confusing? There will be a full exercise later that focuses on data funding and downloading, so you will have more time for that later.*

Other commercial data sources

Commercial satellite data quickly reach costs in the thousands of dollars. Hence the well known commercial data types, such as Ikonos or Quickbird, are often not affordable, and are only briefly mentioned here. However, a few points must be noted. The mentioned commercial satellite operators have managed to increase the spatial resolution by a very impressive margin, for the first time reaching 50cm with GeoEye. These data are of a resolution comparable with many aerial photographs, but are already digital and usually include several spectral bands as well (the multispectral channels are of a lower resolution, usually at 4 times the resolution of the pan-chromatic band). There are also many more countries with their own space technology now. In addition to the traditional space powers – the US, Canada, Europe, Russia, and Japan – we now find many countries building and operating their own satellites instruments. Often these are small and relatively inexpensive satellites, such as micro- or even nanosatellites (less than 100 and 10 kg, respectively), thus we see a very active Earth observation arena, making it easier to get data. Countries that deserve special mention are India, which is operating one of the largest fleet of earth observation satellites, and has very ambitious plans, which are matched by China, which has also been collaborating with Brazil on a satellite program. Also in Africa there have been interesting developments, with Egypt, South Africa, Nigeria, and Algeria having operated Earth observation satellites, and plans exist for an African Resource Management Satellite.

For those who require high resolution commercial data, good search engines exist, such as http://ImageSearch.geoeye.com for GeoEye, Ikonos and OrbView data, or Eurimage for Quickbird data (www.eurimage.com/products/quickbird.html).

Task 2.8: Exercise (duration 45 minutes)
Submit to the discussion board a short overview of the hazard you have chosen, and a summary of the results you obtained in the various tasks. Check the submissions of your class mates, to learn about other hazard types, but also to see what data may exist for your hazard type in other countries.

2.2 Generation of digital stereo imagery

2.2.1 Introduction

We can see three-dimensionally – or "stereo" - because we have two eyes, which enable us to see a scene simultaneously from two viewpoints. The brain fuses the *stereo*scopic views into a three-dimensional impression (together with sensing what appears taller and what smaller, what is partially obscured, etc). We need therefore always two images taken from different positions for the creation of analog or digital stereo viewing (*Figure 2.20*). For applications in the field of hazard and disaster studies experts prefer images taken "from above", which can give an excellent overview of the terrain and the elements at risk.

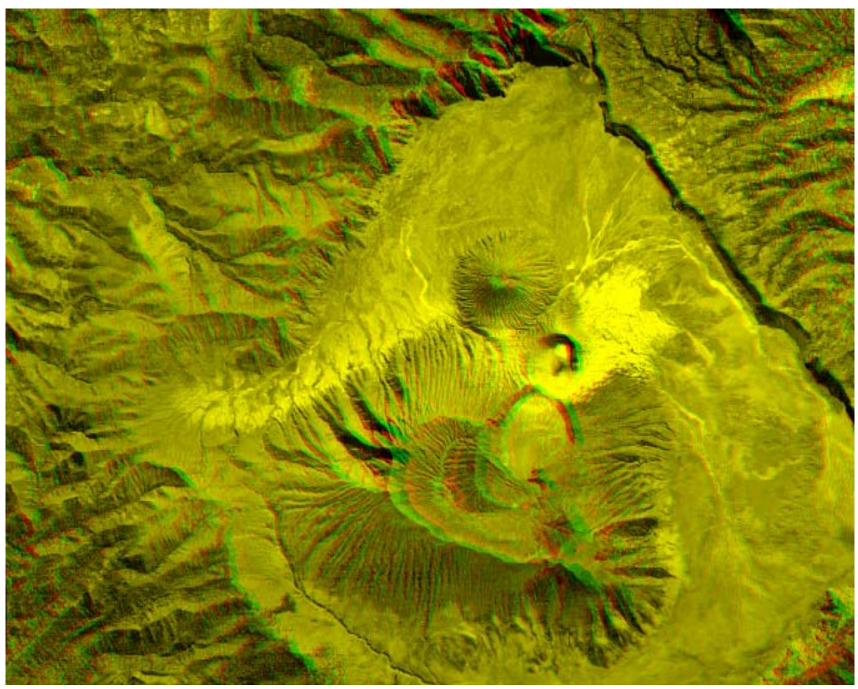


Figure 2.17: Anaglyph image - Bromo volcano, Indonesia (Damen, ITC)

One of the most widely used tools to see stereo is the *stereoscope***.** This device allows the observer to see images in three dimensions. Depending on the scale and image resolution of the (near) vertical images one can see in three dimensions for instance terrain morphology, building heights and other surface objects.

Figure 2.18: Use of screen-scope

Stereoscopes come in all shapes and sizes. The *mirror stereoscope* for instance uses mirrors to bring the two images to the two eyes of the photo-interpreter. The main advantage of using this type is that the *stereo pair* can be completely separated, thus permitting the analyst to see more of the image at once. In the ILWIS software it is possible to resample the left and right images to such a position relative to each other, that stereo vision is possible on the computer screen using a *screen-scope* (Figure 2.18)**;** but *anaglyph* vision is also possible in ILWIS. To make this possible, the overlapping part of the left and right images are combined in *two color layers*, to create a depth effect. For the viewing one need two color anaglyph glasses, with each lens a chromatically opposite color, usually red and green or red and blue (Figure 2.19).

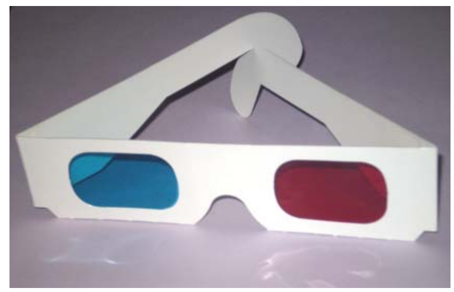


Figure 2.19: Anaglyph glasses

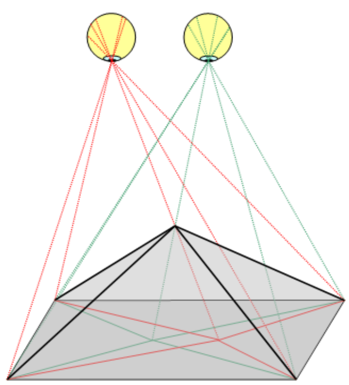


Figure 2.20: Stereoscopy: seeing of objects in three dimensions (RS Core Book, ITC, 2008)

Instead of using two overlapping images, one can create in ILWIS also a 3-D visualization by combining an image with a digital elevation model of the same area. Stereo images that do not have geographical co-ordinates, such as for instance a pair of scanned aerial photographs, can be geo-referenced in ILWIS using for instance a topographical map.

Nowadays more and more data are becoming available – some even free of costs– for the creation of 3-D visualization. Below an overview is given of the most widely used systems, starting with more traditional types such as aerial photographs, followed by laser scanning data together with various space borne systems.

With oblique viewing “as a birds eye” it also possible to receive kind of 3-D visualization. This option is given for instance in Google-Earth, in which the image is “draped over a DEM.

Task 2.9 : Exercise (duration 15 minutes + Optional task)
Have stereo vision yourself with the provided anaglyph glasses.

For the creation of the anaglyph image of Bromo volcano (Figure 2.17), first a digital elevation model (DEM) is made from the overlapping vertical (nadir) and backward looking Infra Red image bands of the Aster satellite sensor. (Remark: Special photogrammetric software is used for this processing; unfortunately this can not be done in ILWIS).
The horizontal spatial resolution of the DEM is 30 m.; the relative vertical accuracy is approximately 1 m. (the relative accuracy however is much higher, and can be 15 m. or more).
To create the anaglyph in ILWIS a"screenshot" of the high resolution image in Google Earth of the area has been "draped"over the DEM. This image has first given the same coordinate system as the DEM by image-to-image rectification.

- *Look at the anaglyph image of Bromo volcano, East Java, Indonesia (Figure 2.17). Keep the red glass to the right. Try to recognize the different geomorphological features, such as the volcanic craters and cones of different phases of eruption. Volcanic ash of one of the most recent eruptions is shown with a light tone.*

Optional task: Open Google Earth and browse to the area yourself (70 57'/ 1120 58').
Interesting websites:
Bromo volcano, ESA: http://www.esa.int/esaEO/SEMUAU0DU8E_index_0.html
ASTER satellite sensor: http://asterweb.jpl.nasa.gov/
You can comment on your findings on the discussion forum in Blackboard.

2.2.2 Aerial photography

Aerial photographs has been used since the early 20th century. The aerial camera using a lens to record data on photographic film is by far the oldest remote sensing method. Depending on the type of film this can be black and white, color infra-red or natural color. Also other options are available. Nowadays it is also possible to make digital aerial photographs

Aerial photos are an extreme useful source of information for specialists in the field of hazard and disaster studies. Not only do they provide detailed spatial data of the terrain, but also of the infrastructure and other elements at risk. By comparing older photos with more recent images, changes can be analyzed of for instance hill slopes, to be used to assess stability, or of the horizontal shifts of the river bed for flood hazard studies. However, many more examples can be given.

Figure 2.21: Sequential aerial photography in one run

The science and technique of making measurements from photos, including terrain models is called *photogrammetry*. Almost all topographic maps are based on aerial photographs, which are replaced nowadays by modern digital aerial images. Also the topographic contour lines are created by photogrammetric measurements.

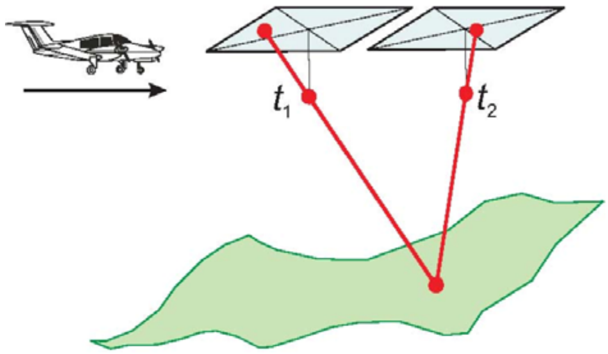


Figure 2.22: Image position at two aerial photos (t1 –t2) of the same terrain feature (RS Core Book, ITC, 2008)

Aerial photographs are mostly taken by a plane in parallel strips or *runs* (Figure 2.21). To create a good stereo vision, all the photos need overlap of about 60 % in the direction of the flight-line; the sideways overlap should be 30 % (Figure 2.24). In overlapping aerial photographs the same feature in the terrain will have a different position in the left and right image (Figure 2.22). By knowing the *internal* and *external* orientation of the camera, a digital or analog stereo model can be created. The *internal* orientation gives the position of the projection center of the camera lens with respect to *the image;* it is also called the *"principal point*" of the aerial photograph. In photo film cameras so called *"fiducial marks"* are printed at the corners and edges of the photo to measure this principal point (Figure 2.23). *External* orientation gives the position and tilt of the camera in respect to the terrain co-ordinate system. As the calibration report of the aerial camera listing all the technical details on the internal and external orientation is not always available, it is in ILWIS also possible to create a stereo image without knowing all the details. A pair of scanned aerial photos with at east three fiducial marks is sufficient. However, one has to accept that the image has no real world co-ordinates.

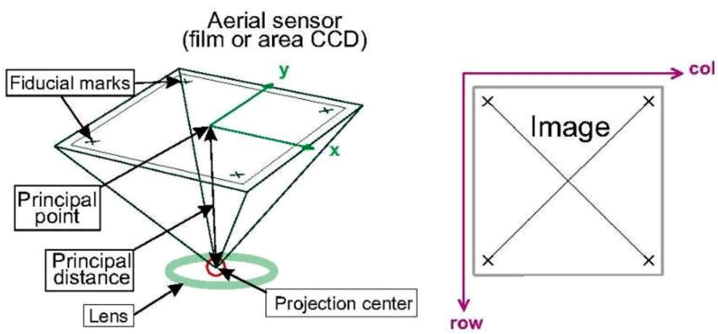


Figure 2.23: Inner geometry of a camera and associated aerial photograph (RS Core Book, ITC, 2008)

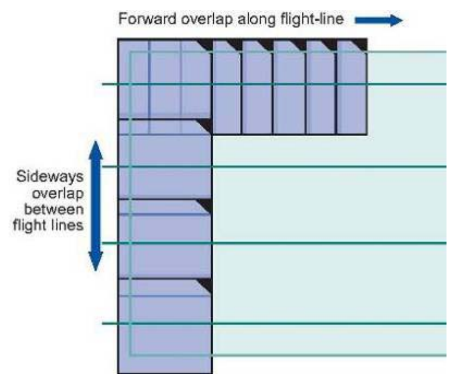


Figure 2.24: Overlap of aerial photographs (RS Core Book, ITC, 2008)

Figure 2.25: Damage mapping using small format aerial photography Aceh tsunami disaster (Photos: B. Widartono, UGM, Indonesia)

In cases were stereo images are not quickly available – for instance for damage assessment immediately after a disaster – also monoscopic images - even in oblique mode - can be extremely useful (Figure 2.25). For the image acquisition one can think of "alternative" platforms, such as a microlight, helicopter or even a kite.

2.2.3 Lidar

Another air-borne system widely used to create 3-D is ***LI**ght **D**etection **A**nd **R**anging (**LIDAR**)*. A laser scanner mounted in an aircraft emits laser beams with a high frequency to record the reflections together with the time difference between the emission and reflection (Figure 2.26). With detailed information about the internal and external orientation using GPS and other devices, the elevation of the 'scanned' area can be measured in centimetre accuracy (Figure 2.28). LiDAR differs from RADAR mainly in its ability to resolve very small targets and penetrate vegetation.

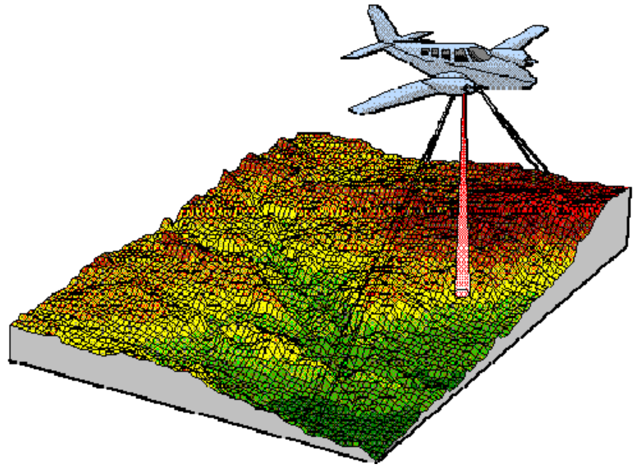


Figure 2.26: Lidar scanning (GEODAN, NL)

The reflection strength depends on the wave length and the terrain type. All terrain features are scanned, not only the terrain itself but also trees, buildings, cars on the street, etc… To create a 3-D *terrain* model all this data has to be filtered out from this original *surface* 3-D model. The multiple reflections from the same surface feature, such as a tree (see Figure 2.27) can also be used for, for instance 3-D vegetation mapping and biomass estimation.

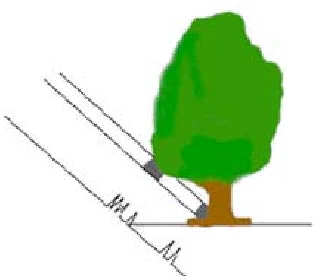


Figure 2.27: Multiple reflections of Lidar beam (Vosselman, ITC)

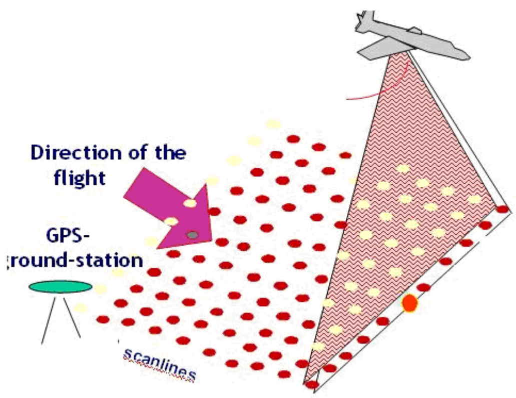
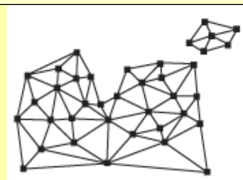
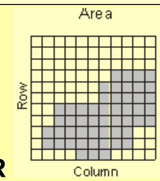


Figure 2.28: Lidar scanning (GEODAN, NL)

An excellent terrain representation can be created if a very high resolution optical image, such as IKONOS or Quickbird is "draped" over the Lidar surface or terrain model. One can use also downloaded high resolution "Google Earth images" for this purpose, after geo-referencing.

Digital Elevation Models (DEMs) consist of a listing of elevations above a defined geographic datum, over some area of the earth.

Digital Elevation Models can either be stored in vector or in raster format. DEMs in vector format are often in the form of Triangulated Irregular Networks (TIN), which can be seen as a set of polygons in the form of triangles where the 3 corners of each triangle have known height values. Programs like ArcGIS use both the vector and raster format to store and manipulate DEMs; in ILWIS DEMs can only be stored in a raster format. In ILWIS it is possible to create a raster DEM by point and contour line interpolation. Good visualizations of terrain can be generated with this (Figure 2.29).

	TIN 	**RASTER** 
Advantages	o ability to describe the surface at different level of resolution o efficiency in storing data	o easy to store and manipulate o easy integration with raster databases o smoother, more natural appearance of derived terrain features
Disadvantages	o require often visual inspection and manual control of the network	o Inability to use various grid sizes to reflect areas of different complexity of relief.

Digital Elevation Models form one of most frequently used spatial data sources in GIS projects. The most important application areas of DEMs are:

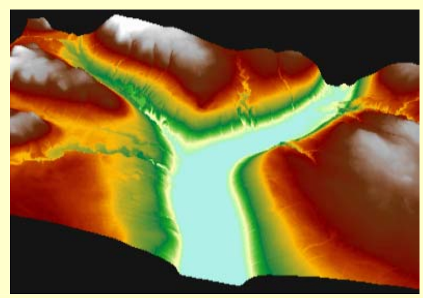


Figure 2.29: 3-D visualization of terrain with elevation in colors – See also DEMO

- ***Slope steepness maps***, showing the steepness of slopes in degrees or percentages for each location (pixel).
- ***Slope direction maps*** (also called slope aspect maps), showing the orientation or compass direction of slopes (between 0˚-360˚).
- ***Slope convexity/concavity maps***, showing the change of slope angles within a short distance. From these maps you can see if slopes are straight, concave or convex in form.
- ***Hill shading maps*** (or shadow maps), showing the terrain under an artificial illumination, with bright sides and shadows. Hill shading shows relief difference and terrain morphology in hilly and mountainous areas
- ***Three dimensional views*** showing a bird's eye view of the terrain from a user defined position above the terrain.
- ***Cross-sections*** indicating the altitude of the terrain along a line and represented in a graph (distance against altitude).
- ***Volume maps*** (or cut-and-fill maps), generated by overlaying two DEMs from different periods. This allows you to quantify the changes in elevation that took place as a result of slope flattening, road construction, landslides etc.

Digital Elevation Models are made via the following techniques:

- ***Photogrammetrical techniques.*** These methods use stereoscopic aerial photographs or satellite images, to sample a large number of ground points, with X, Y and Z elevation values, by means of special developed software. After this, the points are interpolated into a regular grid (raster). It is nowadays possible to buy ready-made DEM products on medium scale created from ASTER, SPOT, and other satellite systems. Large scale DEMs with high accuracy can be derived from Laser scanning or Stereo IKONOS imagery.
- ***Point interpolation techniques***. First elevation point data have to be collected from an area, for instance by ground surveying, using high accuracy differential Global Positioning Systems (GPS). The DEM is generated by point interpolation, in which values of the intermediate elevation points are being estimated;
- ***Interpolation of contour lines*** digitized from topographical maps.

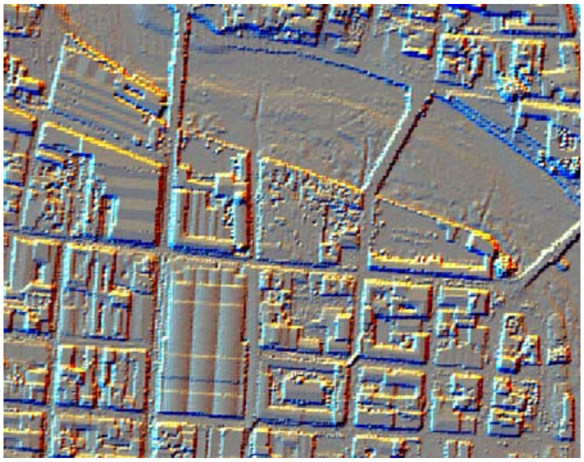


Figure 2.30: Terrain model of Risk City from Lidar – Hillshaded in color

Examples of the use of Lidar are corridor mapping for roads and rail roads, 3-D city modelling (see Figure 2.30), telecommunication planning, archaeological sub-surface site investigation, vegetation mapping and the quantification of erosion and sedimentation volumes. Also a good surface expression can be generated with a hill shade model (Figure 2.30)

> **Task 2.10 : Exercise (duration : 45 minutes)**
>
> 1. *Read the text about the Actual Elevation Model of the Netherlands on: http://www.ahn.nl/english.php*
> 2. *Study also the lidar animations on: http://www.ahn.nl/demoanimaties.php*
> 3. *Animation of lidar acquisition of infrastructure with helicopter: http://nl.youtube.com/watch?v=f1P42oQHN_M*

2.2.4 Shuttle Radar Topography Mission (SRTM)

Other ways to create 3D terrain models are the use of radar. An example of this is data from the **Shuttle Radar Topography Mission** (SRTM) of February 2002, covering large parts of the globe, which can be downloaded for free from the internet (see the task).

The radar signal is recorded with antennas at two slightly different positions: one in the centre of the Space shuttle itself and another at the end of a 60 m long mast (Figure 2.31).

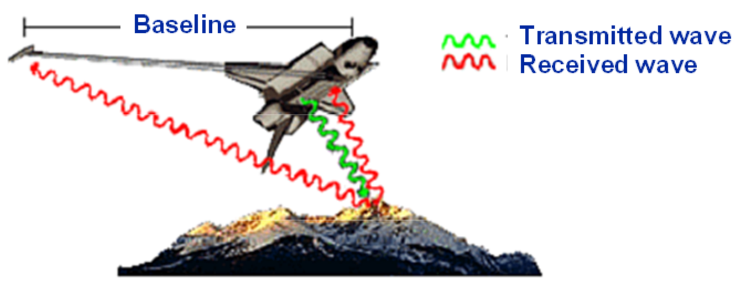


Figure 2.31: SRTM data collection(www2.jpl.nasa.gov/srtm)

Using the information about the distance between the two antennas and the differences in the reflected radar wave signals, elevation data of the Earth's surface can be generated at a relative accuracy. The pixel (*X* –*Y*) resolution of the data is 91 m; the vertical (*Z*) resolution 1 m. with an absolute accuracy of approximately 10 – 15 m.

This means that SRTM is not suitable for the measurement of accurate elevations. However, for medium of low terrain studies of large areas it can be very good. It the field of hazard and disaster studies it is extensively used for among others for tsunami impact studies along the coasts of Sumatra and Sri Lanka. Other applications include the impact of enhanced sea level rise. The map in Figure 2.32 shows low and high areas vulnerable to future sea intrusion along the West coast of Sri Lanka. SRTM data is also used for 3-D viewing in Google Earth.

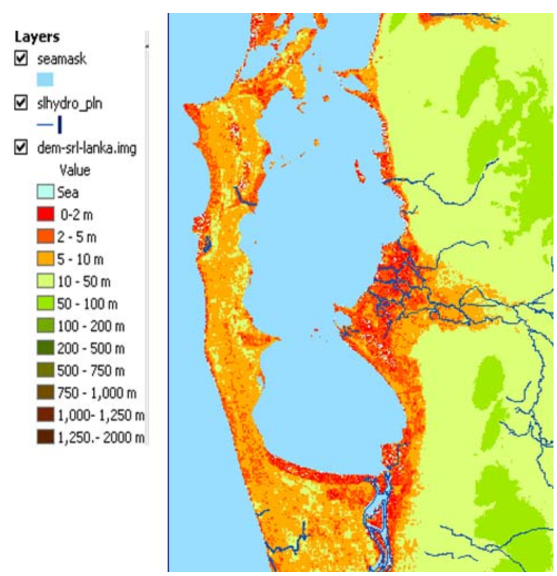


Figure 2.32: Medium scale elevation using SRTM data – West coast Sri Lanka (Damen, ITC)

Task 2.11: Exercise (duration 1.5 hours)

Download of SRTM data from the www – Import and display in ILWIS
Read first the background information on SRTM on NASA website: http://www2.jpl.nasa.gov/srtm/
To download SRTM data from the CGIAR website: http://srtm.csi.cgiar.org/ follow the instructions given in ***RiskCity Exercise 2 Download SRTM & Import in ILWIS***
You can comment on your findings on the discussion forum in Blackboard

2.2.5 Optical satellite systems for 3-D model generation

Various modern satellite sensors have nowadays capabilities to generate 3-D models from the earth surface with sensors using the visible spectrum. Two systems widely used are the Advanced Space borne Thermal Emission and Reflection Radiometer (ASTER) and the French SPOT satellite.

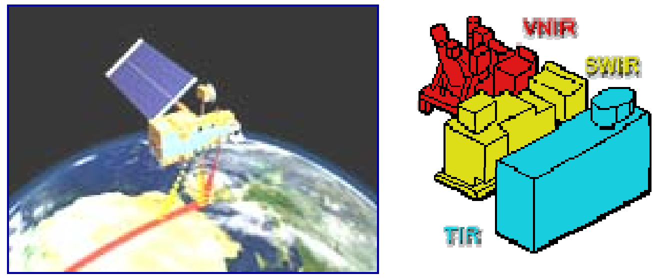


Figure 2.33: ASTER satellite and sensors http://asterweb.jpl.nasa.gov)

The **ASTER satellite** has been launched in December 1999. The orbit has an altitude of 705 km altitude, and is sun-synchronous, so that at any given latitude it crosses directly overhead at the same time each day. Every 16 days (or 233 orbits) the pattern of orbits repeats itself.

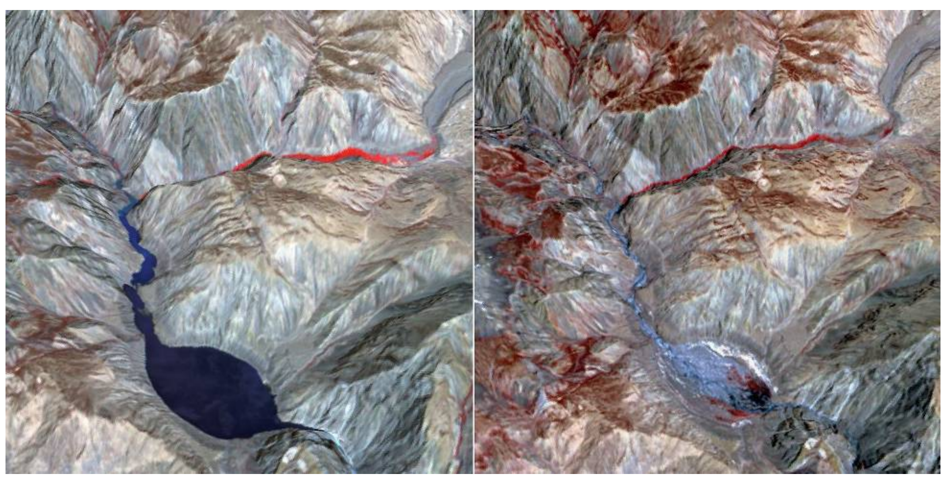


Figure 2.34: Water levels in the Pareechu River in Tibet continue to build behind a natural dam, created by a landslide. On September 1, 2004, ASTER captured the left image of the new lake. The right image was acquired May 24, 2000, before the landslide.
The water has filled the basin and poses a threat to communities downstream in northern India, which will be affected if the landslide-dam bursts. Both perspective views were created by draping a false color ASTER image over ASTER DEM data. (http://asterweb.jpl.nasa.gov)

Aster has three sensors with together 14 image bands in the Visible & Near Infra Red (VNIR), Short Wave Infra Red (SWIR) and Thermal IR (TIR) (see Figure 2.33). The VNIR sensor has in total four bands, of which one is "back-ward" looking. By combining the vertical or "nadir' looking band with the backward looking band a three dimensional terrain model can be generated with a pixel resolution of 30 m (See example in Figure 2.34). The data can be bought relatively cheap from the US Geological Survey (USGS).

The **SPOT satellite** has a different system compared to ASTER to generate 3-D data; it has a very good global coverage (Figure 2.35). The sensor has a steerable mirror by which it can detect terrain across track to the "right" or to the "left" of the satellite overpass (Figure 2.36). By combining this images– which are taken under an angle - from different overpasses, a three dimensional model can be generated.

A SPOT DEM is a digital elevation model produced by stereopairs acquired by SPOT-5. The resampled resolution is 20 m; vertical accuracy 7 m and horizontal accuracy 10m.

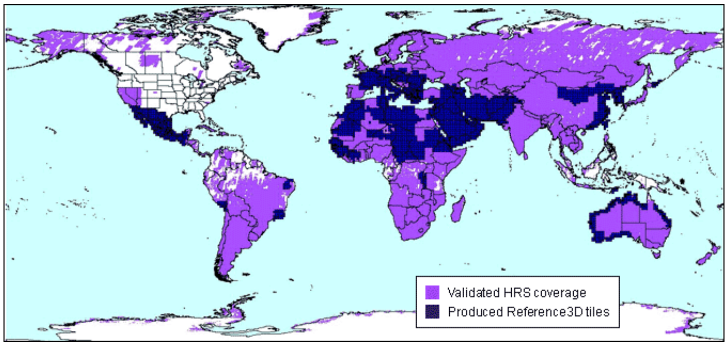


Figure 2.35: DEM Global coverage of SPOT satellite

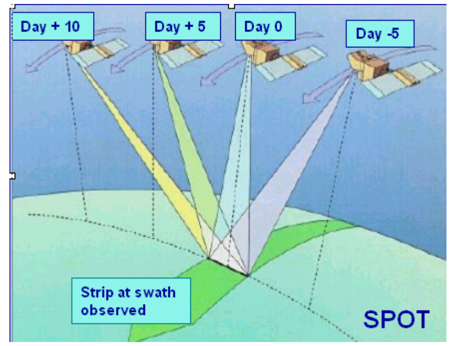


Figure 2.36: SPOT satellite system

Task 2.12: Internet assignment (duration 30 minutes)

Explore the internet pages of ASTER and SPOT:
http://asterweb.jpl.nasa.gov/data.asp & *http://www.spotimage.fr/*
Explore the pages of the mission
Find examples of images from natural hazards in the galleries
Try to find other sensors with stereo capabilities

2.2.6 Examples of the use of DEMs

Many derivate maps can be produced from DEMs using fairly simple GIS operations. An example of DEM derivatives obtained from an SRTM DEM for the watershed area in which RisKCity is located is shown in Figure 2.37. After obtaining the raw data, several processing steps had to be applied in order to correct for the missing data values and to remove so-called "sinks", which are closed depression in the DEM due to artifacts.

The LiDAR DEM of the Riskcity area was obtained from the USGS. It was collected by the University of Texas using an ALTM 1225 in March 2000, at an altitude of 800-1200 resulting in a spacing of 2.6 m between scan lines. A TopScan vegetation removal filter was applied and the data was interpolated into a 1.5 m resolution DEM. The LiDAR DEM was used together with the SRTM DEM (90 m spatial resolution) and with two other DEMS from contour maps. The first contour maps had a scale of 1:2000, 2.5 meters contour lines and the resulting DEM was made at 1 m spatial resolution. The second contour map was at scale 1:50000 with 20 m contour lines interpolated in a DEM with 30 meter pixel size. The four DEMs were used to produce slope angle maps, using horizontal and vertical gradient filters. The resulting slope maps were classified into classes of 10 degrees, and overlain with a landslide inventory. Figure 2.39 shows the 4 slope class maps with the corresponding histograms. The slope class maps derived from SRTM and 1:50000 scale topomaps contain more flat areas as compared to the DEMs from 1:2000 topomaps and LiDAR. From the figure it can be concluded that the resolution and accuracy of the DEM has a very large influence on the slope classes.

Figure 2.37: Examples of different types of optical remote sensing images for El Berrinche landslide in RiskCity,. A: Section of an Aerial-photo, scale 1:14,000 from 16-March-1975, B: Section of an aerial-photo, scale 1:20,000 from 9-February-1990, C: Section of an aerial-photo, scale 1:25,000 from 1998, taken after hurricane Mitch, D: Section of an orthophoto, generated from 1:10,000 photos from May 2001, E: Section of a Aster image, with a spatial resolution of 15 meters from 2005; F: Section of a IRS P6 image, with a spatial resolution of 5.6 m from 14-April 2006; G: Section of a Digital Globe image from Google Earth, from 2007; H: Shaded relief image from a LiDAR DEM with 1.5 meter spatial resolution.

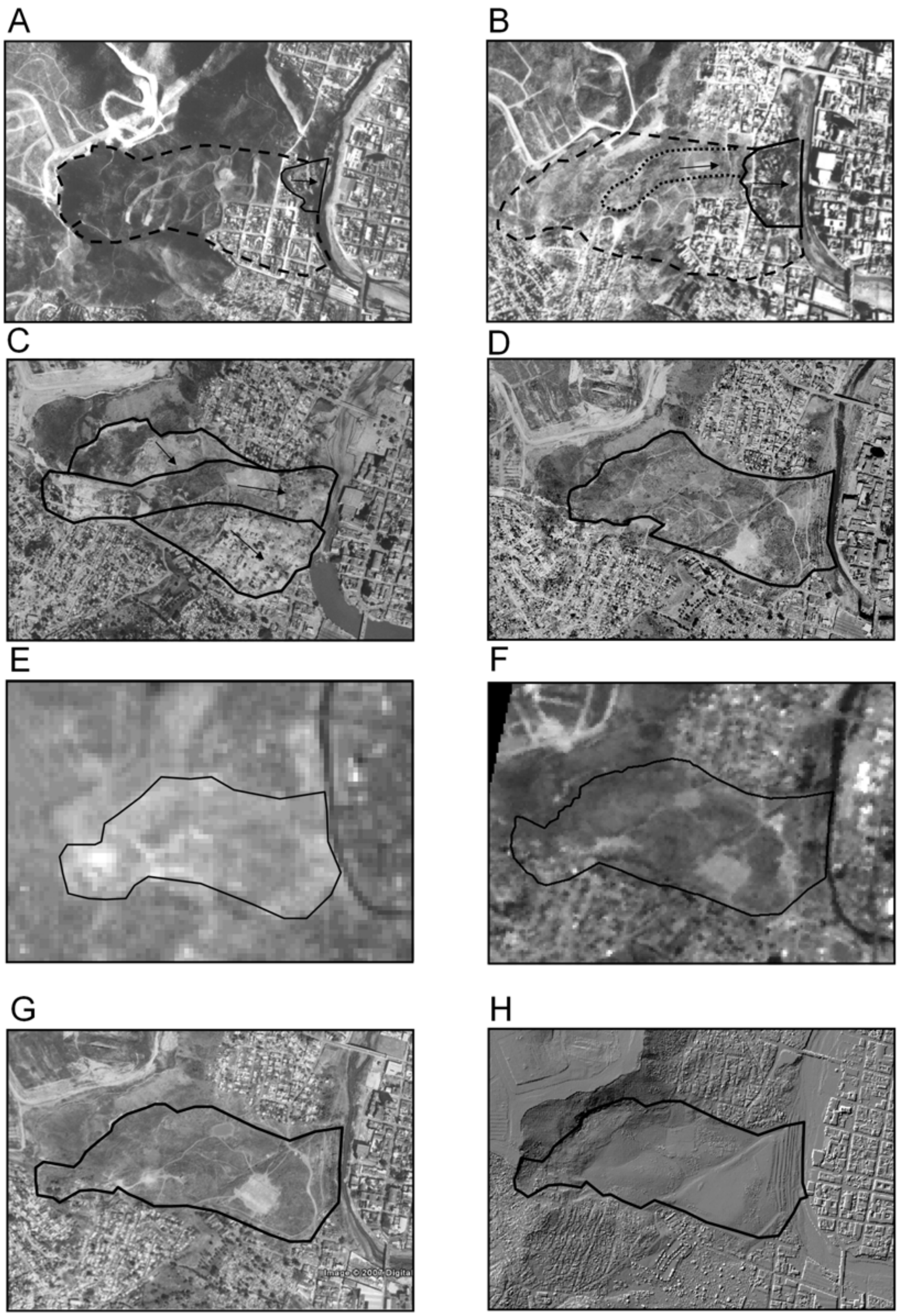


Figure 2.38: Examples of derivative maps from a SRTM DEM of the watershed of the Choluteca River, near Tegucigalpa. A: Altitude, B: Shaded relief image, C: Slope angle (in degrees), D: Slope direction (in degrees), E: Flow accumulation, F: Automatic drainage and catchment delineation, G: Drainage direction, H: Landsat TM image showing the location of Tegucigalpa, and the watershed boundary..

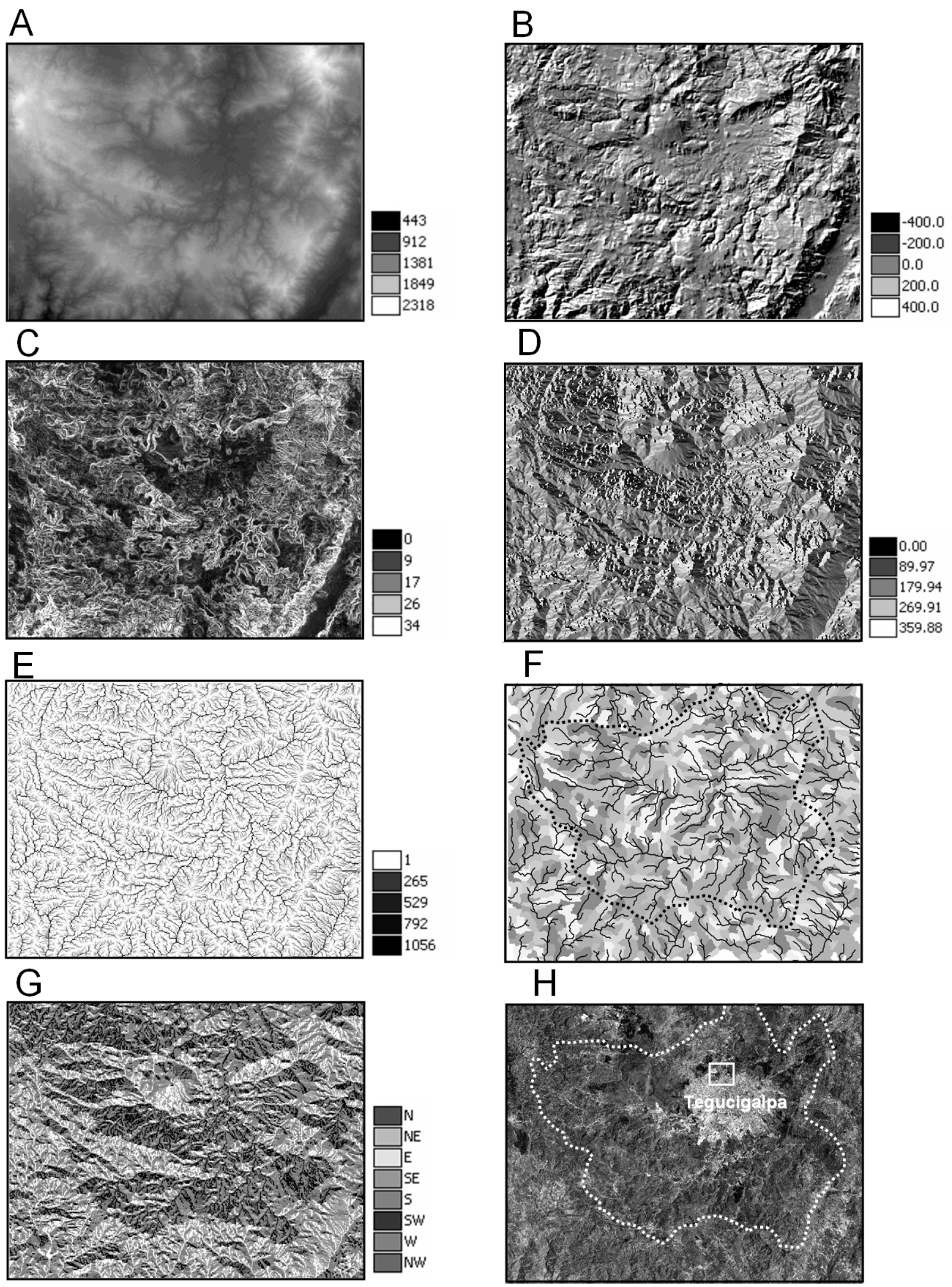
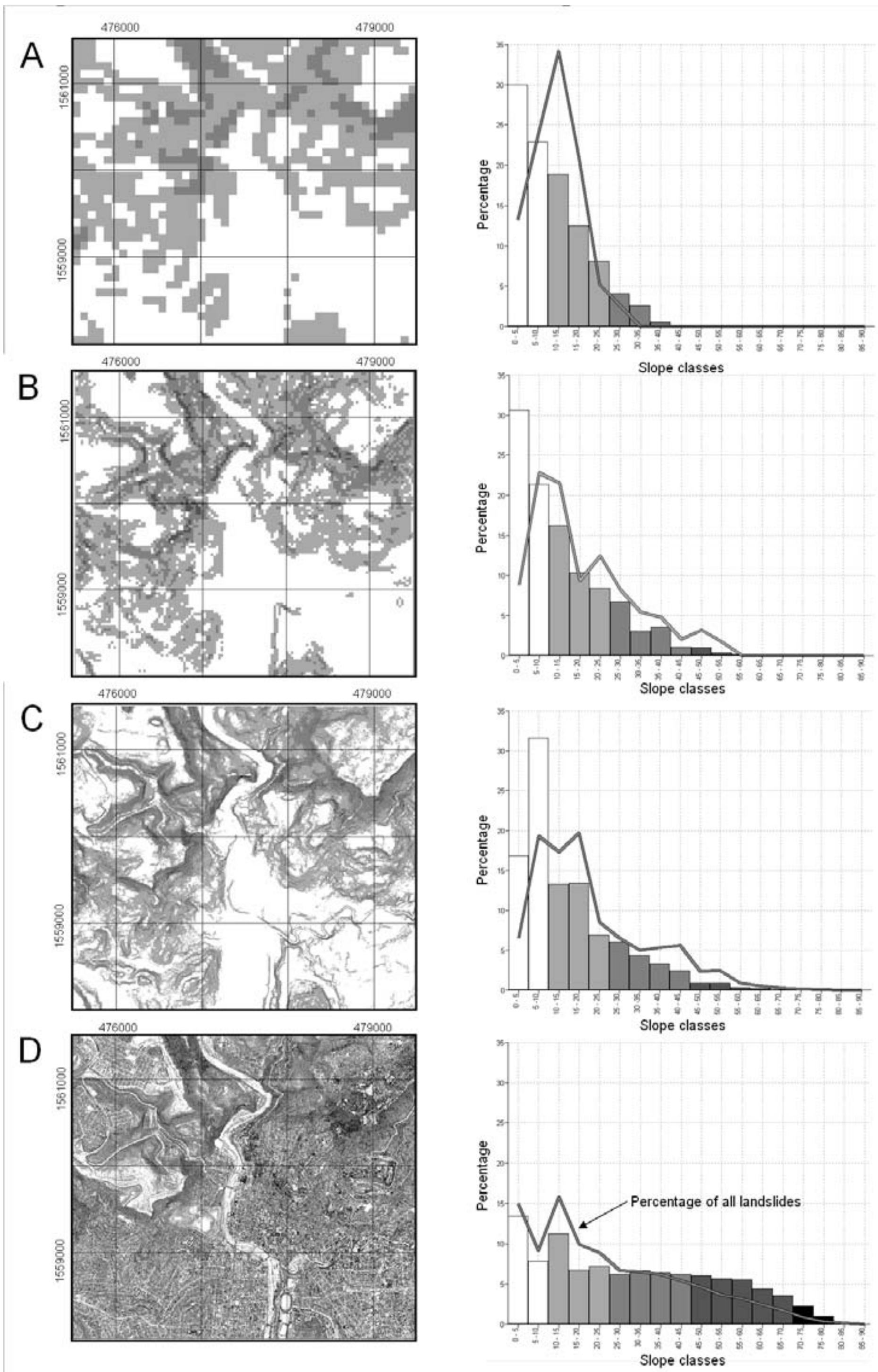


Figure 2.39 : Effect of the use of different DEMs on the generation of slope maps and the relation with landslide distribution. The left side of the figure shows the slope angle maps (in degrees) generated from: A. SRTM data; with 90 m spatial resolution, B. 1:50,000 topomaps with 20 m contour interval, resulting in a DEM with 30 m horizontal resolution, C. 1:2,000 topomaps with 2.5 m contour interval, resulting in a DEM with 1 m spatial resolution, D. a LiDAR image, from which the vegetation has been removed, with 1.5 m spatial resolution. The right side of the figure shows the percentage of area per slope class (bar charts), and the percentage of all landslides per slope class (thick lines).



2.2.7 Overview of different types of RS systems for disaster management

As has been explained before in this Session 2 of the Guidance Notes, optical and active (radar) RS systems as well as digital elevation models can have different characteristics in respect to the number of image bands, temporal coverage and pixel size. Aerial photographs for instance have in most cases a much higher spatial resolution compared to satellite images but a low temporal coverage (may be every 5 or 10 years only). And the relative high resolution IKONOS satellite with its 1 meter panchromatic band has a higher spatial resolution than for instance the 15 m panchromatic band of Landsat Enhanced Thematic Mapper. Digital elevation models derived from Lidar have much smaller pixels (up to 1 m or less) compared to SRTM (pixel size approx. 90 m). Many more examples can be given of this; it will be clear all the available systems have their own specific advantages and disadvantages in respect to disaster risk management.

Table 1 provides an overview of the requirements for different types of information for the various phases of disaster risk management, and the utility of remote sensing and other spatial data types and methods. Note that this is a generalized schematic that does not reflect sub-hazards, the assessment of which may require different data and/or different spatial and temporal characteristics.

Task 2.13: RiskCity Exercise 2 : Creating and interpreting multi-temporal digital stereo images (duration 2.5 hour)

The exercise shows you how you can generate stereo images from digital aerial photographs and Digital elevation Models. The stereo images can be displayed using the anaglyph method and are used to interpret the landslide activity in RiskCity from different periods (1977, 1998, 2001 and 2006).

If you also will do the GIS exercise (Task 1.11) you may also decide to skip this exercise now.

	Phase	Data type	Spat (m)	Temp	Other tools	Satellite sensors				
						VIS/IR	TH	SAR	INSAR	Other sensors
Flood	Hazard mapping/ Prevention	Land use / landcover	10 - 1000	Months	API + field survey	X		X		
		Historical events	10 - 1000	Days	Historical records, media	X		X		
		Geomorphology	10 - 30	Years	API + field survey	Stereo				
		Topography, roughness	1 - 10 *	Years	Topomaps	Stereo		X	X	Laser altimetry
	Preparedness	Rainfall	1000	Hours	Rainfall stations	X	X			Weather satellites/ Passive Microwave/ ground radar
		Detailed topography	0.1 - 1 *	Months	GPS, field measurements				X	Laser altimetry
	Relief	Flood mapping	10 - 1000	Days	Airborne + field survey	X		X		
		Damage mapping	1 - 10	Days	Airborne + field survey	X				
Earthquake	Hazard mapping/ Prevention	Land use / landcover	1 - 10	Years	API + field survey	X				
		Geomorphology	1 - 10	Decade	API + field survey	Stereo				
		Lithology	30 - 100	Decade	API + field survey	X				Hyperspectral
		Faults	5 - 10	Decade	API + field survey	Stereo		X		
		Soil mapping	10 - 30	Decade	API + drilling + lab. testing	X				
	Preparedness	Strain accumulation	0.01 *	Month	GPS, SLR, VLBI				X	
	Relief	Damage assessment	1 - 5	Days	Airborne + field survey	X		X		
		Associated features	10 - 30	Days	Airborne + field survey	X		X		
Volcano**	Hazard mapping/ Prevention	Topography	10 *	Years	Topomaps	Stereo			X	Laser altimetry
		Lithology	10 - 30	Decade	API + field survey	X		X		Hyperspectral
		Geomorphology	5 - 10	Years	API + field survey	Stereo				
		Landcover/snow	10 - 30	Months	API + field survey	X				
	Preparedness	Thermal anomalies	10 - 120	Weeks	Field measurements		X			
		Topography/deformation	0.01 *	Weeks	GPS, tilt meters				X	Laser altimetry
		Gas (composition, amount)	50 - 100	Weeks	IR spectrometer (COSPEC, FTIR)	X				Weather satellites
		Instability	10-30	Months	Field spectrometer					Hyperspectral
	Relief	Mapping ash cover	10 - 30	Days	Airborne + field surveys	X				
		Mapping flows	10 - 30	Days	Airborne + field surveys	X	X	X		
		Ash cloud monitoring	1000	Hours	Field surveys, webcams	X				Hyperspectral / weather satellites
Landslide	Hazard mapping/ Prevention	Landslide distribution	1 - 5	Year	Multi-temporal API, field survey, historic records	Stereo				
		Geomorphology	1- 10	Decade	API + field survey	Stereo				
		Geology	10 - 30	Decade	API + field survey	X				Hyperspectral
		Faults	5 - 10	Decade	API + field survey	Stereo				
		Topography	10 *	Decade	Topomaps	Stereo			X	Laser altimetry
		Landuse	10 - 30	Year	API + field survey	X				
	Preparedness	Slope movement	0.01 *	Days	GPS, field instrumentation				X	Laser altimetry
		Rainfall	100 - 1000	Hours	Rainfall stations	X	X			Weather satellites/ Passive Microwave/ ground radar
	Relief	Damage mapping	1-10	Days	API + field survey	X		X		

*Table 1: Requirements for the application of remote sensing and other spatial data in the various phases of disaster risk management. For each data type an indication is given of the optimal spatial resolution (spat), the minimum time for which successive data should be available (temp), and the sensor types that could be used (API – aerial photos, VIS =.visible, IR =infrared, TH = thermal, SAR = Synthetic Aperture Radar, INSAR = interferometric SAR,), VLBI = Very Long Baseline Interferometry, SLR = Satellite Laser Ranging, FTIR = Fourier Transform Infrared Spectroscopy, * = In this case the minimum resolution of the resulting DEM values are given, ** = this refers to eruptive activity. See Session 03 on more detailed information on volcanic hazards. Depending on the subhazard the data types have to be adapted.*

Self Test

Self test
In order to evaluate whether you have understood the concepts that were presented in this session. Please make the following test, and check the answers in Blackboard.

Note: several answers might be correct

Question 1: Why are spatial data so well suited for disaster risk assessment?

A) Spatial data are 3-dimensional
B) Spatial data have color information
C) All risk aspects are spatial, i.e. have a spatial location and extent
D) Spatial data can be referenced to geographic coordinates and displayed together in a GIS.

Question 2: Why is not every image type suitable for every hazard?

A) Images can have different spatial resolutions that may not always fit a given hazard
B) The observation frequency (temporal resolution) may be too low to pick up fast-changing hazards
C) I lack the right software to process the data
D) Images have variable spectral characteristics that need to match individual hazard types

Question 3: To map and observe a wildfire the following data type(s) or sensors would be useful.

A) Stereo aerial photos
B) Meteorological satellites
C) Laser data
D) Airborne infrared scanners

Question 4: When should I use Google Earth data for hazard assessment?

A) To map volcanic activity or wild fires
B) For landcover change detection
C) For broad visual assessment of hazards with clear surface expression
D) To study the area in preparation for a field campaign

Question 5: Why is it often useful to integrate auxiliary vector data in image analysis?

A) It helps my orientation
B) Many features can only be unambiguously identified in relation to other geographic features
C) It lowers the cost of analysis
D) Many features (e.g. political boundaries) cannot be seen in images, but knowing where they are can make the analysis easier.

Further reading:

Lillesand, T.M., Kiefer, R.W., and Chipman, J.W., 2004, Remote sensing and image interpretation: New York, John Wiley & Sons, 763 p.

Metternicht, G., Hurni, L., and Gogu, R., 2005, Remote sensing of landslides: An analysis of the potential contribution to geo-spatial systems for hazard assessment in mountainous environments: Remote Sensing of Environment, v. 98, p. 284-303.

Showalter, P.S., 2001, Remote sensing's use in disaster research: a review: Disaster Prevention and Management, v. 10, p. 21-29.

Tralli, D.M., Blom, R.G., Zlotnicki, V., Donnellan, A., and Evans, D.L., 2005, Satellite remote sensing of earthquake, volcano, flood, landslide and coastal inundation hazards: Isprs Journal of Photogrammetry and Remote Sensing, v. 59, p. 185-198.

Zlatanova, S. and Li, J., 2008, Geospatial information technology for emergency response, Springer.

Guide book
Session 3:
Hazard Assessment

Dinand Alkema, Marco Rusmini, Malgosia Lubczynska, Cees van Westen, Norman Kerle, Michiel Damen and Tsehaie Woldai

Objectives
After this session you should be able to:
- understand the general concept of Hazard
- identify spatial/temporal characteristics and triggering phenomena for each hazard type
- understand the concept of occurrence probability and perform frequency assessment based on historical data using statistical methods
- select the most suitable hazard assessment method considering the hazard type, scale, data availability
- carry out a complete hazard assessment study

This chapter of the guide book is organized as follows:
- 3.1 Introduction: this section refers to the general concept of hazard and hazard assessment. Basic definitions will be provided for general concepts like hazard and hazard assessment. Hazard characteristics will be defined and discussed. Different hazard types will be briefly described.
- 3.2 Climate change and hazards: the main impacts of climate change scenarios on natural hazard will be described in this section.
- 3.3 Frequency analysis: in this section, the basic knowledge related to the estimation of the occurrence probability for different hazard types will be explained.
- 3.L–3.C Choice topics: after a general overview of Hazard assessment, the main hazard types will be extensively described. The student will select the hazards according to his/her interest.

Material	Task	Required time
Introductory part of this guidance note on different hazards and their assessment methods	Small tasks and assignments included in the guidance notes	1h
Choice topic: selection of a specific hazard type	- RiskCity: Flood hazard assessment - RiskCity: Earthquake hazard assessment - RiskCity: Landslide hazard assessment - RiskCity: Technological hazard assessment - RiskCity: Volcanic hazard assessment - RiskCity: Coastal hazard assessment	2 to 3h
Exercise based on choice topic	Exercise on hazard assessment related to the choice topic	h

3.1 Introduction to Hazard Assessment

We live in an environment that exposes us continuously to hazards, hazards that we somehow have to deal with. Some of these hazards are within our own realm of influence, like participating in traffic, or catching the flu. Other hazards are so extreme that we hardly consider them in everyday live, like a large asteroid impacting on Earth. In fact the whole field of hazards is so large that no introduction text is capable of covering it completely. Many attempts have been made to categorize hazards, like Smith (1991) who identifies three distinct classes:

Natural Hazards (extreme geophysical and biological events)		
	Geologic	Earthquakes, volcanic eruptions, landslides, avalanches
	Atmospheric	Cyclones, tornadoes, hail, ice and snow
	Hydrologic	River floods, coastal floods, drought
	Biologic	Epidemic diseases, wildfires
Technological Hazards (major accidents)		
	Transport accidents	Air crashes, train crashes, ship wrecks
	Industrial failures	Explosions and fires, release of toxic or radioactive materials
	Unsafe public buildings and facilities	Structural collapse, fire
	Hazardous materials	Storage, transport, miss-use
Context hazards (global change)		
	Climate change	Sea-level rise, frequency change of extreme events
	Environmental degradation	Deforestation, desertification, loss of natural resources
	Land pressure	Intensive urbanization, concentration of essential facilities
	Super hazards	Catastrophic Earth changes, impact of near-Earth objects

Table 3.1.1 Classification of hazards (Smith 1991).

However, no unambiguous classification system has been constructed yet. Take for instance landslides, in the classification of Smith (table 3.1.1) they fall in the category of geologic hazards, but one may argue that they should be classified as hydrological, because the trigger is often related to rain. On the other hand, landslides may also be triggered by earthquakes, or by human activities ……

In the context of this course we will limit ourselves to those hazards that are a consequence of geological and geomorphological processes (earthquakes, volcanic eruptions, landslides and floods). We will call these Geo-Hazards from now on although it should be realized that human activities often have a great impact on the occurrence of these events. Another limitation is that in this course we disregard the slow hazards, such as erosion, drought, desertification, sea-level rise, etc.

3.1.1. Definition of Hazard

The word hazard is a normal English word that is used frequently in daily speech. This may cause confusion because the scientific definition differs from the 'intuitive' common meaning. Webster's dictionary of the English language (edition 1990) defines hazard as: "*a risk or associated with danger". As a verb it is defined as: "1) to place (something) in a dangerous or risky situation wittingly or unwittingly; 2) to attempt (an answer, guess, etc.)*". On Wikipedia we find the following entry (9 Febr. 2009): "*A hazard is a situation which poses a level of threat to life, health, property or environment. Most hazards are dormant or potential, with only a theoretical risk of harm, however, once a hazard becomes 'active', it can create an emergency situation*".

But also in scientific literature it has been used imprecisely and with different implicit meanings. For the study of hazards, a more restricted definition is required. In literature and on the internet you'll find many definitions that are similar but not exactly the same (feel free to check this). In this course we will use the definition of hazard as proposed by the UN-ISDR (2004):

> **Definition:** "A hazard is a potentially damaging physical event, phenomenon or human activity that may cause the loss of life or injury, property damage, social and economic disruption or environmental degradation. This event has a probability of occurrence within a specified period of time and within a given area, and has a given intensity."

Especially the last sentence makes this definition workable; it contains four important elements:

1) Hazard is expressed as a probability; the likelihood that something may happen in the future. When, where and how much is not sure, but it is possible to identify areas where a hazard is more likely to occur than in other areas.

2) The hazard probability is restricted to a specified period of time; usually a year. The annual probability is the likelihood that an event will happen in the next year. Without this restriction, the probability expression would be useless. The likelihood that a floodplain will be flooded is 100%, but it could take a 1000 years before it actually happens. It is more relevant to know what the probability is that it is flooded in the coming year, or the year after, …

3) It is valid for a specified area; Earthquakes happen near fault zones, floods on floodplains, landslides on slopes. The site specific characteristics co-define the hazard conditions.

4) The intensity – or magnitude – of the event. To be capable of causing loss of life or damage, the event must be of a certain intensity or magnitude. The intensity may be expressed as the energy released by an earthquake or volcanic eruption, the volume of water during a flood or the size and speed of a landslide. It is clear that the more energy or momentum released by the event, the more damaging potential it has. A mass movement of a few kilograms may cause no problems (unless it is a rock falling on someone's head), but a mud flow of several thousand cubic meters can be quite devastating.

Another aspect of this definition that should be noted is the condition that it may cause damage or loss of life. Of course we study hazards because they may have negative effects on things that we care about, but in principle the concept of hazard is value-free. Risk on the other hand is the potential for disaster. It includes the characteristics of the receiving community; its vulnerability and the value of the exposed elements (see also chapter 4). One should understand that the terms hazard and risk are often mixed, also because hazard assessment is always done from an anthropocentric viewpoint; we do hazard assessment because they may have consequences for "our" society. In this respect one can say that a disaster is the materialization of "high risk". However, high hazard does not necessarily result in damage or loss of life. The flood hazard in Northern Siberia is very high because every year large parts are inundated in spring as result of the melting of snow and frozen rivers. The fact that there is nothing (or at least very little) to be damaged does not diminish the hazard. The risk however, is very low. Hazard is likelihood, no more, no less, something that may happen in the future.

Definition:
*"The hazard related study is named **Hazard Assessment** and it involves the analysis of the physical aspects of the phenomena through the collection of historic records, the interpretation of topographical, geological, hydrological information to provide the estimation of the temporal and spatial probability of occurrence and the magnitude of the hazardous event.*

3.1.2. On the origin of hazards

Hazards do not arise spontaneously. They are the results of continuous processes that we do not always notice (e.g. tectonic movements) or, when we do notice them, we consider them as "normal", such as river flow. As long as these processes operate within a certain band-width, they are not considered as a hazard. Only when the deviation from the mean exceeds some critical threshold beyond the normal band of tolerance, the variable becomes a hazard (Smith (1991). This is illustrated in figure 3.1.1 with annual rainfall. There is a fluctuation around a mean value. As long as the fluctuations are within an acceptable range, the rain is a useful resource. When a disruption threshold is exceeded, and there is too much or too little rain, negative side effects will occur. Notice that at this point the anthropocentric viewpoint enters the equation. Lack of rain will decrease agricultural productivity and will increase costs because crops must be irrigated. Too much rain will swamp farm lands and may cause rivers to flood. When a coping threshold is exceeded, it means that the deviation has become an extreme to such an extend that the local communities cannot deal with the hazard anymore and/or recover from it with their own means. Floods and drought are the results.

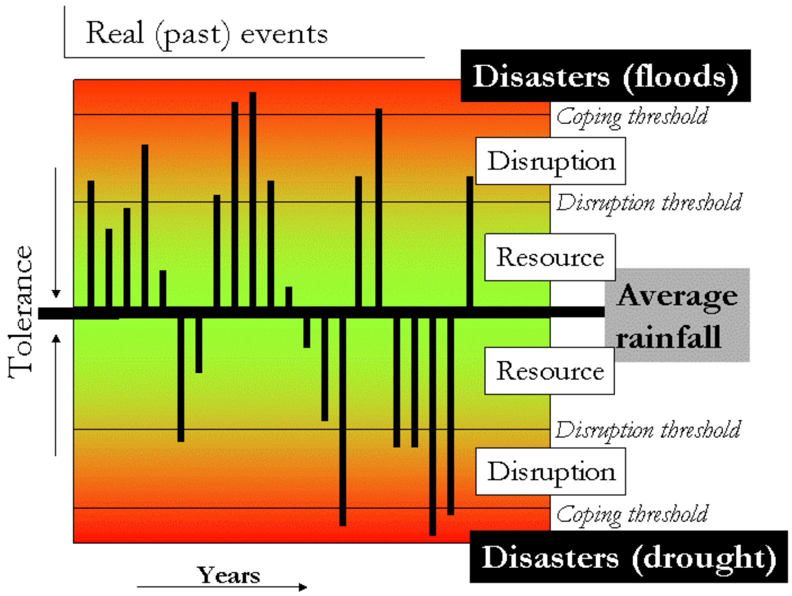


Figure 3.1.1 Example of the possible consequences of deviations from the mean annual precipitation. As long as the deviations are below a given disruption threshold, the precipitation is a resource. Above (or below) the disruption threshold negative consequences due too much or too little rain are being felt. Above or below a coping threshold the deviation has consequences beyond the coping capacity of the affected communities.

In the case of landslides the underlying processes are related to the dynamics of slopes. Gravity exerts a continuous force upon the slope material. This strain is balanced by the strength of the slope material. However the strength is not a constant but depends for instance on soil water content and ground water levels. Also weathering processes change the characteristics of the slope materials. This is illustrated in figure 3.1.2. These processes are less visible than rivers, but they are continuously active nevertheless.

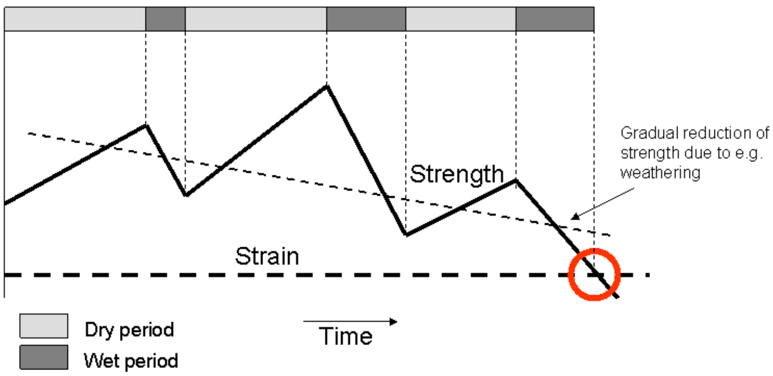


Figure 3.1.2 The bold line indicates the fluctuations in soil strength. The fluctuations are due to (season related) changes in soil moisture content and ground water levels. The strain is the continuous (and constant) force exerted on the slope by gravity. The dotted decreasing line illustrates the gradual reduction of strength due to e.g. weathering processes. When the strength becomes less than the strain, slope instability occurs.

The same holds for earthquakes and volcanoes. They are the manifestation of tectonic plate movements driven by convective currents in the upper mantel of the Earth. Along the plate boundaries this movement is not continuous, but results in the build up of strain. When the strain exceeds the friction strength a rapid and sudden movement occurs that we notice as an earthquake along a fault line. The more strain is build-up the larger the amount of energy that is released during the movement.

3.1.3. Hazard characteristics

The term hazard include a wide variety of phenomena, ranging from local events like tornadoes to events at continental scale like climate change, or from very fast phenomena like lightening to very slow events as desertification. In order to describe the different hazard types, six main characteristics can be defined.

- Triggering factors
- Spatial occurrence
- Duration of the event
- Time of onset
- Frequency
- Magnitude
- Secondary events

In the following section, each of the six characteristics will be introduced and briefly described. The aim is to homogeneously characterize the different hazards in order to compare them among each others.

- **Triggering factors**

Natural causes of hazards can be divided into two main groups: exogenic and endogenic factors. The first class contains all the triggering processes that occur on the Earth's surface. Exogenic factors are mainly related to atmospheric conditions like precipitation, wind, temperature and other atmospheric parameters that can trigger natural hazards like landslides, rivers and coastal floods, and land degradation. Atmospheric phenomena have been widely studied in the last decades and many progresses in forecasts have been achieved; nowadays different techniques of weather forecasting are available. Over the last decades, climate related phenomena have been widely studied and much progress was achieved in forecasting the hazards; nowadays different techniques of weather forecasting are available. A good example is the deterministic medium range forecast information and probabilistic weather forecast techniques based on Ensemble Prediction System (EPS) that allows weather forecasts up to 8-10 days (Demeritt et al., 2007; Persson and Grazzini, 2007). But even considering the new tools available, the forecasting issue is still affected by main uncertainties due to the complexity of the phenomena involved. Forecast information can be gathered through providers' websites like the World Meteorological Organization (WMO, http://www.wmo.int/pages/index_en.html) or the European Centre of Medium-range Weather Forecasts (ECMWF, http://www.ecmwf.int/). Real-time data regarding precipitation, hurricanes, typhoons, are provided by space borne sensors' websites; a useful example is the Tropical Rainfall Monitoring Mission (TRMM http://trmm.gsfc.nasa.gov/). In the case of earthquakes, the triggering factors are unlikely to be predicted with the same accuracy and temporal resolution of the weather-related causes previously described.

Task 3.1.1: Weather forecast information for hazard assessment (10-15 minutes).

- *Explore the meteorological Service of your own country (go to WMO website and enter the "National Meteorological Centers" page. Are precipitation forecasts available for your country? If not, where do you think you can find such data?*
- *From the TRMM homepage, chose "global floods and landslides monitoring" and then "heavy rain areas". Did extreme precipitation events affect your country during the last 24 hours?*
- *Go to "Meteoalarm" page (from WMO homepage) and identify which is the European country (and its regions) that will be mostly affected by rainfall and coastal storms in the coming 2 days.*

Fig. 3.1.3: Chernobyl nuclear power plant after the explosion.

The second group of natural triggers is represented by the endogenic factors that take place below the Earth's surface. Let's consider for instance earthquakes; they are triggered by the accumulation of enormous quantities of energy during tectonic displacements: the convective movements in the liquid part of the mantle apply massive forces to the tectonic plaques that, after certain thresholds, release the accumulated stress in the form of sudden fractures in rock bodies. The waves travel through the crust and produce earthquakes when they reach the surface. Such triggering factors are unlikely to be predicted with the same accuracy and temporal resolution of the weather-related causes previously described. The result of this difference in monitoring the triggering factors is that the natural hazards caused by exogenic factors have more probability to be predicted than earthquakes. Other examples of hazards triggered by endogenic factors are volcanoes and tsunamis.

Next to the natural causes, hazards can be directly caused by malfunctioning or accidents due to human activities. Man–induced hazards can have local effect but may also have widespread consequences Probably the best known example of a man-made disaster that had widespread consequences is the explosion at the reactor number 4 in Chernobyl's nuclear power plant on the 26th of April 1986 (see figure 3.1.3). Man-induced hazards are unpredictable, can cause property damage and loss of life, and can significantly affect infrastructure in many areas worldwide. FEMA (U.S. Federal Emergency Management Agency) classifies such events under the general definition of Technological Hazards.

The boundary between natural and man-induced hazards is far from clearly defined. A landslide can be triggered by heavy rainfall but deforestation or road construction may also have played a role. Landuse changes can affect areas by increasing the occurrence of erosion phenomena. River dams' constructions can lead to inundations during periods of extreme discharges or due to dam failures. The identification of the triggering factors is one of the first steps in hazard assessment.

- **Spatial occurrence**

In understanding the various dynamics related to natural/man induced hazards, spatial characteristics of single events play a very important role.

> **Definition:** *Spatial occurrence related to hazards has a double meaning: on one hand it refers to the* ***location*** *of the area affected by a certain hazard type, thus the characteristics of such zone and the presence of triggering factors; on the other hand it refers to the* ***dimension*** *of the affected area.*

One of the main targets of hazard assessment activities is to identify which areas are more prone to hazard events considering topographical, geological, hydrological, climatic characteristics. Hazards don't occur in random areas, but they often follow defined patterns identified by the presence of certain characteristics. Landslides can occur only in areas with sufficient slope gradients, but not all the slopes are prone to landslides; activity of previous mass movements in an area in combination with additional stability-affecting conditions (landcover-landuse, internal and external drainage system, precipitation rates) may be used to forecast the occurrence of future landslides in that area. This basic concept is illustrated in figure 3.1.4-1; it represents the earthquakes location in South America during the last decade of the XX century. The observed seismic events occur mainly along the Andes Range, at the oceanic ridge between Nazca Plate and Antarctic plate (Pacific Ocean), and at the ridge location between South American plate and African plate (Atlantic Ocean, northern part). After having observed this map, even without further knowledge on seismic hazard assessment will recognize the seismic hazard map shown in figure 3.1.4-2. This map shows the peak ground acceleration with a 10% chance of exceedance in 50 years; at each location, the map indicates the expected magnitude of seismic activity which has the 10% of probability to be exceeded in 50 years. As is clear from the comparison between the two maps, the red zone in map 2 (high hazard area) represents the area in which the epicenters of earthquakes are located in map one.

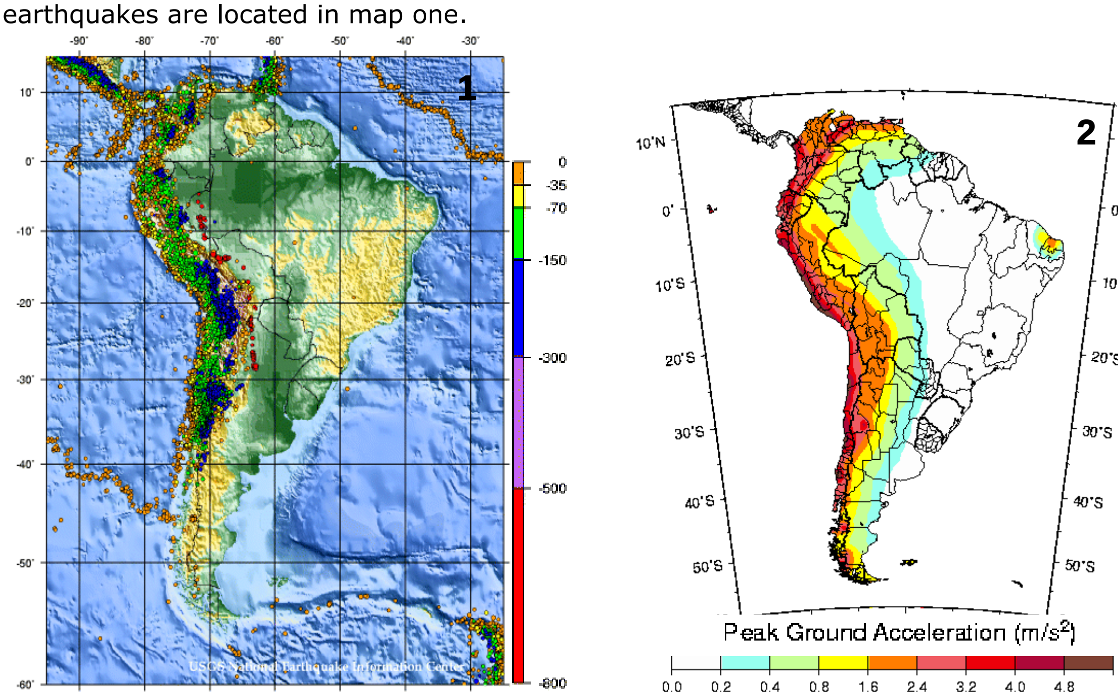


Fig. 3.1.4: 1) Seismicity map of South America (1990-2000); the legend refers to the sources' depth in Km.
2) Seismic hazard map of South America. PGA with a 10% chance of exceedance in 50 years is depicted in m/s^2. Source: USGS-NEIC Earthquakes hazard program.

Key concept: *In hazard assessment, the hazard events occurred in the past represent an important key to understand and predict the future spatial occurrence of such hazards.*

Regarding the dimension of the hazardous phenomena, single events can affect specific areas (**concentrated** events), examples are flash floods, small landslides, or lightening; they affect limited areas. Other phenomena can occur at regional or continental scale (**diffuse** events), for instance, desertification, el Niño, and climate change related phenomena. The areal extension of the hazardous event is a key point in order to choose the appropriate mapping and analysis tools. As already discussed in section 2, awareness of the spatial characteristics of the hazard will help to select the tools. Single landslides can have dimensions varying from few cubic meters up to millions cubic meters; flood events can be small and affect a small village crossed by a seasonal stream in a mountainous area or a wide floodplain area covering many square kilometers. But the areal extension of such hazards is not comparable to the extension of events related to continental or global scale. Figure 3.1.5 shows the spatial and temporal distribution of the main natural and man-induced hazards. The X axis refers to the spatial extension of the single hazards according to the observation scale. This classification represents just a simplification; the areal dimension can widely vary among the same hazard type: if we consider technological hazard, it is referred to the city (large) scale, considering events like the explosion of a gasoline tank. At the same time, the extraordinary Chernobyl reactor explosion described in the previous section belongs to the same category and it had effects at continental scale. Once again, the analysis and the mapping tools have to be appropriate to the hazard's dimension; at the same time the observation scale can depend on the nature of the hazard and on the purpose of the hazard study; a site scale landslides hazard study can't be used by decision-makers in order to plan funding for national activities; on the other hand, a pan-American landslide susceptibility map can't support an urban planning project at municipality level.

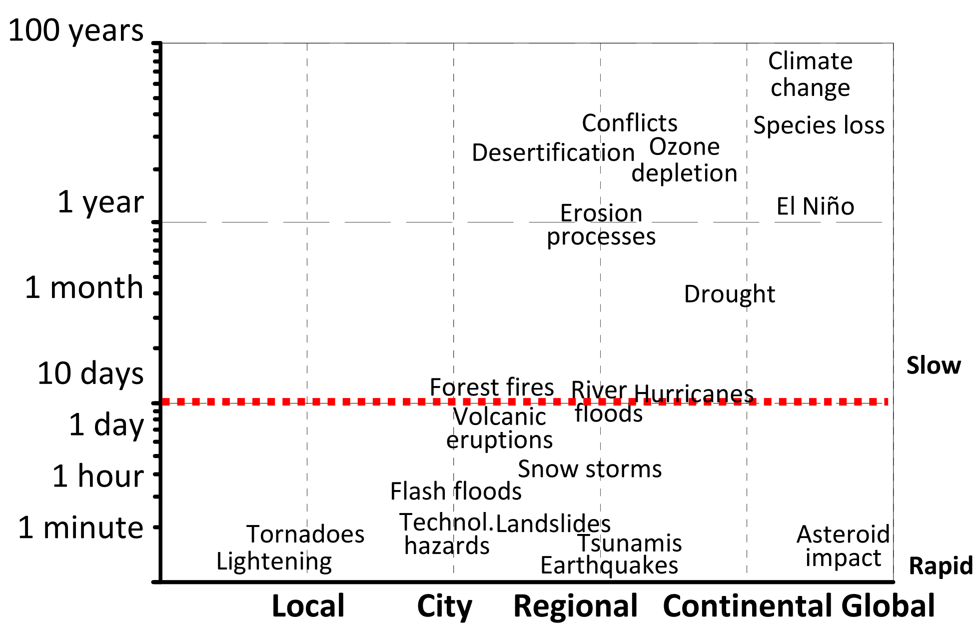


Fig 3.1.5: Spatial and temporal distribution of the major natural and human-induced major hazardous events (the red line represents the boundary between fast and slow processes, with the threshold set on 10 days).

Definition: Scales of Hazard maps

- *Investigation site scale: 1:200 – 1:2.000 hazard maps accurately describe hazards in areas where detailed designs of engineering works have to be planned.*
- *Large/local scale: 1:2.000 – 1:25.000 representing the hazard assessment for a town or part of a city; they represent basis for quantitative risk assessment, disaster prevention plans, and for preliminary phase of engineering designs.*
- *Medium scale: 1:25.000 – 1:100.000 including entire municipalities or small catchments, such hazard maps are used as basis for projects regarding urban planning or environmental impact at municipality level.*
- *Regional scale: 1:100.000 – 1:500.000 Hazard maps regard large catchment areas, or political entities of the country like regions or federal districts. Such maps aim at providing support for: planning projects for construction of infrastructural works, agricultural development projects, decision – making at regional scale.*
- *National–Continental scale: less than 1:1.000.000 including entire countries or even continents; hazard maps at this scale intend to generate awareness among decision makers and the general public. They are created using qualitative assessment techniques, such as the use of general indices or the use of susceptibility scales.*

A good example of hazard assessments at different scales is represented by the following two maps. They both represent flood hazard assessment studies carried out by applying flooding simulation tools. In figure 3.1.6, a subset of the official flood hazard map provided by Federal Emergency Management Agency (http://www.fema.gov/) of the US government is shown. The map represents a flood event with a return period of 100 years for the section of Santa Clara River in the North area of Los Angeles City, California. The map is part of the project Flood Insurance Rate Maps (http://www.fema.gov/media/fhm/firm/ot_firm.htm, FEMA-FIRM). The main aim of this project is to provide useful information for floodplain management, regulation, and insurance at administrative level. In details it is used to assess whether or not single buildings need insurance assistance, and if it is the case with which risk level they have to be insured. The flooded area is represented at investigation site scale (1:2000). If you want to learn more about FEMA-FIRM, explore its online tutorial (http://www.fema.gov/media/fhm/firm/ot_firm.htm).

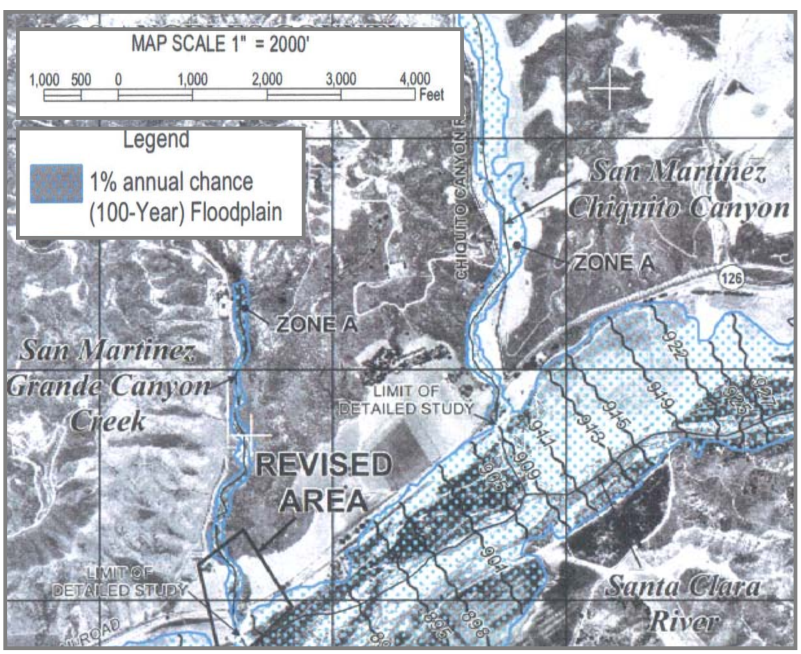


Fig. 3.1.6: Flood hazard map regarding an event with occurrence probability of 1 into 100 years for the Northern part of the city of Los Angeles (1% annual chance). The map is provided by the Federal Emergency Management Agency (FEMA) within the project called Flood Insurance rate maps (FIRM). The flood hazard map is calculated by simulating the 100 years return period flood event through a detailed two dimensional flood propagation model. The scale allows the map to be used in flood hazard assessment for insurance companies.

Figure 3.1.7 represents the flood hazard map based on a 100 years return period flood event calculated at pan-European scale (less than 1:1000.000) by the Natural Hazard

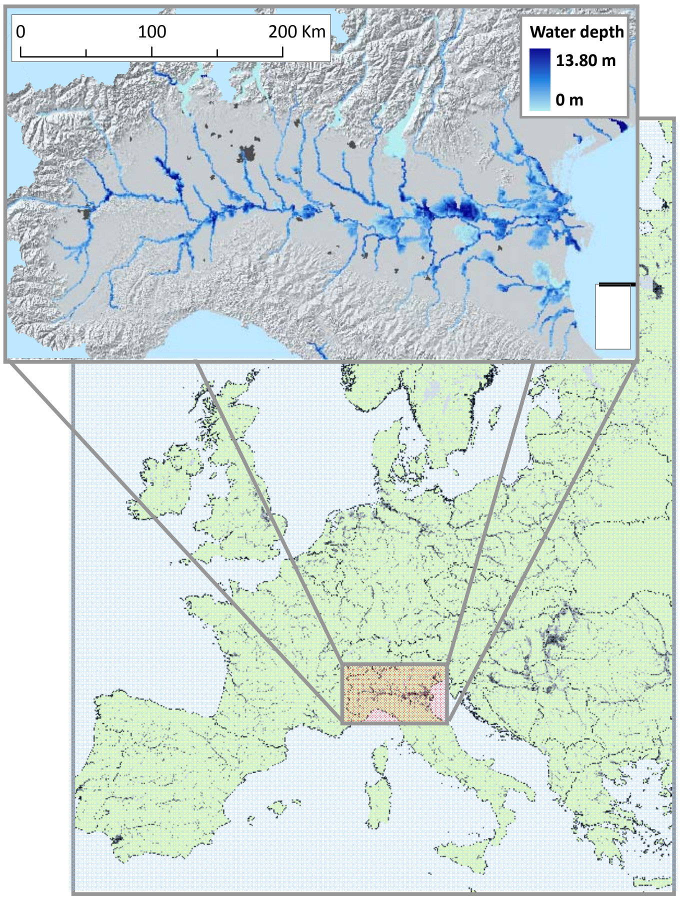


Fig. 3.1.7: Pan-European hazard map calculated on the basis of EFAS (European Flood Alert System). The map represents water extent and depth for a general 100 years return period flood event.

Action of the Institute for Environment and Sustainability (IES, Join Research Centre, http://ies.jrc.ec.europa.eu/). This high research institute was created by the European Community (EU) in order to promote the scientific research on natural hazards management at an European level. The map was calculated by applying the flood simulation model used in the European Flood Alert System (EFAS, http://efas.jrc.ec.europa.eu/). EFAS is a project at a pan-European scale that aims at providing forecast information three to ten days in advance. EFAS is based on the one dimensional (1D) LISFLOOD distributed hydrologic model (Van Der Knijff and De Roo, 2008) driven by harmonized data regarding soil, topography, landcover, and by real-time weather forecasts from the European Centre for Medium-range Weather Forecasts (EMCWF) and from the Deutche Wetterdienst (DWD German Weather Forecasts Centre http://www.dwd.de/). The LISFLOOD model provided the discharges for a flood event with a probability of 1 in 100 years. The discharges were transformed into water levels and the flood extent and depth were extrapolated through a GIS technique based on the intersection of the flood wave, considered as a plane, and a 100m resolution Digital Elevation Model (Bates and De Roo, 2000). The resulting hazard map at pan-European level is the basis for further studies and assessments at continental level. LISFLOOD was run on the basis of different climate change future scenarios from the HIRHAM model to assess the impact of climate change on flood hazard in Europe (Dankers and Feyen, 2008).The availability of a pan-European flood hazard map suggested more advanced applications; the EFAS team developed a methodology to carry out from the flood extent and depth map, the potential damage assessment based on stage damage functions (http://natural-hazards.jrc.ec.europa.eu/downloads/public/2008map_Barredo_et_al_MAP_Flood_damage_potentia.pdf). It is clear form the two examples described above that the analysis scale has to be chosen in relation to the hazard type and to the purpose of the study. The first example aims at providing information to single house owners or local organizations, while the second one targets to support other authorities and organizations in decision-making at Continental or National level.

- **Duration of the event**

Definition: *The duration of a hazardous event refers to the time span in which such event takes place. To quantify the duration, the starting and the ending points have to be defined.*

Fig. 3.1.8: Lightening during a storm in Oklahoma City, U.S.A. an example of a fast process.

Fig. 3.1.9: sand dunes advancing on Nouakchott, the capital of Mauritania; an example of a slow process.

For sudden phenomena like earthquakes or landslides it is easy to define the beginning and the ending points; but for other gradual events this is more complex. An appropriate example is represented by river floods: high discharge conditions periodically alternate with normal or low discharge periods. When does the high discharge phase become a flood? When does it end? Usually, when the water level exceeds the bankfull conditions the high discharge condition turns into a river flood hazard (see flood hazard section 3.F for more explanations). For gradual processes like desertification or erosion the determination of the duration is even more difficult. Concerning the duration, natural and man-induced hazards can be classified into two main categories: fast and slow processes. In the first class, hazards like tornadoes, earthquakes, and tsunamis are included; such events happen in a very short lapse of time, from few seconds, in the case of lightning (see figure 3.1.8), up to few days like volcanoes eruptions. Moreover, their sudden nature makes them being perceived as dangerous situations by the majority of the people. On the other hand, slow processes have a duration ranging from months, for instance desertification (see figure 3.1.9) and erosion, to hundreds years in the case of temperature rise or greenhouse gases' increase caused by climate change. Due to their extremely wide temporal extension and their gradual development, they are perceived in many cases only as gradually degrading situations. In figure 3.1.5, the Y axis represents the duration of the event; the red bar indicates the arbitrary boundary between the slow and rapid processes.

However, duration and dimension can widely vary within the same hazard class: volcanic eruptions, for instance, are considered in the graphic as fast events. Plinian eruptions occur in volcanoes with acid lava (more viscous), they are the most powerful and they involve huge explosions; such kind of eruption can be considered as a fast event: examples are Vesuvius (Italy, 79 AD), Mount St. Helen (USA, 18th May 1980), Pinatubo (Philippines 15th June 1991, http://www.youtube.com/watch?v=Lf1PWap_GTw). On the other hand volcanic eruptions on Etna Mountain in Italy are slow and less destructive events, due to the high fluidity of its basic lava; the volcano has picks of activity where huge and slowly moving lava flows can erupt for various months (Etna's eruption in 2008, it is the most recent event of three years of continuous activity from 2006 to 2008 http://www.youtube.com/watch?v=j4lkyyD4Vmk&feature=related,). According to the scale in the graph, such eruptions can be classified as slow processes.

This example states that the duration of a hazard type has a wide range of variety. Each event has a series of characteristics that often significantly differ from other events of the same type.

- **Time of onset**

Before a hazard occurs, some foregoing events can anticipate the main phenomenon. These events are defined as **precursors**. Depending on the hazard type, such "signs" can occur days, hours, or seconds before or there cannot be at all. In order to better explain the concept, few examples will be shown.

Landslides and mass movements are hazardous phenomena that can be triggered by various causes like heavy rainfalls, earthquakes, soil weathering, increase of superficial load due to snow, etc. Areas prone to landslides can show forewarning features that "announce" the occurrence of such events. Especially after heavy rainfalls, in hazardous areas, new cracks can suddenly open; springs and/or saturated ground can appear in slope areas not typically been wet before; the water level in creeks can unexpectedly increase, or can suddenly decrease even during rainfall. Such phenomena are typical precursors of landslides (see figure 3.1.10). To explore more signs that can predict the occurrence of a landslide, check the USGS website: http://landslides.usgs.gov/learning/prepare/.

Fig. 3.1.10: precursors of landslides. Image 1: multiple crack array in the area of Upper Killha, Azad Kashmir; failure of these slopes in the forthcoming monsoon looks to be very probable. Image 2: springs on a slope after heavy rainfalls.

Floods are mostly caused by heavy and/or persistent precipitations. Rainfall can be considered flood triggering factors and a precursor of flood hazards as well; because when heavy rainfall is observed in a flood prone area, it is likely to expect a flood event in a short period of time. There is a delay between the occurrence of rainfall and the flood wave arrival. It depends on the morphologic characteristics and on the landuse of the entire catchment. Figure 3.1.11 represents a graph showing the temporal relation between discharge rate and rainfall in a monsoonal area. In the graph, two flood events are recorded: the first at the 11th day, and the second, smaller than the previous, at the 29th day; they are caused mainly by the rain fallen in the 8th day, and in the 21st day. Once the concept of precursor is clear we can define the time of onset as follows.

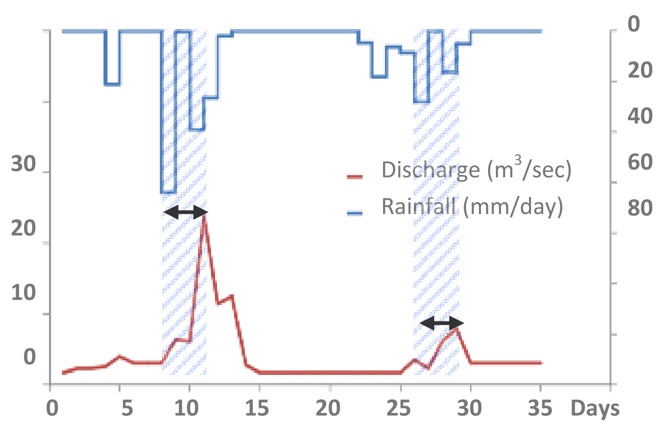


Fig. 3.1.11: A Discharge-Rainfall relation graph: the area with blue stripes and the two arrows show the time lapse between the precursor (rainfall) and the hazard pick (flood max discharge).

Definition: *The time of onset is the lapse of time from the occurrence of the first precursor to the intensity peak of the hazardous event.*

In the last example, time of onset is represented by the delay between the rainfall and the discharge peak (area with blue stripes in figure 3.1.11). The time of onset can be very short or even null like in the case of earthquakes.

- **Magnitude / Intensity**

In general, a hazard is a phenomenon that, for its intensity, represents an exceptional and harmful condition. Rainfalls and storms are common atmospheric events that occur everywhere; but if those phenomena exceed certain thresholds of intensity they become hazardous hurricanes, or they trigger floods, landslides etc. The same concept is valid for other natural hazards: every year, more than ten thousands earthquakes are recorded by seismic stations worldwide. Out of them, the hazardous events are very few in number. What does transform a normal event into a hazard? A natural event becomes a hazard when it exceeds certain common magnitude or intensity thresholds. In hazard assessment, magnitude and intensity have different meanings:

Definitions:

– ***Magnitude*** *is related to the amount of energy released during the hazardous event, or refers to the size of the hazard. Magnitude is indicated using a scale, consisting of classes, related to a (logarithmic) increase of energy.*

– ***Intensity*** *is used to refer to the damage caused by the event. It is normally indicated by scales, consisting of classes, with arbitrarily defined thresholds, depending on the amount of damage observed.*

<table>
<tr><th>Richter</th><th>Mercalli</th><th>Damages according to Mercalli's scale</th></tr>
<tr><td>1.0-3.0</td><td>I</td><td rowspan="6">**I**: Not felt except by a very few under especially favorable conditions.
II: Felt only by a few persons at rest, especially on upper floors of buildings.
III: Felt by few persons indoors. Many people don't recognize it as earthquake.
IV: Felt indoors by many, outdoors by few. Sensation like heavy truck striking building.
V: Felt by nearly everyone; windows broken. Unstable objects overturned. Pendulum clocks may stop.
VI: Felt by all, many frightened. Some heavy furniture moved. Damage slight.
VII: Damage negligible in buildings of good design and construction; slight to moderate in well-built ordinary structures; considerable damage in badly designed structures.
VIII: Damage slight in specially designed structures; considerable damage in ordinary substantial buildings with partial collapse.
IX: Damage considerable in specially designed structures; Damage great in substantial buildings, with partial collapse.
X: Some well-built wooden structures destroyed; most masonry and frame structures destroyed with foundations. Rails bent.
XI: Few, if any structures remain standing. Bridges destroyed. Rails bent greatly.
XII: Damage total. Lines of sight and level are distorted. Objects thrown into the air.</td></tr>
<tr><td>3.0-3.9</td><td>II-III</td></tr>
<tr><td>4.0–4.9</td><td>IV-V</td></tr>
<tr><td>5.0–5.9</td><td>VI-VII</td></tr>
<tr><td>6.0–6.9</td><td>VII-IX</td></tr>
<tr><td>7 more</td><td>X-XII</td></tr>
</table>

Table 3.1.2: Relations between Magnitude (Richter) and Intensity (Mercalli) scales for earthquakes.

An example is represented by earthquakes. They can be classified into magnitude or intensity scales depending on the purpose of the study. The Richter magnitude scale expresses the amount of seismic energy released by an earthquake. It is a base-10 logarithmic scale obtained by calculating the logarithm of the amplitude of seismic waves recorded by a Wood–Anderson torsion seismometer. Richter Magnitude scale goes from 0 to 10 (even if a magnitude 10 was never recorded). Mercalli Intensity scale measures the damages produced by an earthquake on the Earth surface to human beings, and man-made structures; it was estimated using historic damage records and personal experiences from individuals involved in earthquakes. It ranges from level I to level XII; for each level the damages to buildings bridges, roads, and the impact on human beings are described.

A magnitude scale measures the absolute dimension of a seismic event in terms of energy involved; an intensity scale measures the effects of an event related to the presence of damageable assets or human beings in the area: an earthquake of magnitude 9 in an uninhabited areas has intensity 0.

Other natural hazards are described through magnitude or intensity scales: hurricanes, tornadoes, and tsunamis. For further readings on the topics above mentioned the following websites are suggested.

Task 3.1.2: Magnitude / Intensity scales (5-10 Min)

Search on the web examples for Magnitude/Intensity scales for at least one other hazard type among the ones listed below, or chose a hazard outside the list according to your interest. We suggest considering the following websites:

- *Earthquakes: http://pubs.usgs.gov/gip/earthq4/severitygip.html.*
- *Hurricanes: http://www.weather.com/encyclopedia/charts/tropical/saffirscale.html; http://powerboat.about.com/od/weatherandtides/tp/Saffir-SimpsonScale.htm.*
- *Tornadoes: http://library.thinkquest.org/16132/html/tornadoinfo/types.html.*
- *Tsunamis: http://geology.about.com/library/bl/bltsunamiscalenew.htm; http://www.riskfrontiers.com/scales/scalespage16.htm.*

- **Frequency**

While studying geo-hazards, the most important aspects are spatial and temporal characteristics of the events. As described before, the word spatial has a dualistic meaning: the identification of the location, and the evaluation of the dimension of the affected area. On the other hand, temporal characteristics refer to different aspects of the phenomena; we have already discussed about the duration and the time of onset of different hazards. Another temporal characteristic of a hazardous event is the frequency of occurrence.

Definitions:

- ***"Frequency is:*** *the rate of occurrence of anything; the relationship between incidence and time period; the number of occurrences within a certain period of time; the property of occurring often rather than infrequently; the quotient of the number of times n a periodic phenomenon occurs over the time t in which it occurs: f = n / t" (from different sources in the web).*
- ***Related to geo- hazards, Frequency is:*** *the (temporal) probability that a hazardous event with a given magnitude occurs in a certain area in a given period of time (years, decades, centuries etc.).*

In hazard assessment, frequency is a key point to study the occurrence probability of hazardous events in the future. The analysis of historical records and their frequency allows scientists to understand when a certain hazard with a certain magnitude is likely to occur in a given area. In most of the cases there is a fixed relation between magnitude and frequency for natural events (see figure 3.1.12). The frequency of events with a low magnitude is high, while the frequency of events with great magnitude is low: i.e. small flood events occur every year while enormous and devastating inundations are likely to happen once every one or more centuries. Table 3.1.3 shows the number of

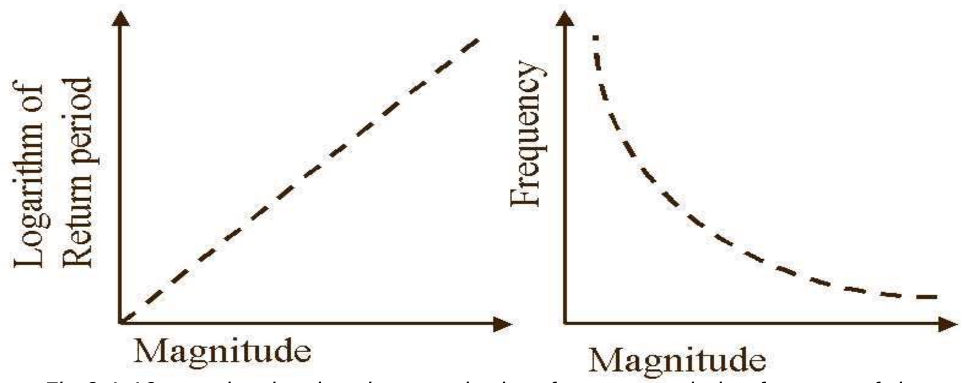


Fig.3.1.12: graphs showing the magnitude – frequency relation for most of the natural hazards.

earthquakes of different magnitudes expected per year based on historical records. The table clearly demonstrates how the frequency-magnitude relation described in figure 3.1.12 is followed. Few hazards don't follow this rule; an example of events with random relation between magnitude and frequency is lightening.

Average annually	Magnitude (Richter)
1[1]	8 or higher
17[2]	7.0-7.9
134[2]	6.0-6.9
1.319[2]	5.0–5.9
13.000	4.0-4.9
130.000	3.0-3.9
1.300.000	2.9 or less

Tab. 3.1.3: frequency-magnitude relation for earthquakes based on observations since 1900[1] 1990[2] (source USGS)

Frequency is generally expressed in terms of exceedance probability; which is defined as the chance that during the year an event with a certain magnitude is likely to occur. The exceedance probability can be shown as a percentage: a hazard, that statistically occurred once every 25 years, has an exceedance probability equal to 0.25 (or 25%). Another method is the calculation of the return period: it indicates the period in years in which the hazards is likely to occur based on historic records; an example can be a flood with a return period of 100 years (100 years return period flood = 1 event in 100 years = 0.01 probability). In part 3.3 of this section the frequency analysis will be explained in depth and different tools and methods for its calculation will be provided.

- **Secondary events**

When hazards hit an area, they cause directly potential damages to human beings and man-made structures according to their magnitude and the vulnerable elements in the affected area. But hazards can hit people and their properties indirectly by triggering other harmful events. When a natural hazard is studied the interactions with other events have to be taken into consideration. In the Sichuan province of China a violent earthquake occurred on May, 12th 2008. It killed approximately 69.000 inhabitants of the province. Such amount of casualties was not caused directly by the earthquake itself but also by other hazardous events. The earthquake caused hundreds of landslides in the mountainous area of the province. When occurred next to rivers courses, such landslides obstructed the streams causing devastating floods (see image 2 and 3 in figure 3.1.13). In the affected area 12 quake-lakes were created. Moreover, other harmful events were triggered by the earthquake, like debris flows and other mass movements, fires in the cities (see image 1 in figure 3.1.13) interruption of lifelines.

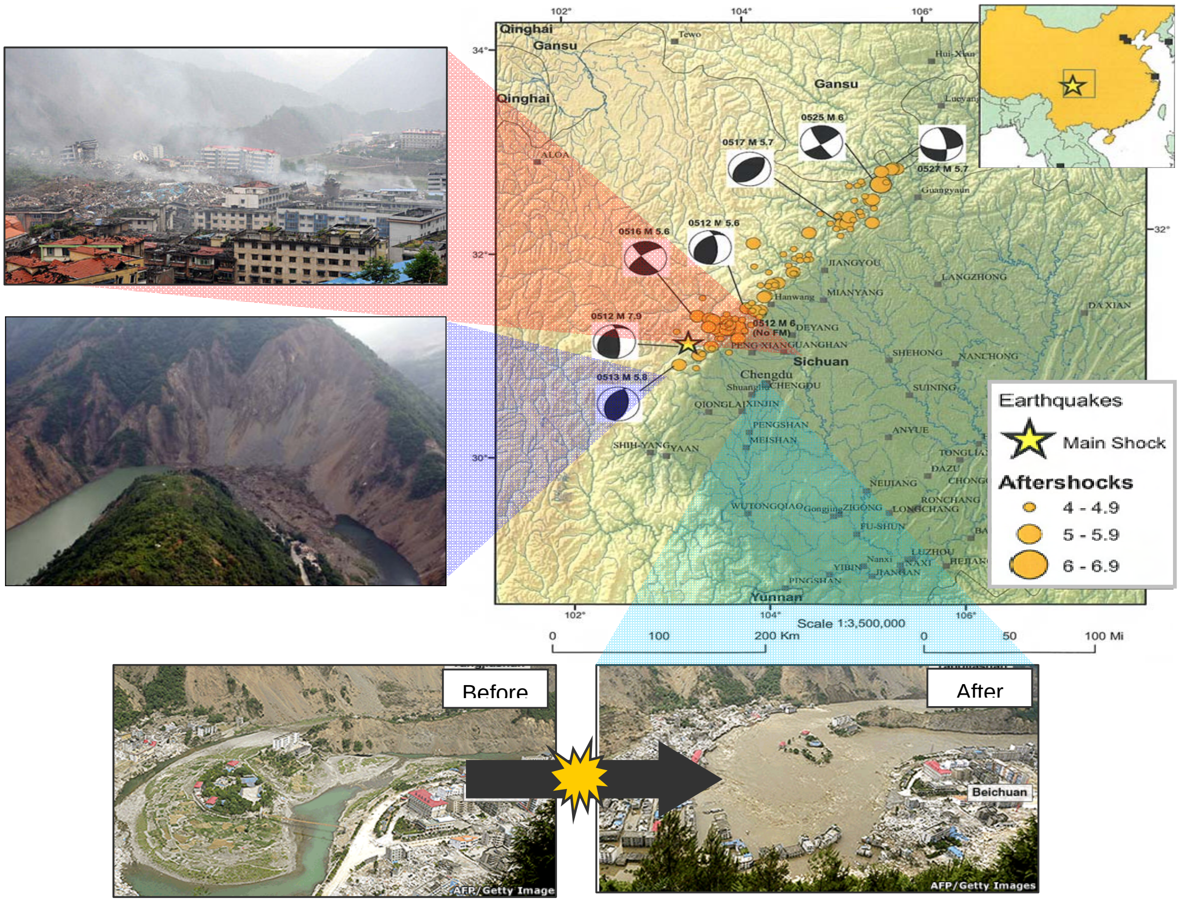


Fig. 3.13: Earthquake occurred on May 12, 2008 in Sichuan province of China, at least 69,000 people were killed. Image 1: fires triggered by the earthquakes. Image 2 and 3a/b The main earthquake triggered landslides that obstructed rivers streams and produced floods. Sources: http://mceer.buffalo.edu/infoService/disasters/china-earthquake-sichuan.asp; www.eeri.org/cds_publications/newsletter/2008_pdf/Wenchuan_China_Recon_Rpt.pdf

Task 3.1.3: According to the example, try to characterize each of the given hazards by drawing a line through the graph.

Earthquakes; Landslides; Floods; Volcanic Eruptions; Lightening; Tsunami

Frequency	Frequent		Rare
Duration	Long		Rapid
Time of Onset	Long		Null
Temporal Spacing	Regular		Random
Areal Extent	Wispread		Limited
Triggering Factors	Exogenic	Both	Endogenic

3.1.4 Hazard types

In the next part the main 6 hazard types will be briefly described according to their nature, spatial and temporal characteristics: landslides, floods, earthquakes, volcanic, coastal and technological. Afterward, in choice sections 3.4 to 3.9 the single hazard types will be introduced and discussed more in depth.

- **Landslides**

Landslides are classified among the main category of geologic hazards, together with land subsidence and expansive soils; geologic hazard are defined as non-seismic ground failures. The term "Landslide" refers to the downward and outward movement of slope-forming materials reacting under the gravity forces. A wide category of processes falls under the definition of landslides: mudflows, mudslides, debris flows, rock falls, debris avalanches, earth flows. Landslides may involve movement of natural rock or soil, artificial fill, or a combination of such materials. Landslides can be triggered by many factors, exogenic, endogenic or man-induced and they can trigger other hazards like floods. They occur in slope areas where one or many of the triggering factors co-exist. Frequency and magnitude are related to each other through an inverse proportion. The study of previous events is the key point in landslides frequency analysis, and more in general in hazard assessment; the old landslides catalogue is compiled through mapped past events analyzed using dating methods for determining the age of large historical events.

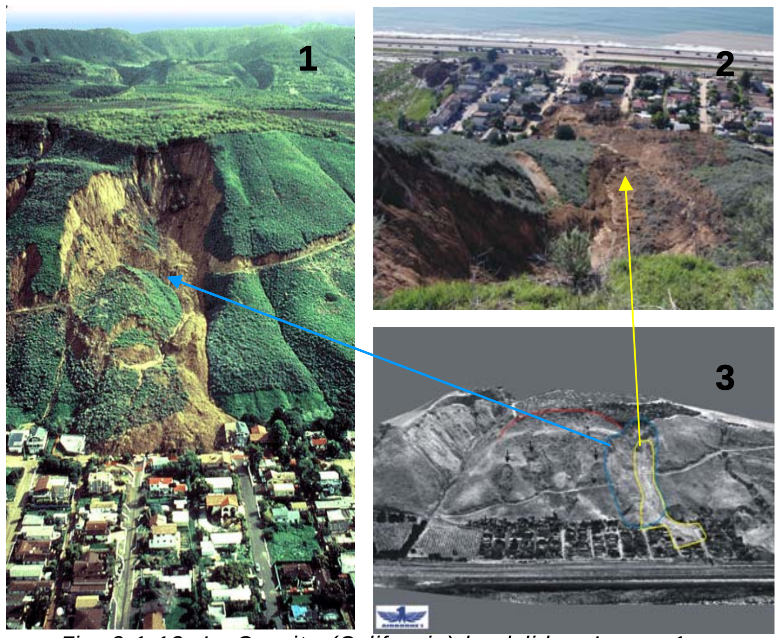


Fig. 3.1.13: La Concita (California) landslides. Image 1: landslide event of 1995. Image 2: reactivation event of 2005. Image 3: oblique view after the landslide in 2005 (http://www.youtube.com/watch?v=W4KWxglDL3o&feature=related).

Landslides	
Triggering factors	Exogenic: heavy rainfalls, land degradation, weathering; Endogenic: earthquakes; Man-induced: deforestation, wrong landuse plans.
Spatial occurrence	Location: slope areas with previous landslide activity and/or under the effect of heavy rainfalls and/or with weathered soil.
Duration of the event	Rapid: from seconds to minutes.
Time of onset	From seconds to months.
Frequency/Magnitude	It depends on the location but they follow an inverse relation: the higher is magnitude the smaller is frequency.
Derived events	They can trigger floods if the body falls into a river, fires in cities. Tsunamis (if they fall into water bodies and the dimensions are sufficiently large)

Two events in La Concita town, California are highlighted in figure 3.1.13; the first landslide occurred in 1995, the second in 2005 right at the same location of the first. Both phenomena were triggered by heavy rainfall and by the unsafe conditions of the slope: weathered material, slope cuts to build roads.

- **Floods**

Floods fall within the main category of hydrologic hazards, which include also storm surges, coastal erosions and droughts. Different definitions can be adopted to describe flood events:

"A flood is any high stream flow which overtops the natural or artificial banks of a stream"

"A flood is a body of water that inundates land that is infrequently submerged and, in doing so, causes or threatens to cause damages and loss of lives"

"Flooding is a natural and recurring event for a river or stream"

By summarizing the meaning of the previous definitions, rivers and water courses in general are subject to cyclical periods of low and high level during every year, in relation to the atmospheric conditions on the different locations. During high level periods, rivers can effort in containing the exceeding quantity of water until a certain point, according to the morphology of the area, and the impact of human-made structures that can affect positively or negatively the river capacity. When the mass of water exceeds that threshold (represented by the natural or artificial levees) a flood occur. Next to the causes related to the precipitation rate, other factors can trigger flood events.

The term flood includes several types of events. According to FEMA Multi Hazard Identification and Risk Assessment (MHIRA, see further reading), six major classes can be recognized.

- Riverine floods are events occurring in downstream wide low-land floodplains (it is the adjoining channel of a river or stream that is susceptible to flooding). They are triggered by large-scale rainfall events over a wide system of catchments that drain to major rivers. Annual spring floods can result from seasonal snowmelt. The floodwaters are typically slow-moving and relatively shallow (ratio between depth and width very small) and they can remain several days on the flooded areas.
- Flash floods occur in upstream areas with high slope gradient and involve smaller areas than riverine floods. They are characterized by a rapid rise of water level, very high velocity, and large debris content; they are triggered by heavy and localized rainfall events. Flash floods may also result from dams' failure or sudden break-up of an ice jam. The time of onset is short to null in the case of dams' failure.
- Fluctuating lake levels: water level in lakes can fluctuate on short-term or seasonal basis due to heavy rainfalls or snowmelt. Fluctuations can occur also in long-term; they can cause flooding problems lasting for years or even decades. Water bodies completely landlocked or without adequate outlets are the most affected.
- Local drainage or high ground water levels: both are events that affect areas outside direct influence of rivers or water bodies in general; local heavy precipitations cannot be accommodated through infiltration and runoff and the water may accumulate and cause local drainage problems. High ground water levels occur in prone areas with specific hydro-geologic characteristics, especially after long period of extraordinary rainfalls.

Floods	
Triggering factors	Exogenic: heavy or elongated rainfalls. (endogenic: earthquakes)
Spatial occurrence	Flash floods (ff): valleys bottom in mountainous areas, small inundated areas; River floods (rf): floodplains, large areas, up to hundreds hectars; Dams/bank failure floods (dff): randomly wherever rivers are located, dimension varying according to the location.
Duration of the event	Ff: rapid from less than one hour to few hours; rf: from less than one day up to ten days
Time of onset	From seconds (dff) to few days (rf)
Frequency/Magnitude	They follow an inverse relation: the higher is magnitude the smaller is frequency (ff and rf). Totally random (dff)
Derived events	Downslope erosion and possible landslides (ff).

In 2002, a series of heavy and prolonged rainfall caused a series of flood events in the major European rivers (Rhine, Danube, Odra, Vistula) culminating in the disastrous August flood in the river Elbe (see image 1 in figure 3.1.14) and part of the Danube. Losses for the Elbe basin were estimated around 3 billion Euros in Czech Republic and 9 billions Euros in Germany. Elbe is one of the major rivers in Europe (1,091 Km), and around 18 million people live in the German part of the catchment. The flood hit the major cities along the river; Dresda, located in the Southern part was the most affected city (see images 2 and 5). That flood event can be classified as a riverine flood; the inundation was destructive also for the erosive power of the flow that damaged many networks (see image 4).

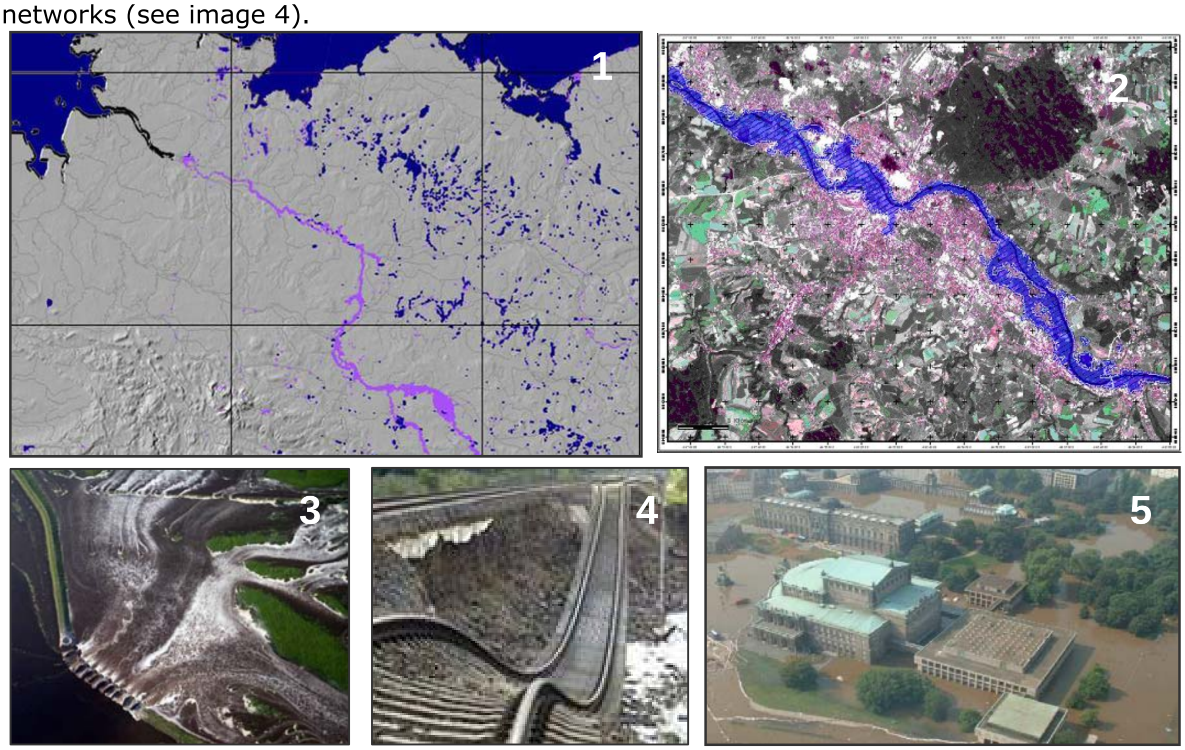


Fig. 3.1.14: 2002 Elbe flood. Image 1: Satellite image of flood extension in Northern Germany. Image 2: flood extent in the city of Dresda. Image 3: dike failure in a polder area. Image 4: damages to railways network caused by flood erosion. Image 5: flood effects in the city of Dresda.

- **Earthquakes**

An earthquake is a sudden motion or oscillation caused by a sudden release of strain accumulated on tectonic plates that form the Earth's crust. Tectonic plates theory explains the evolution of the crust as formed by many rigid (70 to 90 km thick) plates slowly and continuously moving over the liquid external part of the mantle, meeting in some areas (subduction zones) and separating in others (rifts and oceanic ridges). The movements are from less than one cm up to 4-5 cm per year. The "engine" is represented by the convective fluxes in the mantle. The plates (continental crust) are separate by oceanic crust, thinner than the other. They form together a rigid system that, when moved accumulates stress until the rupture; faults are formed instantaneously in the plates at different depths. The stress caused by the rupture creates two waves (shear and compressional), when those waves reach the surface, they generate other two kind of waves (Love and Rayleigh) responsible for the horizontal and vertical ground shaking (see figure 3.1.15). Earthquakes are not spread randomly on the planet, but they focus in zones with high seismic activity. The dimension of earthquakes can be measured as function of magnitude (amount of energy) or intensity (amount of damages). The dimension of the affected areas is a function of the magnitude and of the depth at which the earthquake occurs. Earthquakes don't have any forewarning sign and the duration of the event is from less than one to few seconds.

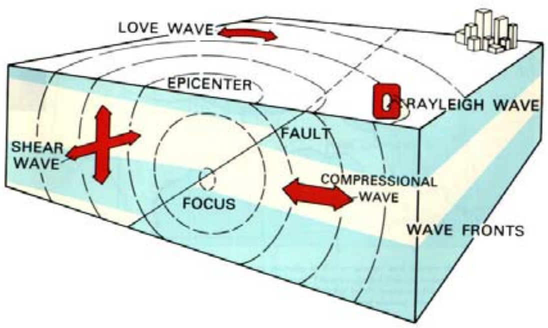


Fig. 3.1.15: Schematic representation of an earthquake caused by a fault.

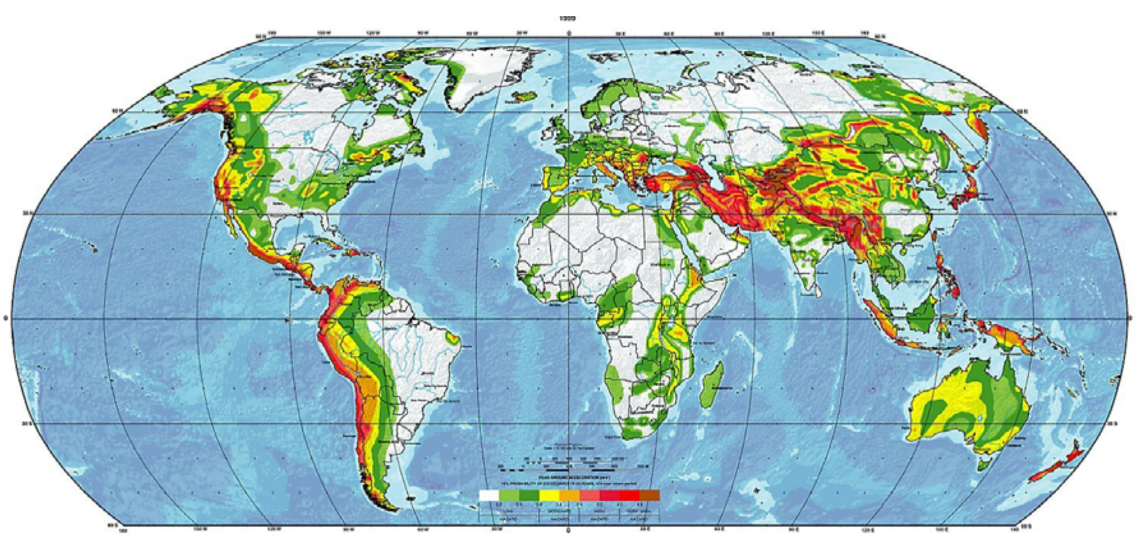


Fig. 3.1.16: Global Seismic Hazard Map: Global Seismic Hazard Assessment Program (GSHAP), United Nations- International Decade of Natural Disaster Reduction.

As mentioned before, the last devastating event occurred in the Sichuan province of China a violent earthquake occurred on May, 12th 2008. For further reading on this catastrophe, refer to the websites listed in the previous part on the derived events.

Earthquakes	
Triggering factors	Endogenic: tectonic movements
Spatial occurrence	Depends on the magnitude (from local to regional scale)
Duration of the event	Rapid, less than one minute
Time of onset	null
Frequency/Magnitude	Inverse relation; dimensions of the event can be expressed through magnitude scale or intensity scale
Derived events	Earthquakes can trigger: Tsunamis (in marine environment) landslides debris flows, floods, fires, etc.

Task 3.1.4: earthquakes (15 minutes).

How many earthquakes with a magnitude higher than M 4.5 happened in your country/continent in the last 7 days?
http://earthquake.usgs.gov/eqcenter/recenteqsww/; follow the link and check in the World regional maps.
Which is the largest earthquake from 1900 up to now? Which devastating other disaster did it cause?
http://earthquake.usgs.gov/eqcenter/eqarchives/year/byyear.php

- **Volcanic eruptions**

Volcanic eruptions affect large areas worldwide; they are related to the tectonic movements of the crust and the focus mainly on the areas in which fractures are created within or among plaques. Eruptions can be broadly classified as non-explosive or explosive. Non explosive eruptions occur in volcanoes with a basic (iron- and magnesium-rich) magma, which is relatively fluid and allows gas to escape. Such eruptions are characterized by fluid lava flows; they have very long activity periods with frequent eruption phenomena. Such events are the less destructive and usually they don't cause a restrict number of victims among the population because they have relatively long time of onset. Examples of this kind are the Hawaii Island volcanoes (USA) and the Etna Volcano (Italy).

The explosive type of eruptions consists of violent explosions caused by acid (silica-rich) magma colder (500-800°C) than the basic one (950-1200°C). Such explosions occur because the top of the volcano is occupied by a thick hat of consolidate rocks that retains all the gasses released in the magma chamber. Explosive eruptions produce large amount of debris in the form of airborne ash, pyroclastic flows, bombs, debris flows; large explosions can produce very high red hot ash columns that can collapse and flow along the volcano flanks at more than 300 Km/h devastating everything on their route. Examples of such kind of eruptions occur at the Vesuvius Volcano (Italy) and in the volcanic chain in Alaska. In the following paragraphs the main events involved in an eruption will be listed and shortly described.

Fig. 3.1.17: Lahar flow caused by the Mount St. Helens' eruption in 1980.

– Lava Flows: are flows that form proper streams of molten lava that erupt without huge explosions. The dimension and the length depend on: viscosity and temperature, slope steepness, obstructions; they can reach 40 Km of length. They totally damage everything they meet on their path. They are associated mainly with non-explosive eruptions; they are not dangerous for people because of their relatively slow movement.

They can cause related hazards like floods and mudflows (Lahars see figure 3.1.17) caused by ice and snow melt, and wildfires.

- Pyroclastic Flows: are high density mixture of hot, dry rock debris and gases ejected by the volcano's craters that flow over wide areas tens of kilometers away from the sources. They result from ash columns collapse, from the fall of rocks from volcanic domes, or from explosive lateral eruptions. Rock debris consists of mainly pumice fragments (volcanic rock formed during fast cooling with porosity higher than 70%). Debris flows are extremely dangerous especially when associated with explosive eruptions.

- Pyroclastic surges: are turbulent clouds of rock debris mixed with gases and air; they can reach high temperatures and fast speeds. They can trigger casualties and destructions in wide areas up to six kilometers far from the sources.

- Volcanic ash (Tephra): is a wide cloud of rock fragments with various dimensions carried upward by the column of red hot gases or by the explosion. The fragments fall on the ground forming ash deposits. Close to the source the dimension of fragments can cause disruption and victims; due to the high temperature tephra can also cause forest wildfires. Away from the source the danger for lives is caused by the effect of ash on respiratory system of animals and humans.

- Volcanic gases: consist mainly in carbon dioxide and compounds of sulfur and chlorine, in minor part of carbon monoxide and fluoride. The spread of gases is controlled by the wind direction and speed. Gases can have deadly effects on humans and animals and they can corrupt metals.

Volcanic eruptions' characteristics differ according to the eruption types. The duration can vary from few minutes or hours, in explosive cases, to months or years, when they are formed by basic magma. They occur in localized volcanic areas well known and mapped worldwide. Various forewarning signs may occur before an eruption like fumaroles, gas evacuations, small earthquakes, depending on the type of volcano. The time of onset can vary from minutes in the case of explosive eruptions, to months during non-explosive events. The frequency and the magnitude are related to the type of event: a volcano causing explosive events has less frequency and more devastating eruptions: non explosive basic volcanoes like Enta have frequent eruptions but are less dangerous.

One of the most important causes of disasters during eruptions is represented by the hazards of different nature triggered by the volcano's activity. Floods, debris flows or mudflows otherwise called lahars can occur during an eruption caused by snowmelt or rupture of lakes on the volcano. Landslides can be triggered by the seismic activity that usually follows an eruption. Atmospheric pollution can occur over large areas, even hundreds of kilometers far from the sources due to the gases or the presence of thin ashes.

Volcanoes	
Triggering factors	Endogenic: tectonic movements that create ruptures in the continental/oceanic crust
Spatial occurrence	Localized in particular locations
Duration of the event	From minutes to years
Time of onset	From minutes to weeks
Frequency/Magnitude	It depends on the characteristics of single volcanoes
Derived events	Lava flows, debris/mud flows, landslides, earthquakes, glaciers melting or crater lake outbreaks and subsequent flood or mudflows, bombs, pyroclastic flows, ash-tephra, gas clouds into the atmosphere

Fig. 3.1.18: Mount. St. Helens' eruption in 1980. (USGS source).

In the 80's volcanoes caused more than 28,500 victims worldwide; that decade experienced more volcanic activities than any other according to recorded history. Mount St. Helens is one example of that devastating series; it erupted explosively in 1980; more than 10.000 local earthquakes and hundreds of stream blasts were triggered by the explosion. The eruption caused destructions in a 596 Km^2 area; over 290 tons of ash were spread over 57.000 Km^2. A column of ash invaded the atmosphere around the volcano and it deposited in during several days afterward on eleven neighboring US states. During the eruption glaciers and snows melted. Landslides and mudflows occurred along the volcano's flanks travelling in the worst cases for more than 22 Km and destroying bridges and temporarily interrupting all the communication networks (roads railways shipping on the Columbia River). More than 60 casualties were recorded and the losses exceeded 1.5 billion dollars.

More information can be found exploring the numerous websites that treat the Mount St. Helens' eruption. Most of the information listed in this paragraph come from the official USGS web page: http://vulcan.wr.usgs.gov/Volcanoes/MSH/May18/framework.html. Another interesting webpage is: http://www.fs.fed.us/gpnf/volcanocams/msh/ where links to real-time webcams on the volcano can be found.

- **Technological hazards**

The field of technological hazards is even more complicated than the one related to natural hazards. This category includes all the disasters related to disruption or malfunctioning of human activities that occur in habited areas or natural environments. Such events widely differ from each other in terms of temporal and spatial characteristics, but they are usually totally unexpected and they seriously affect human beings and their activities directly or indirectly.
Technological hazards can be differentiated into three main categories, according to the

Technological	
Triggering factors	Casual accidents
Spatial occurrence	From localized to widespread, it can occur wherever there are hazardous human-made structures or activities
Duration of the event	From seconds to months
Time of onset	Sudden events without any foregoing
Frequency/Magnitude	Random
Derived events	Explosions can trigger fires; pollutant dispersion can cause environmental disasters etc.

nature of the event and to their direct and indirect impact on population and environment.

- Explosions, fires in populated areas due to accidents related to hazardous industries and plants, or any other human activity. This class includes sudden and fast events that involve relatively small areas with a short duration (from seconds to few days). The triggering factors can be malfunctioning or accidents to: factories, plants, single buildings, tanks containing inflammable materials or storage sites located in or next to urban areas. Accidents consist of explosions and/or fires; the severity of the events is related to the nature of the materials involved. Usually the damages are caused by the direct impact of the event on buildings and the population; other hazardous situations can be derived from the smoke clouds in case of toxic substances involved. Such events don't show any clear relation between frequency and magnitude. They mostly depend on the development of security controls of single countries and regions about the treatment and the storage of hazardous materials.The event occurred in the Netherlands well represents this category. On May 2000, in the City of Enschede in the Eastern part of the Twente Region, what is recalled as the Fireworks Disaster was caused by an explosion in the fireworks factory located in the city. The blasts were felt up to 30 Km far from the source: roughly 1.500 houses were damaged or destroyed. The fireworks deposit went on fire during the day. The chain reaction of explosions caused 22 casualties and more than 900 people were injured (see figure 3.1.19); the damages related to insured houses only exceeded 500 million ***f*** (Dutch guilders, ca. 302 million US$).

Fig. 3.1.19: Fireworks factory explosion on May 13^{th} 2000 in Enschede, the Netherlands. It caused more than 20 victims

- Hazardous material events: uncontrolled release of dangerous materials from storage sites or during transportation activities; it can occur in the atmosphere, in water bodies in groundwater, in the subsoil. This category includes events that occur when hazardous materials are accidentally or illegally released into the environment; they involve relatively large populated or inhabited areas and usually the duration of the events is longer than the first class (from days to months); it depends on the nature of the substance (gas liquid or solid) and on the environment in which such substance is released (atmosphere, soil and groundwater, or water). Duration can also be related to the possibility and the rapidity of intervention by specialized task forces. The severity and the area involved are usually related to the dispersion velocity of the material: in the case of uncontrolled gas dispersion in the atmosphere, the propagation is much higher than the leakage of dense oil in a clayey soil. Frequency and magnitude don't seem to have any relation but casual. The damage is mainly related to environment contamination; population can be affected indirectly through air, water or food long term contamination. One of the worldwide most dangerous examples of this kind of disasters is the well known Exxon Valdez oil spill; it occurred in the Prince William Sound located in the Gulf of Alaska. On March 29^{th}, 1998 the vessel struck a reef off the Bligh Island and it spilled about 200 million liters of oil (see figure 3.1.20). When the spill stopped, the oil had covered 28.000Km^2 of ocean. The consequences for the environment were devastating; in 2007 a study conducted by NOAA stated that more than 98.000 liters of oil were present in the pores of the sandy soil of the contaminated shoreline. About 500.000 seabirds, more than 1.000 sea otters died immediately and many animals showed high death rates in following years mainly due to oil ingestion.

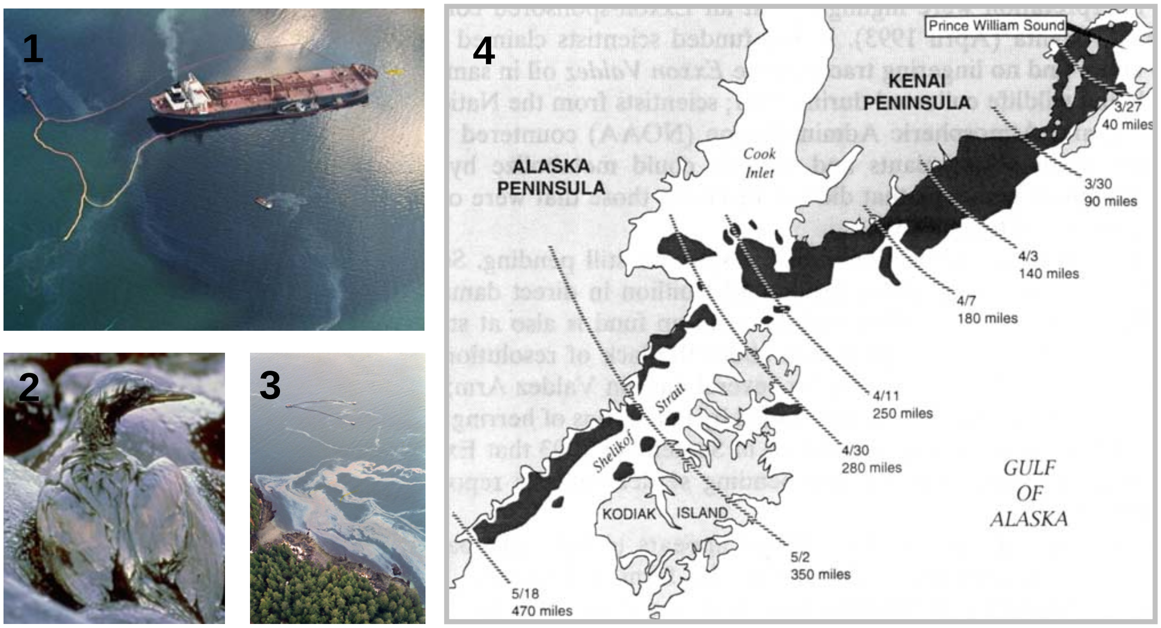


Fig. 3.1.20: Image 1, 2, 3 are related to the ecological disaster due to the Exxon Valdes oil spill. Image 4 represents the development of the contamination in the subsequent days.

– Nuclear accidents: unexpected and uncontrolled nuclear contamination caused by accidents to nuclear plants or any other nuclear reactor facility. Hazards related to nuclear activity or radioactive materials can be mainly of two kinds. They can derive from malfunctioning or failures in nuclear plants that can cause explosions or hazardous material leakage; they can occur if radioactive material is handled without sufficient protections, or it is lost, stolen, or abandoned. Such hazards are extremely dangerous for lives in general and the environment because the persistent effects can affect lives for many years. The dispersion of radioactivity is uncontrollable and can occur at continental scale. In the case of Chernobyl in 1989, products like vegetables and milk were forbidden for children until various months after the disaster all over the Europe.

Task: Technological hazards (15 minutes).

Watch the following videos related to the disasters described above:
(Fireworks disaster)http://www.youtube.com/watch?v=MVqCWErj2Pc&feature=related
(Exxon Valdes spill) http://video.google.com/videoplay?docid=5632208859935499100
Next to the example showed in these pages, can you find other three cases of technological hazards possibly related to your country/continent?

- **Coastal hazards**

Coastal zones represent one of the mostly densely inhabited areas worldwide; about 70% of the entire world's population lives in coastal environments; most of the megalopolises are located in delta areas or at the coasts of estuaries. Such areas are affected by a combination of hazardous events: degradation in the form of surface and groundwater pollution such as salt water intrusion, coastal flooding, erosion & accretion, land subsidence as impact from land-based settlements activities, mining activities of oil and gas. Due to the strong interactions among the effects that such phenomena have on the coastal areas, the hazards affecting this kind of environments are described in this guide book within a single category.

A selection of few coastal hazards is chosen for this section; the most devastating phenomena are the rapid hazard: cyclones and tsunamis. Other slow processes can trigger to hazardous situations in particular cases; therefore they will be mentioned apart.

Rapid Coastal Hazards

In this class two events are included, cyclones and tsunamis; these phenomena have dramatic and destructive effects on the population and the coastal environment. They are recognized as extremely dangerous events because the seriously affect people and their properties in a very short lapse of time.

Cyclones (also known as hurricanes or typhoons) are caused by tropical revolving storms caused by low pressure systems. This pressure drop might cause the sea level to rise, which accompanied by very strong winds (over 90 km/hr) gives storm surges of 5 meter or more, causing severe damage to agriculture and infrastructure and many casualties. About 80 cyclones are formed every year. They move fast (up to 160 km/h) affecting large coastal areas. The duration can vary from hours to days depending on the magnitude of the event; usually they grow up on the oceans and they dissipate over land. They evolve from compact storms to cyclones through the increase of wind speed and the formation of the circular movement (see figure 3.1.21). This gradual growth can allow evacuation or the placement of shelters and protections to limit the impact of the event. The relation between frequency and magnitude is inversely proportional: small cyclones are more frequent than the bigger ones. Cyclones bring heavy rainfalls and strong winds; they frequently trigger correlated hazards like coastal floods, landslides and mudflows in hilly areas.

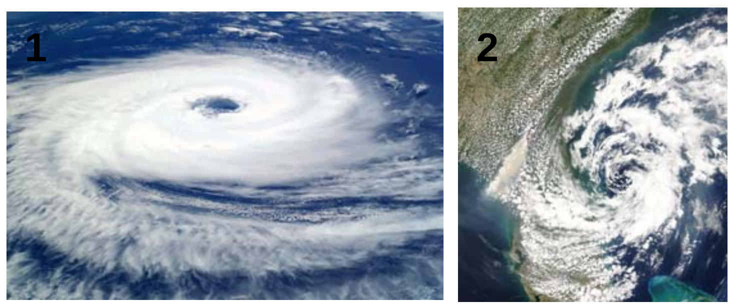


Fig. 3.1.21 Image 1 is the devastating South Atlantic tropical cyclone Catrina (2004). Image 2 is the subtropical cyclone Andrea (2007).

A tsunami is an exceptional disturbance of the sea level caused by an earthquake, landslide or volcanic eruption in and around the oceans. This can generate a sea wave of extreme length and period, travelling outwards in all directions from the source area with speeds up to 500 km/hr. Tsunami waves may attain heights of more than 30 meters by the time they hit the coast. The duration can vary from few seconds to hours; several waves may follow each other at intervals of 15 – 45 minutes, but the most hazardous ones are the first. The frequency-magnitude relation is dependant on the occurrence of the triggering factors.

The well known tsunami of December 26, 2004, was caused by an earthquake of a magnitude of 9 and with the epicentre located off the West coast of Sumatra, Indonesia. It is know as one of the most devastating phenomena ever happened. The main wave that reached the closest Indonesian coasts to the epicentre was more than 30 metres high and travelled at a speed of more than 500 Km/h. The United Nations established that the tsunami killed over 180.000 people and caused approximately 125.000 injuries and damages for more than 1.69 million dollars (see figure 3.1.22).

Fig. 3.1.22: Destructive effects of the 2004 tsunami in Sumatra, Indonesia; left image before; right image after the event

Rapid coastal hazards	
Triggering factors	Cyclones: Atmospheric conditions. Tsunamis: earthquakes, volcanic eruptions and landslides next to water bodies
Spatial occurrence	From hundreds to thousands kilometers of coasts
Duration of the event	Cyclones: from hours to days. Tsunamis: from seconds to hours
Time of onset	Cyclones: from hours to days. Tsunamis: from seconds to hours
Frequency/Magnitude	The most devastating events are the most rare
Derived events	Coastal floods

Slow Coastal Hazards

Enhanced sea level rise. Due to global warming and the Greenhouse Effect, the sea level will rise substantially in the near future. The International Panel of Climate Change (IPCC) has developed various scenarios for this. In the "Business as Usual" scenario this rise will amount up to 40 cm or even more until the end of this century. The enhanced Sea level rise has to be differentiated from long term sea-level change. These changes are so slow, that they are not considered as a hazard. World-wide changes in average sea level are described as eustatic to distinguish them from local influences, such as tectonic uplift or land subsidence. Eustatic sea-level changes result from two main causes: (1) changes in the volume of the ocean basins; and (2) changes in the volume of sea water. An example of the last course is sea level rise due to melting of glaciers after the last ice age.

Subsiding coasts can be considered as severe hazards, especially in urban areas situated in geologically young and "soft' sedimentary deposits. They can be caused by excessive ground-water extraction through industrial or private wells, as well as decreased discharge of the coastal aquifer. Subsiding rates up to 15 cm a year or even more might occur. The subsided land is prone to flooding both from sea and rivers. A good example is Semarang city, Indonesia with subsidence rates up to 11.5 cm /year.

Coastal erosion & accretion is basically a natural process, which can become a risk to coastal infra-structure or other types of land uses, such as shrimp and fishponds or rice fields. The combined effect of wind-generated waves, tidal waves and currents from rivers, produce a highly variable and complex near-shore hydrodynamic system. By the movements of sediment on the sea floor and onshore, offshore and alongshore the shaping of the coastline is taking place in a dynamic system in a continuous process.

3.2 Climate Change and Hazards

3.2.1. Introduction

Climate change that we experience nowadays can partly be ascribed to human activity. Since the industrial revolution, more and more greenhouse gases (GHGs) are being emitted into the atmosphere, causing an increasing trapping of the heat (see Box). These gasses are mainly released during the burning processes of fossil fuels such as coal, oil and gas and due to the changes in land use and land cover. GHGs include carbon dioxide, methane, water vapor, nitrous oxide, ozone and halocarbons. The increase in the emission of GHGs equals 70% between 1970 and 2004 (IPCC).

Definitions of climate:

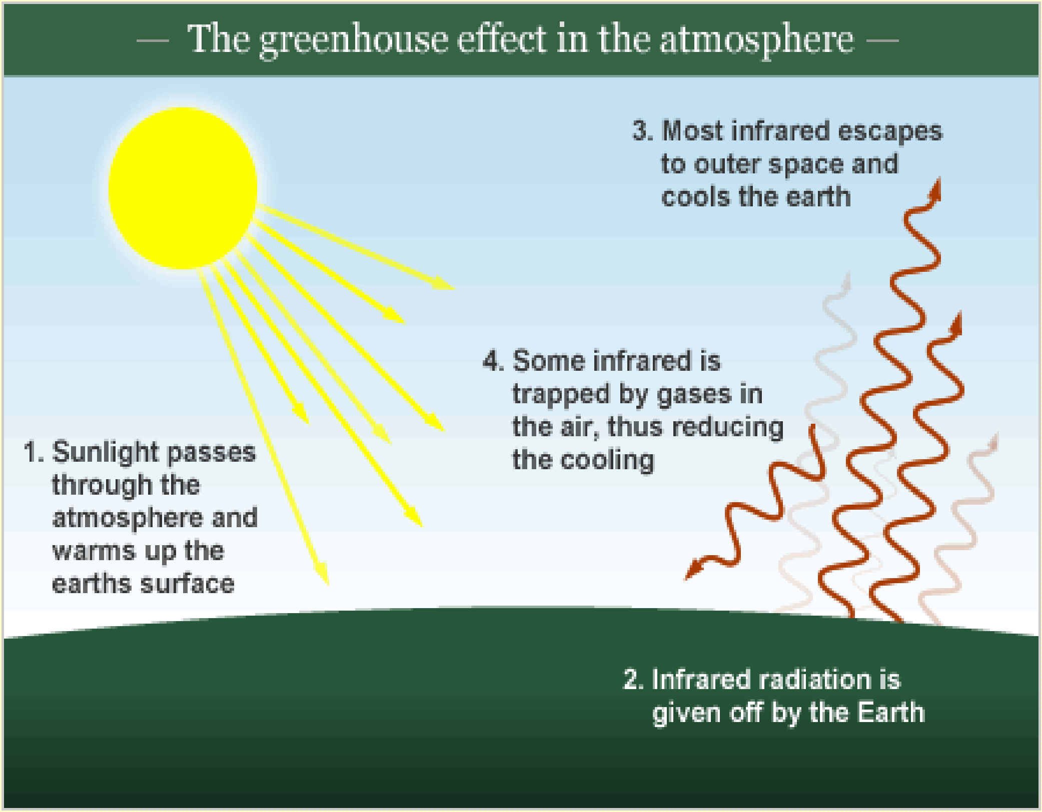
- The long-term average weather pattern of a region.
- The long-term average weather of a region including typical weather patterns, the frequency and intensity of storms, cold spells, and heat waves. Climate is not the same as weather.
- The historical record of average daily and seasonal weather events.

The life time of carbon dioxide molecules in the atmosphere is around 100 years, and the concentration of CO2 now stands at about 385 parts per million (ppm), compared to a pre-industrial concentration of about 280 ppm. The current concentration of carbon dioxide is at least a quarter higher than at any other time during the past 650,000 years. If we carry on burning fossil fuels in a "business as usual" way, the concentrations will rise to 600 or 700 ppm by the year 2100. Even in case where the whole world would work very hard to limit emissions, carbon dioxide concentrations are unlikely to stabilize below 450 ppm.

Evidently, the trapping of the heat by greenhouse gasses causes a global temperature rise. This rise is responsible for numerous secondary effects on our climate. Examples of these secondary effects include a widespread retreat of glaciers with an increase in the global mean sea level as a result (one to two millimeters per year over the course of the twentieth century), a decrease in snow cover, thawing of permafrost and ice sheets, shifts of plant and animal ranges (pole ward, and upward in elevation), earlier flowering of plants, bird breeding seasons and emergence of insects, and increased frequency of coral bleaching events, particularly during El Niño episodes.

The global surface temperatures rise equals over 0.7 °C during the 20th century – making it the warmest period in at least the past 1,300 years. And climate change is accelerating: 11 out of the 12 years in the period between 1995 and 2006, rank among the warmest years since records began (see figure 3.2.1).

Greenhouse Effect



When sunlight strikes the Earth's surface as short wave radiation, a part of this radiation is reflected back to the atmosphere as long wave radiation, also called the infrared radiation (heat). This causes a cooling of the earth. However, the GHGs present in the atmosphere absorb this infrared radiation and trap the heat in the atmosphere. Many gases exhibit these "greenhouse" properties. Some of them occur in nature (water vapor, carbon dioxide, methane, and nitrous oxide), while others are exclusively human made (certain industrial gases). Most GHGs occur in nature, but are also emitted by the burning of fossil fuels. The best example is carbon dioxide.

The trapping of the heat caused by GHGs makes life on earth possible. Without the greenhouse effect, the earth surface will cool down to temperatures that are unsuitable for life. However, over time, if atmospheric concentrations of greenhouse gases keep increasing, the amount of heat trapped in the atmosphere will increase as well, leading to an enhanced greenhouse effect and consequently, what we experience nowadays already, in an increase of the mean global temperature, the global warming.

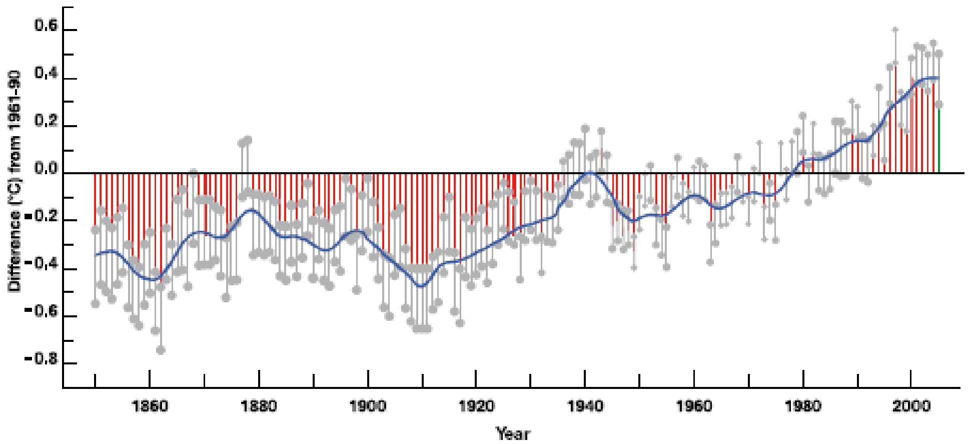


Figure 3.2.1: Observed changes in global average surface temperature (source: IPCC, 2007)

As these changes in climate started to occur around the 1970s, it is hard to tell what effect they have on extreme events. By definition, extreme events are rare, with return periods at a specific location usually in excess of 10 to 20 years, as the environment is generally designed to endure the impacts of more frequent extremes. Thus, not enough years have passed yet, since the onset of anthropogenic climate change, to be able to present solid facts concerning the change in occurrence of natural hazards related to the climatic change.

Task 3.2.1: See the effects of climate change for yourself (duration 10 minutes)

Go to www.google.com and type in the search balk: google earth outreach showcase. Choose the first hit named Google Earth Outreach – Showcase.
On the left side you can find Showcase: Environment & Science. Check out different KMLs, as for example "Per Capita CO2 Emissions" and "Climate Change in Our World".

3.2.2. Effects of climate change on hazards

There are, however, many changes observed that have a high possibility to be related to climate change. According to IPCC, the increase in geomorphologic hazards with hydro-meteorological grounds is clearly linked to the effects of climate change, which are complex and have a large spatial variation.
In the past years, there has been a large rise in the number of disasters (from between 200 and 250 in the period 1987–97 to about double that in the first seven years of the 21st century). This rise is caused almost entirely by an increase in weather-related disasters (see figure 3.2.2). For instance, the number of disastrous storms has doubled. Disaster statistics also show that floods are occurring not just more often but that they also cause damage to greater areas than they did two decades ago. And these rises are accompanied by a rapid increase in socio-economic losses and in the number of people affected. Although since the 1970s, the number of people killed by natural disasters has decreased, largely due to better disaster preparedness, in the past years that decrease has been tapering off and even reversing.

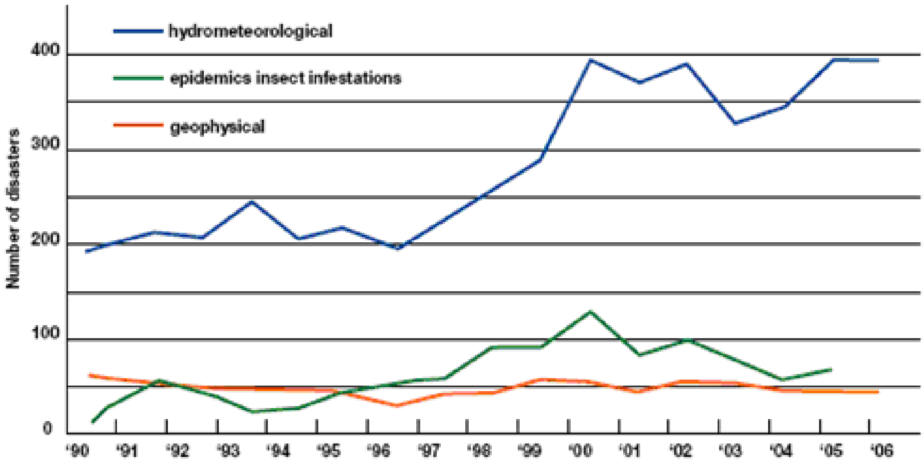


Figure 3.2.2: Annual number of natural disasters (source: CRED EM-DAT)

Temperature

Following the consensus of scientists, the most likely changes related to climate change are an increase in the number of hot days and nights (with some minor regional exceptions), or in days exceeding various threshold temperatures, and decreases in the number of cold days, predominantly including frosts. These are virtually certain to affect human comfort and health, natural ecosystems and crops.

Extended warmer periods are also very likely to increase water demand and evaporative losses, increasing intensity and duration of droughts, assuming no increases in precipitation takes place. Thereupon, long periods of dry condition are very likely to enhance the possibility of the occurrence of heat waves.

Precipitation

According to climate models, precipitation is generally predicted to increase in high latitudes and to decrease in some mid-latitude regions, especially in regions where the mid-latitude westerlies move pole wards in summer seasons, and thus steer fewer storms into such 'Mediterranean climates' (Meehl et al., 2007 in IPCC, 2007). These changes, together with a general intensification of rainfall events (Meehl et al., 2007), will very likely cause an increase in the frequency of flash floods and floods of large areas in many regions, especially the regions at high latitudes. This will be exacerbated, or at least seasonally modified in some locations, by earlier melting of snow packs and melting of glaciers. Contrariwise, regions of constant or reduced precipitation will very likely experience more frequent and more intense droughts, particularly in Mediterranean types of climates and in mid-latitude continental midlands.

Sea level rise

Due to global warming, the mean sea level is rising with the rate of approximately 3 mm/year. This is mainly caused by the melting of the glaciers and by the rise in sea water temperature, and thus the expansion of the water volume. The rise in sea level can have serious effects on countries with low lands. Increased floods are the main effect of the sea level rise. But also salinization of land, water pollution and increase of vector-borne diseases are consequences of sea level rise.

Forest Fires

Extended warm periods and increased dry conditions will increase water stress in forests and grasslands and increase the frequency and intensity of wildfires (Cary, 2002; Westerling et al., 2006 in IPCC), especially in forests and peat land, including thawed permafrost. Forests are a major depot for carbon dioxide. The burning down of forest areas may lead to large losses of accumulated carbon from the soil and from the biosphere into the atmosphere, thereby amplifying global warming (see Langmann and Heil, 2004; Angert et al., 2005; Bellamy et al., 2005 in IPCC, 2007).

Tropical cyclones

Tropical cyclones (including hurricanes and typhoons) develop over large bodies of warm water. With the increasing sea surface temperatures, tropical cyclones are likely to become more intense and more wide-spread. Moreover, several data reanalyses suggest that since the 1970s, tropical cyclone intensities have increased far more rapidly in all major ocean basins where tropical cyclones occur (Trenberth et al., 2007 Section 3.8.3), and that this is consistently related to the increasing sea surface temperatures. Some researchers have doubts about the reliability of these reanalysed data, in part because climate models do not predict such large increases; however, the climate models could be underestimating the changes due to inadequate spatial resolution. This issue currently remains unresolved. Some modelling experiments suggest that the total number of tropical cyclones is expected to decrease slightly (Meehl et al.), but it is the more intense storms that have by far the greatest impacts and constitute a key vulnerability.

The combination of rising sea level and more intense coastal storms, especially tropical cyclones, would cause more frequent and more intense storm surges, with damages exacerbated by more intense inland rainfall and stronger winds. With the increase of coastal populations, the exposure to intense storm surges increases as well.
A summary of the expected effects of climate change on disasters is given in the table 3.2.1.

Task 3.2.2: Internet assignment (duration 10 minutes)

Hurricanes of 2005

Read the CNN article about the hurricane season of 2005:
http://www.cnn.com/2005/WEATHER/11/29/hurricane.season.ender/index.html

Task 3.2.3: Internet assignment (duration 15 minutes)

Go to the website of EM-DAT (www.em-dat.be) and find out which year since 1970 had the largest number of storms for south-east Asia.

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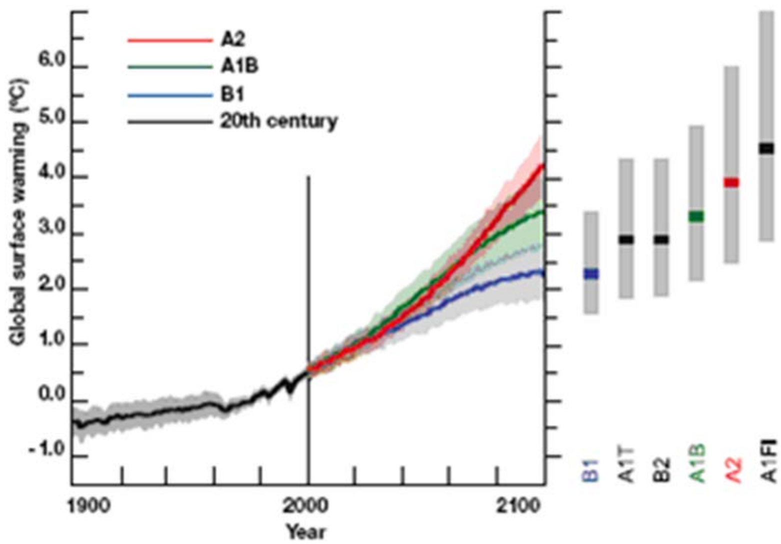
Expected effect of climate change on disasters (IPCC 2007 WG 2)			
Phenomenon and direction of trend	**Likelihood that trend occurred in late 20th century**	**Likelihood of future trend**	**Examples of major impacts**
Over most land areas, warmer and fewer cold days and nights, warmer and more frequent hot days and nights	Very likely	Virtually certain	• Increased agricultural yields in colder environments, decreased yield in warmer environments • Increased insect outbreaks • Effects on water resources relying on snow melt • Reduced mortality from cold exposure • Declining air quality in cities.
Over most land areas, more frequent warm spells/heatwaves	Very likely	Very likely	• Reduced yields in warmer regions due to heat stress • Increased risk of bushfire • Increased water demand, water-quality problems • Increased heat-related mortality, particularly for the elderly, chronically sick, very young and socially isolated.
Over most areas, increasing frequency of heavy precipitation	Likely	Very likely	• Damage to crops • Soil erosion • Adverse effects on quality of surface and ground water • Water scarcity may be relieved • Increased risk of death, injuries, and infectious, respiratory and skin diseases • Disruption of settlements, commerce, transport and societies due to flooding • Pressures on urban and rural infrastructure • Loss of property.
Increasing area affected by drought	Likely in many regions since 1970s	Likely	• Land degradation • Lower yields, crop damage • Increased livestock deaths • Increased risk of wildfire • Increased risk of food and water shortage • Increased risk of malnutrition • Increased risk of water- and food-borne diseases • Migration.
Increasing intensity of tropical cyclones	Likely in some regions since 1970s	Likely	• Damage to crops and trees • Power outages causing disruptions of public water supply • Increased risk of deaths, injuries and disease spread through water or food • Post-traumatic stress disorder • Disruption by flood and high winds • Withdrawal by private insurers of risk coverage in vulnerable areas • Migration, loss of property.
Increased incidence of extremely high sea levels	Likely	Likely	• Salinization of irrigation water and fresh water systems, and decreased freshwater availability • Increased risk of deaths and injuries by drowning in floods • Migration-related health effects • Costs of coastal protection versus relocation • Potential for relocation of people and infrastructure • Tropical-cyclone effects.

Table 3.2.1: Summary of the expected effects of climate change on disasters (IPCC 2007 Working Group II, Summary for Policymakers)

3.2.3. The future scenarios

The IPCC has made four different future scenarios to study the possible effects of climate change (see Box for the explanation of the scenarios). As mentioned previously, carbon dioxide molecules can live around 100 years in the atmosphere, so even if the emissions would be cut down totally, the concentration of CO2 is going to rise for the next years. Therefore, no matter what scenario is studied, all of them show a continuing rise in global mean temperature, see fig 3.2.3.



Each colored line represents the likely change in global temperature that would occur for a specific GHG IPCC emission scenario. The shading around it indicates model uncertainty. The bars on the right show the likely temperature in 2100 for the full set of the scenarios.

The black line with gray shading represents the observed global temperatures during the 20th century.

Figure 3.2.3: Warming scenarios for the 21st century (source: IPCC, 2007)

Concerning the change in intensity and frequency of natural hazards related to climate change, no certain predictions can be made. It is hard to predict what effects the climate change will have on different sectors, and thus predicting the whole package is even more difficult. Thereupon, as mentioned previously, not enough years have passed yet since the set on of anthropogenic climate change, to be able to present solid facts concerning the change in occurrence of natural hazards related to this climatic change. This is because of the fact that the return periods of extreme events are in excess of 10 to 20 years.

Scientists are confronted with surprising effects on regularly basis even though the studies done are solid and robust. The only certain fact about the relationship between climate change and natural hazards is that the uncertainty will increase.

However, the expectations of the effects are unanimous: further increases in heat waves, floods, droughts and in the intensity of tropical cyclones, as well as extremely high sea levels. If the extreme events indeed increase with climate change as is the overall expectation, this will have a great effect on the extent of the risk. As can be seen in figure 3.2.4., the increase in the number of extreme events, combined with an increase in the extent of vulnerable societies, will lead to an increased extent of societies at risk.

Figure 3.2.4: Effect of climate change on risk

Task 3.2.4: Video (duration 10 minutes)
Relation climate change and disasters.
- *Watch the video (8 min): http://www.youtube.com/watch?v=IdPT6CuDBZI*

Box: Emission scenarios created by IPCC.

Box SPM.1: The emission scenarios of the IPCC Special Report on Emission Scenarios (SRES)

A1. The A1 storyline and scenario family describes a future world of very rapid economic growth, global population that peaks in mid-century and declines thereafter, and the rapid introduction of new and more efficient technologies. Major underlying themes are convergence among regions, capacity building and increased cultural and social interactions, with a substantial reduction in regional differences in per capita income. The A1 scenario family develops into three groups that describe alternative directions of technological change in the energy system. The three A1 groups are distinguished by their technological emphasis: fossil intensive (A1FI), non fossil energy sources (A1T), or a balance across all sources (A1B) (where balanced is defined as not relying too heavily on one particular energy source, on the assumption that similar improvement rates apply to all energy supply and end use technologies).

A2. The A2 storyline and scenario family describes a very heterogeneous world. The underlying theme is self reliance and preservation of local identities. Fertility patterns across regions converge very slowly, which results in continuously increasing population. Economic development is primarily regionally oriented and per capita economic growth and technological change more fragmented and slower than other storylines.

B1. The B1 storyline and scenario family describes a convergent world with the same global population, that peaks in mid-century and declines thereafter, as in the A1 storyline, but with rapid change in economic structures toward a service and information economy, with reductions in material intensity and the introduction of clean and resource efficient technologies. The emphasis is on global solutions to economic, social and environmental sustainability, including improved equity, but without additional climate initiatives.

B2. The B2 storyline and scenario family describes a world in which the emphasis is on local solutions to economic, social and environmental sustainability. It is a world with continuously increasing global population, at a rate lower than A2, intermediate levels of economic development, and less rapid and more diverse technological change than in the B1 and A1 storylines. While the scenario is also oriented towards environmental protection and social equity, it focuses on local and regional levels.

An illustrative scenario was chosen for each of the six scenario groups A1B, A1FI, A1T, A2, B1 and B2. All should be considered equally sound.

The SRES scenarios do not include additional climate initiatives, which means that no scenarios are included that explicitly assume implementation of the United Nations Framework Convention on Climate Change or the emissions targets of the Kyoto Protocol.

This box summarizing the SRES scenarios is taken from the Third Assessment Report and has been subject to prior line by line approval by the Panel.

3.2.4. Climate change and vulnerability

Not only the extent of vulnerable societies is about to increase. Other sectors or systems are likely to have a wide variation in the vulnerability across regions as well, partly as a consequence of climate change. Here we discuss 5 different sectors/systems; ecosystems; hydrology and water resources; food and fiber production; coastal systems; and human health.

Ecosystems
Ecosystems are of primary importance to environmental function and to sustainability, and they provide many goods and services vital to individuals and societies. In addition, natural ecosystems have cultural, religious, aesthetic and intrinsic existence values.
Changes in climate have the potential to affect the geographic location of ecological systems, the mix of species that they contain, and their ability to provide the wide range of benefits on which societies rely for their continued existence. Ecological systems are intrinsically dynamic and are constantly influenced by climate variability. The primary influence of anthropogenic climate change on ecosystems is expected to be through the

rate and magnitude of change in climate means and extremes—climate change is expected to occur at a rapid rate relative to the speed at which ecosystems can adapt and reestablish themselves—and through the direct effects of increased atmospheric CO_2 concentrations, which may increase the productivity and efficiency of water use in some plant species.

Hydrology and Water Resources

Water availability is an essential component of welfare and productivity. Currently, 1.3 billion people do not have access to adequate supplies of safe water, and 2 billion people do not have access to adequate sanitation.

Changes in climate could exacerbate periodic and chronic shortfalls of water, particularly in arid and semi-arid areas of the world. There is evidence that flooding is likely to become a larger problem in many temperate and humid regions, requiring adaptations not only to droughts and chronic water shortages but also to floods and associated damages, raising concerns about dam and levee failures. The impacts of climate change will depend on the baseline condition of the water supply system and the ability of water resources managers to respond not only to climate change but also to population growth and changes in demands, technology, and economic, social and legislative conditions.

Food and Fiber Production

Currently, 800 million people are malnourished; as the world's population increases and incomes in some countries rise, food consumption is expected to double over the next three to four decades. The most recent doubling in food production occurred over a 25-year period and was based on irrigation, chemical inputs and high-yielding crop varieties. Problems associated with intensifying production on land already in use are becoming increasingly evident.

Changes in climate will interact with stresses that result from actions to increase agricultural production, affecting crop yields and productivity in different ways, depending on the types of agricultural practices and systems in place. The main direct effects will be through changes in factors such as temperature, precipitation, length of growing season, and timing of extreme or critical threshold events relative to crop development, as well as through changes in atmospheric CO_2 concentration (which may have a beneficial effect on the growth of many crop types). In regions where there is a likelihood of decreased rainfall, agriculture could be significantly affected. Fisheries and fish production are sensitive to changes in climate and currently are at risk from overfishing, diminishing nursery areas, and extensive inshore and coastal pollution.

Coastal Systems

Coastal zones are characterized by a rich diversity of ecosystems and a great number of socioeconomic activities. Coastal human populations in many countries have been growing at double the national rate of population growth.

Changes in climate will affect coastal systems through sea-level rise and an increase in storm-surge hazards and possible changes in the frequency and/or intensity of extreme events. Coasts in many countries currently face severe sea-level rise problems as a consequence of tectonically and anthropogenically induced subsidence. Climate change will exacerbate these problems, leading to potential impacts on ecosystems and human coastal infrastructure. A growing number of extremely large cities are located in coastal areas, which means that large amounts of infrastructure may be affected.

Human Health

In much of the world, life expectancy is increasing; in addition, infant and child mortality in most developing countries is dropping. Against this positive backdrop, there appears to be a widespread increase in new and resurgent vector borne and infectious diseases, such as dengue, malaria, Hantavirus and cholera.

Climate change could affect human health through increases in heat-stress mortality, tropical vector-borne diseases, urban air pollution problems, and decreases in cold-related illnesses. Compared with the total burden of ill health, these problems are not likely to be large. In the aggregate, however, the direct and indirect impacts of climate change on human health do constitute a hazard to human population health, especially in developing countries in the tropics and subtropics; these impacts have considerable potential to cause significant loss of life, affect communities, and increase health-care costs and lost work days. Some increases in non-vector-borne infectious diseases—such as salmonellosis and giardiasis—also could occur as a result of elevated temperatures and increased flooding. However, quantifying the projected health impacts is difficult because the extent of climate-induced health disorders also depends on other factors, such as migration, provision of clean urban environments, improved nutrition, increased availability of potable water, improvements in sanitation, the extent of disease vector-control measures, changes in resistance of vector organisms to insecticides, and more widespread availability of health care. Human health is vulnerable to changes in climate— particularly in urban areas, where access to space conditioning may be limited, as well as in areas where exposure to vector borne and communicable diseases may increase and healthcare delivery and basic services, such as sanitation, are poor.

The text on climate change and vulnerability originates from IPPC special report: The regional impacts of climate change: an assessment of vulnerability, 1997

3.3 Frequency Analysis

3.3.1. Introduction

In session 1 an introduction was given to risk, which was defined as the probability of expected losses (deaths, injuries, property, livelihoods, economic activity disrupted or environment damaged) resulting from interactions between natural or human-induced hazards and vulnerable conditions. In this section we will concentrate in particular on the probability aspect, by looking at the magnitude-frequency (M-F)relationship of hazard events.

What is a magnitude-frequency relationship?

Magnitude-frequency relationship is a relationship where events with a smaller magnitude happen more often than events with large magnitudes.

As indicated in figure 3.3.1-a, most hazard events have a relationship between the magnitude of the event and the frequency of occurrence. This means that events with a small magnitude (e.g. small earthquakes) occur more frequently than those with large magnitudes. This is true more or less for all types of hazards, although for some hazards, like lightning, this would perhaps not be the case.
For some events both the occurrence of low magnitudes (e.g. rainfall) leads to a catastrophe (drought) as well as the occurrence of high magnitudes (flooding).

Task 3.3.1: Magnitude of event (duration 5 minutes)

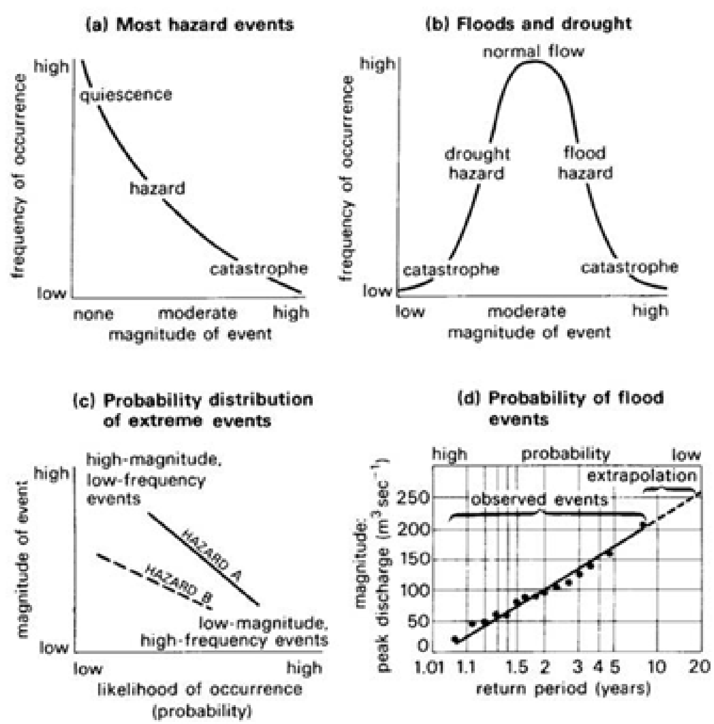
Give another example of an event for which it holds true that low magnitudes as well as high magnitudes can lead to a catastrophe and give examples of the catastrophes.

Most hazard types display a relationship between the likelihood of occurrence (probability) and the magnitude of the event, as shown in figure 3.3.1-c. This relationship might differ substantially depending on the hazard type. Apart from the classification of disasters, which was given in session 1, there is also a classification which is based on the magnitude-frequency relationship and the temporal aspects of the disasters (See table 3.3.1). The frequency magnitude relationship can be valid for the same location (e.g. a particular slope, x-y location, building site). This is the case for events like flooding, where each location will have its own height-frequency relationship depending on the local situation. The flood itself will also have its own discharge-frequency relationship for the entire catchment, but this can be used as input to calculate the height-frequency relationship for a particular point. In other cases the frequency magnitude relationship cannot be established for an individual point, but is done for a larger area (e.g. catchment, province, country, globe). For instance the occurrence of landslides cannot be represented for a particular location as a magnitude-frequency relationship (except for debris flows and rock fall) as the occurrence of a landslide will modify the terrain completely. Thus you cannot say that small landslides occur often in the same location and large landslide less frequently. However, you can say that for an entire watershed.

A frequency-magnitude relationship is normally based on a historical record of hazardous events. These can be in the form of a catalog, which can be derived from:

- recorded information from instruments (e.g. flood levels, earthquakes)- mapped events (e.g. flooded areas, landslides)
- historical archives (e.g. newspapers, municipal archives)
- participatory mapping at community level. - dating methods for determining the age of large historical events (e.g. past earthquakes or landslides).

Figure 3.3.1: Relationship between magnitude and frequency of events. (Source:....)



Historical information is always incomplete, as we can only obtain information over a particular period of time, e.g. the period over which there was a network of seismographs. The length of the historical record is of large importance for accurately estimating the magnitude-frequency relation. If the time period is too short, and didn't contain any major events, it will be difficult to estimate the probability of events with large return periods. The accuracy of prediction also depends on the completeness of the catalog over a given time period. In the case that many events are missing, it will be difficult to make a good estimation.

According to table 3.3.1 the frequency-magnitude distributions can be in different forms. They can be completely random, meaning that there is no relation between the two. The M-F distribution can also be irregular, which means that there is generally a relation but it is not regular, and differs from place to place. In those situations it is also difficult to make an equation that relates probability with magnitude. There are also a number of events that have a relation which can follow different distribution functions: e.g. log-normal, binomial, gamma, Poisson, exponential. In the following section three examples are given of the generation of magnitude-frequency relations: for flooding, earthquakes and landslides.

Table 3.3.1: Classification of disasters by occurrence and by Magnitude-Frequency relationship.

	Disaster type	Occurrence possible	Magnitude - Frequency relationship
Hydrometeorological	Lightning	Seasonal (part of the year)	Random
	Hailstorm	Seasonal (storm period)	Poisson , gamma
	Tornado	Seasonal ("tornado season")	Negative binomial
	Intense rainstorm	Seasonal (rainfall period)	Poisson, Gumbel
	Flood	Seasonal (rainfall period)	gamma, log-normal, Gumbel
	Cyclone/ Hurricane	Seasonal (cyclone season)	Irregular
	Snow avalanche	Seasonal (winter)	Poisson, gamma
	Drought	Seasonal (dry period)	Binomial , gamma
Environmental	Forest fire	Seasonal (dry period)	Random
	Crop disease	Seasonal (growing season)	Irregular
	Desertification	Progressive	Progressive
	Technological	Continuous	Irregular
Geological	Earthquake	Continuous	Log-normal
	Landslide	Seasonal (rainfall period)	Poisson
	Tsunami	Continuous	Random
	Subsidence	Continuous	Sudden or progressive
	Volcanic eruption	Intermittent (magma chamber)	Irregular
	Coastal erosion	Seasonal (storm period)	Exponential , gamma

Task 3.3.2: Frequency distribution (duration 15 minutes)

What would be the relation between magnitude and frequency of events for the following types of hazards? Answer the following questions:

- *Is there a M-F relation for a given location or for an area?*
- *Can the M-F relation be based on historical records?*
- *If so, from where and how should these be obtained?*

A. Flooding
B. Earthquakes
C. Landslides
D. Volcanic eruptions
E. Cyclones
D. Coastal erosion

3.3.2. Flooding frequency

Hydrologic systems are sometimes impacted by extreme events, such as severe storms, floods, and droughts. The magnitude of such an event is inversely related to its frequency of occurrence, very severe events occurring less frequently than more moderate events. The objective of frequency analysis of hydrologic data is to relate the magnitude of extreme events to their frequency of occurrence through the use of probability distributions. The hydrologic data analysed are assumed to be independent and identically distributed, and the hydrologic system producing them (e.g. a storm rainfall system) is considered to be stochastic, space-independent, and time-independent.

Table 3.3.2: Record of annual maximum discharges of the Guadalupe River

Year	1930	1940	1950	1960	1970
0		55,900	13,300	23,700	9,190
1		58,000	12,300	55,800	9,740
2		56,000	28,400	10,800	58,500
3		7,710	11,600	4,100	33,100
4		12,300	8,560	5,720	25,200
5	38,500	22,000	4,950	15,000	30,200
6	179,000	17,900	1,730	9,790	14,100
7	17,200	46,000	25,300	70,000	54,500
8	25,400	6,970	58,300	44,300	12,700
9	4,940	20,600	10,100	15,200	

The hydrologic data employed should be carefully selected so that the assumptions of independence and identical distribution are satisfied. In practice, this is often achieved by selecting the annual maximum of the variable being analysed (e.g. the annual maximum discharge, which is the largest instantaneous peak flow occurring at any time during the year) with the expectation that

successive observations of this variable from year to year will be independent.
The results of flood flow frequency analysis can be used for many engineering purposes: for the design of dams, bridges, culverts, and flood control structures; to determine the economic value of flood control projects; and to delineate flood plains and determine the effect of encroachments on the flood plain.

Return period
Suppose that an extreme event is defined to have occurred if a random variable X is greater than or equal to some level x_T. The recurrence interval t is the time between occurrences of $X \geq x_T$.
For example, table 3.3.2 shows the record of annual maximum discharges of the Guadalupe River near Victoria, Texas, from 1935 to 1978. If x_T = 50000 cfs[1], it can be seen that the maximum discharge exceeded this level nine times during the period of record, with recurrence intervals ranging from 1 year to 16 years, as shown in table 3.3.3

Table 3.3.3: Years with annual maximum discharge equalling or exceeding 50000 cfs on the Guadalupe River and the corresponding recurrence intervals

Years were 50000 is exceded	1936	1940	1941	1942	1958	1961	1967	1972	1977	Average
Recurrence interval		4	1	1	16	3	6	5	5	5.1

The return period T of the event $X \geq x_T$ is the expected value of t, E(t), its average value measured over a very large number of occurrences. For the Guadalupe River data, there are 8 recurrence intervals covering a total period of 41 years between the first and last exceedence of 50000 cfs, so the return period of a 50000 cfs annual maximum discharge on the Guadalupe River is approximately T = 41/8 = 5.1 years. Thus the return period of an event of a given magnitude may be defined as the average recurrence interval between events equalling or exceeding a specified magnitude.

The probability $p = P(X \geq x_T)$ of occurrence of the event $X \geq x_T$ in any observation may be related to the return period in the following way. For each observation, there are two possible outcomes: either "success" $X \geq x_T$ (probability p) or "failure" $X < x_T$ (probability 1-p). Since the observations are independent, the probability of a recurrence interval of duration T is the product of the probabilities of t-1 failures followed by one success, that is, $(1-p)^{t-1}.p$.
Assuming that the series of data is infinite, the E(T) can be expressed as:

$$E(t) = \sum_{t=1}^{\infty} (1-p)^{t-1} \cdot p \quad \text{Eq 1}$$

Developing this expression in terms and after some algebra:

$$E(t) = T = \frac{1}{p} \quad \text{Eq 2}$$

Therefore, the probability of occurrence of an event in any observation is the inverse of its return period.

$$P(X \geq xT) = \frac{1}{T} \quad \text{Eq 3}$$

For example, the probability that the maximum discharge in the Guadalupe River will equal or exceed 50000 cfs in any year is approximately p= 1/t= 1/5.1= 0.195 (19.5%)

Probability and risk
Suppose a certain flood (F) has a probability of occurrence of 10% - meaning a probability of 10% that this flood level will be reached or exceeded.
In the long run, the level would be reached on the average once in 10 years. Thus the average return period T in years is defined as:

[1] Cfs= cubic foot per second (feet^3/sec). Equivalence: 1000 cfs = 28.3168 m^3/s

$$T = \frac{1}{P_R(F)} \quad \text{Eq 4}$$

and the following general relations hold:

1. The probability that F will occur in any year:

$$P_R(F) = \frac{1}{T} \quad \text{Eq 5}$$

2. The probability that F will not occur in any year

$$P_L = 1 - P_R(F) = 1 - \frac{1}{T} \quad \text{Eq 6}$$

3. The probability that F will not occur in any of n successive years

$$P_L^n = \left(1 - \frac{1}{T}\right)^n \quad \text{Eq 7}$$

4. The probability R, called risk, that F will occur at least once in n successive years

$$R = 1 - \left(1 - \frac{1}{T}\right)^n \quad \text{Eq 8}$$

Extreme value distributions

A large amount of process events in hydrology are right skewed, leading to differences between the mode, median and mean of their distributions (see figures 3.3.2 and 3.3.3).

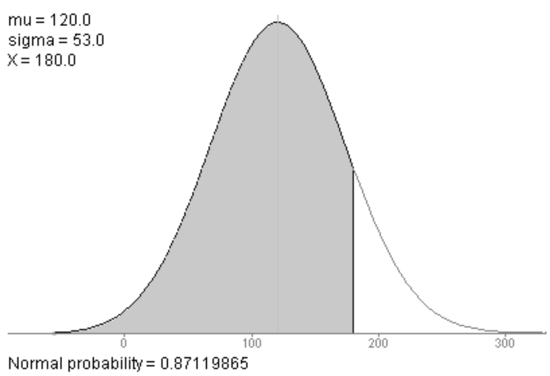


Figure 3.3.2: A normal distribution accurately describes facts in nature that apart evenly for a mean.

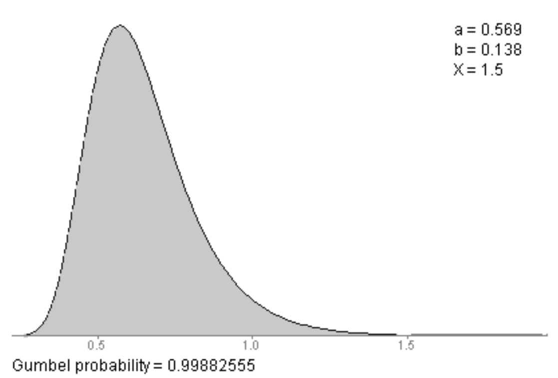


Figure 3.3.3: River discharges and rainfall are right skewed events. Their value cannot be lower than zero and extreme events might occur far form the average.

There are a number of influences that promote this characteristic right-skewness of recorded natural events:

1. Where the magnitude of given events is absolutely limited at the lower end (i.e. it is not possible to have less than zero rainfall or runoff), or is effectively so (i.e. as with low temperature conditions), and not at the upper end. The infrequent events of high magnitude cause the characteristic right skew.
2. The above-mentioned limitation of the lower magnitudes implies that as the mean of the distributions approaches this lower limit, the distribution becomes more skewed.
3. The longer the period of record, the greater the probability of observing infrequent events of high magnitude, and consequently the greater the skewness.
4. The shorter the time interval within measurements are made, the greater the probability of recording infrequent events of high magnitude and the smaller the skewness.
5. Other physical principles tend to produce skewed frequency distributions. For example the limited size of high intensity thunderstorms means that the smaller the drainage basin, the higher the probability that it will be completely blanked by heavy rain and this leads to an increase in skewness in the distribution of runoff as basin

size decreases. Similarly, stream discharge frequencies are extremely skewed where impermeable strata allow little infiltration.

The right skewed distributions present certain problems of description and of inferring probabilities from them. When plotted on linear-normal probability paper, right skewed distributions appear as concave curves.
There are three methods to calculate the extreme value distribution in case of right skewness; Gumbel, Frechet and Weibull, see Fig 3.3.4. These methods are called the Extreme Value methods (EV's) and they are all based on one general equation called the General Extreme Value (GEV) distribution. The extreme value transformation or double exponential transform is extensively used to straighten out cumulative plots of highly skewed distributions. The probability distribution function for the GEV is:

$$F(x) = \exp\left[-\left(1 - k \cdot \frac{x-u}{\alpha} \right)^{1/k} \right]$$

where k, u and α are parameters to be determined.

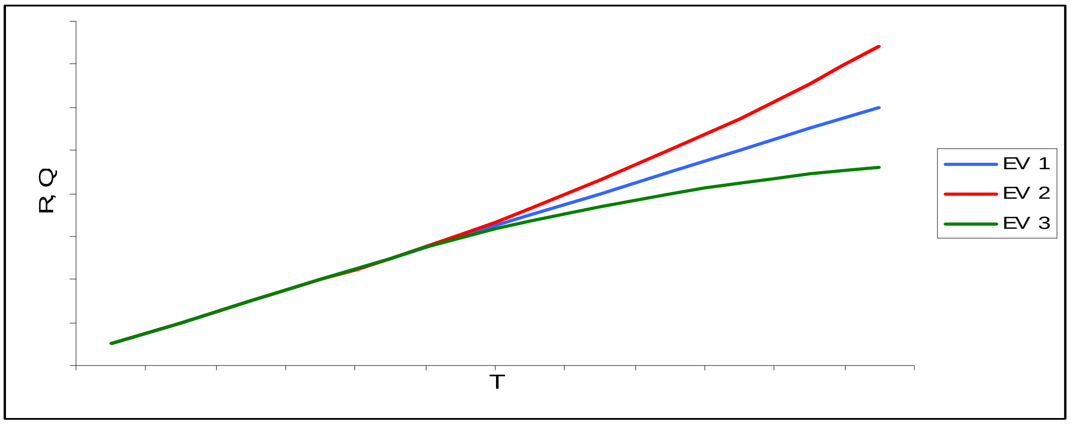


Figure 3.3.4: Gumbel distribution (EV 1), Frechet distribution (EV 2) and Weibull distribution (EV 3) with discharge or rainfall on the y-axis and return period on the x-axis.

The Gumbel distribution is a distribution with a light upper tail and it is positively skewed. It often underestimates the actual situation. Frechet gives a better estimation, but as three variables are needed for Frechet and just two for Gumbel, the Gumbel method is generally used. Frechet is a distribution with a heavy upper tail and infinite higher order moments. The Weibull distribution is a distribution with a bounded upper tail. It used to estimate the drought. For this method, also three variables are needed.

Critical notes extreme frequency analysis
The statistical methods discussed are applied to extend the available data and hence predict the likely frequency of occurrence of natural events. Given adequate records, statistical methods will show that floods of certain magnitudes may, on average, be expected annually, every 10 years, every 100 years and so on. It is important to realize that these extensions are only as valid as the data used. It may be queried whether any method of extrapolation to 100 years is worth a great deal when it is based on (say) 30 years of records. Still more does this apply to the '1000 year flood' and similar estimates. As a general rule, frequency analysis should be avoided when working with records shorter than 10 years and in estimating frequencies of expected hydrologic events greater than twice the record length.
Another point for emphasis is the non-cyclical natural of random events. The 100-year flood (that is, the flood that will occur on average, once in 100 years) may occur next year, or not for 200 years or may be exceeded several times in the next 100 years. The accuracy of estimation of the value of the (say) 100-year flood depends on how long the record is and, for floods, one is fortunate to have records longer than 30 years.

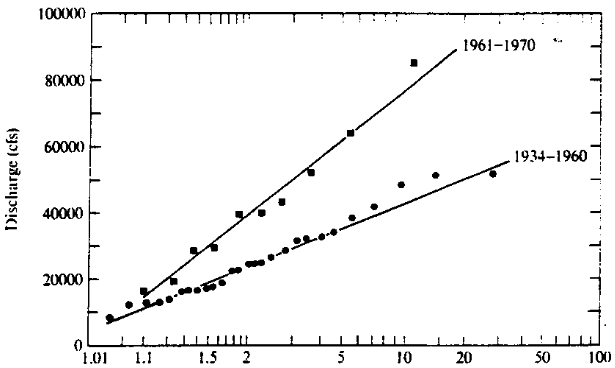


Figure 3.3.5: Changes in climatic conditions might alter the statistics of extremes.

Notwithstanding these warnings, frequency analysis can be of great value in the interpretation and assessment of events such as flood and the risks of their occurrence in specific time periods.

Many parts of East Africa, for example, have undergone a striking change of rainfall since 1960 and it is doubtful whether floods from before and after this date should be mixed in constructing a flood frequency curve. As an illustration, available records have been segregated into two sets of years and re-plotted in figure 3.3.5 as two flood frequency curves that are strikingly different. Unfortunately there are no hard and fast roles to guide the hydrologist in such a situation. So he or she must make a judgement about the significance of the separation of these two curves.

- Does it represent only a short run of wet years?
- Or has the hydrologic regime of the basin undergone a radical change?

If the latter hypothesis is correct, use of the longer but mixed record could lead to a serious underestimation of floods in the new regime. In this case the shorter record, although subject to grave sampling errors, would be the one to use for planning. A question would also arise about the probable duration of the new regime and again there are no precise statistical answers. The hydrologist would have to consult climatologists. We raise the problem here, not because we can give answers, but so that the hydrologist and planner can see that flood frequency curves and the statistics they yield are subject to large uncertainties and that they should be treated conservatively.

For such reasons, flood frequency curves should be checked and updated from time to time. If the record remains homogeneous, its increasing length will reduce the standard deviation and narrow the confidence intervals around the mean. Land use changes, dam construction and channel changes are rendering flood records of little value.

Another factor that may cause a lack of homogeneity in a flood record is the variation of the causative meteorological event. In New England, for example, some annual floods are generated by summer rainstorms others by autumn hurricanes, others by snow melt and still others by rain on melting snow, sometimes coupled with surges following break-up of ice dams. Usually all such floods are included in the frequency analysis. Whether they should be or not is a subject for debate.

Sometimes the observed flood distribution is not fitted well by a straight line on any of the graph papers and the hydrologist must sketch a curve to fit the points. He should be fully aware of the possible errors when using the information obtained in this manner. It is also strongly advisable not to rely on one method of flood prediction, but to use several methods in an attempt to obtain consensus.

3.3.3. Earthquake frequency assessment

The outer shell of the earth is composed of a number of almost rigid "plates" that slowly move against each other. Stresses can build up at these boundaries, caused by the general movement of the plates against each other over time, with stress accumulating at the plate boundaries. It may then be released suddenly, in the form of an earthquake. Most of the extreme magnitude earthquakes occur near the plate boundaries. Most of these boundaries are under deep water, but the effects spread for many miles, and so can be felt on land in these cases too. Earthquakes happening under the sea might trigger tsunamis, bringing damage to coastal communities, in a wide area. The USGS (U.S. Geological Survey) estimates that several million earthquakes occur in the world each year. Many go undetected because they hit remote areas or have very small magnitudes. The NEIC (National Earthquake Information Center) now locates about 50 earthquakes each day, or about 20,000 a year.

Task 3.3.3: USGS and NEIC (duration 15 minutes)

Visit the websites of USGS and of NEIC:

http://www.usgs.gov/
http://neic.usgs.gov/

A measurement of earthquake magnitude is the Richter scale. On a logarithmic scale this measures the size and energy released from an earthquake. That means that larger earthquakes occur less frequently, the relationship being exponential; for example, roughly ten times as many earthquakes larger than magnitude 4 occur in a particular time period than earthquakes larger than magnitude 5. On this scale, there are usually dozens of "earthquakes" occurring daily, with a magnitude of below 2.5. These are usually not felt by humans. It takes a much stronger earthquake for damage to occur. For example, a magnitude 6.0 earthquake is ten times larger than a magnitude 5.0, but it has 32 times the amount of energy released, so is more likely to cause damage. An earthquake registering between 6.0 and 6.9 could be considered fairly major. Above 7.0, the earthquake is considered more serious, with a larger area of damage anticipated. Loss of life is dependent on location (close to settlements etc.) as well as whether or not buildings can withstand the earth tremors. The larger the magnitude, the more likely fatalities will occur. However, earthquake statistics show that this is strongly location dependent. Some of the largest earthquakes ever recorded did not result in any casualties (see http://earthquake.usgs.gov/ for more details).

Richter scale no.	No. of earthquakes per year	Typical effects of this magnitude
< 3.4	800 000	Detected only by seismometers
3.5 - 4.2	30 000	Just about noticeable indoors
4.3 - 4.8	4 800	Most people notice them, windows rattle.
4.9 - 5.4	1400	Everyone notices them, dishes may break, open doors swing.
5.5 - 6.1	500	Slight damage to buildings, plaster cracks, bricks fall.
6.2 6.9	100	Much damage to buildings: chimneys fall, houses move on foundations.
7.0 - 7.3	15	Serious damage: bridges twist, walls fracture, buildings may collapse.
7.4 - 7.9	4	Great damage, most buildings collapse.
> 8.0	One every 5 to 10 years	Total damage, surface waves seen, objects thrown in the air.

Task 3.3.4: Richter scale (duration 10 minutes)

Answer the following questions:
- What the last earthquakes with a magnitude >8.0?
- What magnitude did the last earthquake in or near your country have?

In the past few decades it seems as if earthquake activity has strongly increased. In the 1960's around 5000 earthquake per year were recorded and that number has steadily increased till over 20000 in this century (see also figure 3.3.6). A partial explanation may lie in the fact that in the last twenty years, we have definitely had an increase in

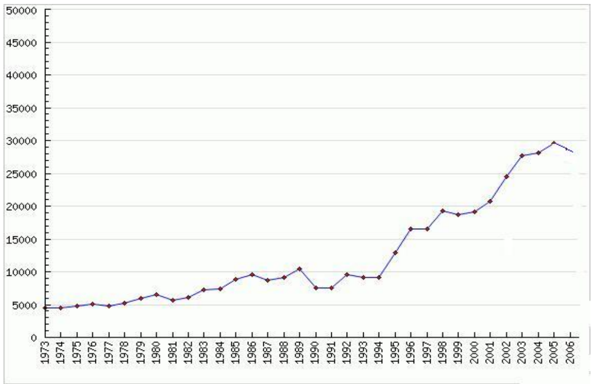


Figure 3.3.6: Number of earthquakes recorded per year (source: DL Research. - http://www.dlindquist.com

the number of earthquakes we have been able to locate each year. Lower intensity earthquakes have been noticed because of a general increase in the number of seismograph stations across the world and improved global communications. This increase has helped seismological centers to locate many small earthquakes which were undetected in earlier decades. In 1931, there were about 350 stations operating in the world; today, there are more than 8,000 stations and the data now comes in rapidly from these stations by electronic mail, internet and satellite. This increase in the number of stations and the more timely receipt of data has allowed us and other seismological centers to locate earthquakes more rapidly and to locate many small earthquakes which were undetected in earlier years. This is illustrated by the fact that the number of large earthquakes (magnitude 6.0-7.0 and greater) has remained relatively constant in the past few decades. Another effect is that people are more aware of earthquakes, because of the improvements in communications and the increased interest in the environment and natural disasters.

In seismology, the Gutenberg–Richter law expresses the relationship between the magnitude and total number of earthquakes in any given region and time period of that specific magnitude and larger.

$$\log N = A - bM$$

or

$$N = 10^{A-bm}$$

Where:

- N is the number of events in of the minimum magnitude M and above
- M is a magnitude minimum
- A and b are constants

The relationship was first proposed by Richter and Gutenberg. The constant *b* is typically equal to 1.0. This means that for every magnitude 4.0 event there will be 10 magnitude 3.0 quakes and 100 magnitude 2.0 quakes. Although the relationship is surprisingly stable for different earthquake prone areas, small deviations (max 0.15) are possible and those indicate areas with relatively more larger or smaller magnitude earthquakes for lower and higher b-values, respectively. An exception is during earthquake swarms when the b-value can become as high as 2.5 indicating an even larger proportion of small quakes to large ones. A b-value significantly different from 1.0 may suggest a problem with the data set; e.g. it is incomplete or contains errors in calculating magnitude. The "roll off" of the b-value is an indicator of the completeness of the data set at the low magnitude end (see also the exercise). The *a-value* simply indicates the total seismicity rate of the region.

3.3.4. Landslide frequency assessment

Temporal Probability-Rainfall Threshold Analysis

The most challenging aspect of landslide hazard evaluation is establishing the temporal component ie., when the slide will take place. For rainfall triggered landslides, this component forms the temporal probability of slide inducing rainfall to occur. Though landslides can be triggered by earthquake also, the rainfall induced slides are relatively most common. They are caused by the build up of high pore water pressure into the ground (Campbell, 1975). The groundwater conditions responsible for slope failures are related to rainfall through infiltration, soil characteristics, antecedent moisture content and rainfall history. It is therefore important to incorporate their effect in evaluating landslide initiation. However, their effect is totally different for condition related to slide type and volume. Shallow translational soil slips are related to intense rainfall periods ranging from 1 to 15 days, while deep slope movements (translational slides, rotational slides and complex and composite slope movements) occur in relation to longer periods of less intense rain, lasting from 30 to 90 days (Zezere et al., 2005). Intense rainfall is responsible for the rapid growth of pore pressure and loss of the apparent cohesion of thin soils, leading to failure within the soil material or at the contact with the underlying impermeable bedrock. Long duration less intense rainfall periods allow a steady rise of groundwater table and result in the occurrence of deep failures through the reduction of shear strength of affected materials. It is therefore important to establish the relation between rainfall and landslide initiation. This is being done by defining minimum and maximum threshold of rainfall require for resulting a landslide.

In general, a "threshold" is defined as the minimum or maximum level of some quantity needed for a process to take place or a state to change (White et al., 1996). A minimum threshold defines the lowest level below which a process does not occur. A maximum threshold represents the level, above which a process always occurs, i.e., there is a 100% chance of occurrence whenever the threshold is exceeded (Crozier, 1996). For 'rainfall-induced slope failures' a threshold may represent the minimum intensity or duration of rain, the minimum level of pore water pressure, the slope angle, the reduction of shear strength or the displacement required for a landslide to take place. Thresholds can also be defined for parameters controlling the occurrence of landslides, such as the antecedent hydrogeological conditions or the (minimum or maximum) soil depth required for failures to take place (Reichenbach et al., 1998).

The possible approaches for establishing rainfall threshold for land sliding can be grouped under three models (Armonia Report, 2005):

a) *Statistical or empirical models* (*black-box models*): where a direct correlation between rainfall height, in a defined time interval, and slope movements is analyzed without implementing physical laws that rule the transformation rainfall-infiltration-piezometric response. They are generally presented as lower limit curves separating areas with specific combinations of values of the plotted variables. More rarely, the rainfall conditions that did not result in landslides are considered to better constrain an empirical rainfall threshold.

b) *Deterministic models*: where hydrological models are used for analysis of various parameters (rainfall, run-off, effective infiltration) and hydrogeological models for analysis of piezometric height and aquifer recharge;

c) *Hybrid models*: where the above approaches are usually coupled (e.g. aquifer recharge through a hydrological model and piezometric response by means of a statistical analysis). However, the assessment of temporal and spatial variability of pore water pressure, through statistic, is only possible with routine and high resolution temporal frequency of sampling (Rezaur et al., 2002).

Rainfall triggering thresholds can be *global*, *regional* or *local*. A global threshold is obtained by using all the available data from different regions world-wide. The meaning of these thresholds consists in the possibility of having a general threshold which is independent of local conditions and of typical rainfall patterns. The easiest way to define a global threshold consists in tracing a lower limit line embracing all the recorded rainfall conditions that resulted in landslides i.e. thresholds that define the lowest level above which one or more than one landslide can be triggered (Aleotti, 2004). The threshold at a regional scale is also calculated in the same way except the data limit is defined by the region under consideration. A local rainfall threshold explicitly or implicitly considers the local climatic regime and geomorphological setting. The most commonly investigated rainfall parameters are: (i) total ("cumulative") rainfall, (ii) antecedent rainfall, (iii) rainfall intensity, and (iv) rainfall duration.

Numerous models are available for calculating rainfall threshold for landslides. Some models are based on direct daily rainfall while others take into account the intensity-duration or soil moisture condition. Glade (1998) calculated the regional thresholds rainfall for landslide initiation on the basis of daily rainfall data in New Zealand. He calculated the maximum and minimum threshold for daily rainfall required to cause at least one or more landslides. Gabet et al., (2004) modeled the rainfall thresholds for land sliding in the Himalayas of Nepal from erosion model. The model suggested that, for a given hill slope, regolith thickness determines the seasonal rainfall necessary for failure, whereas slope angle controls the daily rainfall required for failure. Some researchers have used approaching storms, subtropical moisture flow and the existence of a warm layer, along with a 4-week antecedent rainfall and the 24-h measured rainfall for threshold calculation (Jakob et al., 2006). Rainfall threshold at a local level is successfully calculated by considering antecedent rainfall. It is well known that it is an important predisposing factor in the activation of slope failures (Wieczorek, 1987). Prolonged rainfall causes saturated zone to develop, with elevated pore-water pressures in the substrate and contributes directly to the occurrence of the landslide (Chen et al., 2006), more particularly deep-seated landslides. The influence of the antecedent rainfall is difficult to quantify as it depends on several factors, including the heterogeneity of soils (strength and hydraulic properties) and the regional climate. Variations in permeability and pore water pressure distribution within two layers can greatly influence the onset of the failure (Lourenco et al., 2006). According to Canuti et al., (1985) and Crozier (1986), the impact of a particular rainy event decreases in time due to drainage processes. In order to consider that effect in rainfall landslide analysis, Canuti et al., (1985) developed an index for sites in Italy that accounts for the calibrated cumulative rainfall. It takes into account the loss of water with preceding days. However, in using antecedent rainfall in threshold estimation, it is very important to select the right number of antecedent days. Aleotti, (2004) considered antecedent periods of 7 and 10 days for threshold calculation. On the contrary, Zezere (2005) showed that for shallow landslide episodes, the 5 days calibrated antecedent rainfall (CAR) was required for the failure and 30 days for deep landslide events. Kim et al., (1992) and Glade, (1997) have demonstrated that, in certain regions, antecedent conditions have a major influence on the initiation of landslides, whereas in other regions, storm characteristics appear to dominate. Alcantara-Ayala, (2004) introduced the concept of rainfall event and cycle and total coefficient, as defined as the ratios between event and antecedent rainfalls, respectively, and the mean annual rainfall, are summed to give a total coefficient. For landslide-triggering rainfalls in the Sierra Norte, he calculated the values for the total coefficient of 0.8 and 0.4 for beginning and end of the wet season, respectively. Chleborad (2006), made a scatter plot between the 3 days precipitation immediately prior to the landslide event and 15 days antecedent precipitation that occurred prior to the 3 days incorporating ideas of antecedent wetness and unusual recent rainfall. From this scatter plot, an approximate lower-bound precipitation threshold was defined. He also computed the probabilities based on the number of days on which one or more landslides occurred and rainfall exceeded the cumulative 3-day/15-day precipitation threshold (CT) all or part of the day at one rain gage. For validation of threshold he carried out an exceedance test. The test indicated that, of the 172 days on which landslides in the database occurred, only 53 percent had CT exceedance. The CT failed to predict 47 percent of days on which landslides occurred. He found that a majority of landslides that occurred below the CT had a reported or identified human influence. Failure to predict greatly decreases if the landslide intensity increases.

Crozier et al., (1999) used frequency-magnitude analysis of rainfall events that resulted into slides for calculating threshold and return period. He stressed to distinguish between first-time failures and reactivations of existing landslides as the first-time failures, in a given material, need to overcome higher material strength values than in the case of reactivations. Remier (1995), for example, has noted that two-thirds of the landslides entering reservoirs are reactivations of existing slides. Giannecchini, (2005) also considered rainfall events that have not resulted in any slides for threshold calculation. He analyzed and divided all 152 main rainfall events which occurred in the southern

Apuan area in the 1975–2002 period, into three groups on the basis of the extents of the effects caused by the rainstorms:
Events A- that induced several shallow landslides and floods;
Events B- that locally induced some shallow landslides and small floods and;
Events C – that has no information about the effects induced.
He used duration/intensity, intensity/Normalised Storm Rainfall (NSR) (Corominas, 2001) and duration/NSR relationships and depicted two threshold curves, which could separate field with different degrees of stability.
Crozier, (1999) and Godt (2006) used model, referred to as the Antecedent Water Status Model, that calculates an index of soil water, by running a daily water balance and applying a soil drainage factor to excess precipitation, over the preceding ten days. Together with the daily rainfall input, the soil water status was used empirically to identify a threshold condition for landslide triggering. Glade, (1997) showed that almost all major slope failures occur at water contents in excess of field moisture capacity, indicating that the development of positive pore water pressures is critical for failure.
An alternative approach employed in some regional climate/landslide research, involves the delimitation of triggering thresholds by using characteristics of the triggering storm such as rainfall intensity and duration (Caine, 1980; Brand et al., 1984; Keefer et al., 1987; Julian and Anthony, 1994; Wilson and Wieczorek, 1995). Wieczorek (1987) studied the intensity-duration characteristics of storms that initiated landslides, and concluded that antecedent rainfall is important in determining ***whether*** landslides would initiate, while rainfall intensity and duration are important in determining ***where*** landslide would occur. This model, though used very frequently, fails to account for those landslides that can occur several hours after the end of the rainfall event, and it also does not take into account site specific rainfall conditions. Besides, this model has certain other limitations. It does not consider the antecedent moisture conditions. For this reason, it is less suited to predict the occurrence of deep-seated landslides or of slope failures triggered by low-intensity rainfall events. Besides, intensity-duration thresholds require data of high quality and resolution (at least hourly rainfall data), which are available only locally.
Once the minimum threshold of rainfall is established, the next important step is to calculate the temporal probability of the event to occur. The most established way to achieve this is the assessment of landslide return times. The return period and probability of such events was computed either directly from frequency analysis or using Poisson/ binomial distribution (Guzzetti et al., 2005) or by using Gumbel distribution (Zezere, 2005), a statistical method that establishes relation between the probability of the occurrence of a certain event, its return period and its magnitude (Gumbel, 1958).
In terms of speed and low cost, the statistical or empirical based approach appears to be more convenient. The main advantage of empirical rainfall thresholds lies in the fact that rainfall is relatively simple and inexpensive to measure over large areas. Where information on landslides and rainfall is available, plots can be prepared and threshold curves can be fitted as lower bounds for the occurrence of slope failures. By incorporating antecedent rainfall and ground water variation (measured from physically based dynamic models in different rainfall scenario), there is a certain scope for improving the predictive quality of the threshold.
Limitations:
Operational limitations for the definition of rainfall thresholds refer mostly to the availability of data of adequate quality, resolution and recording length. During an event, a dense network of recording rain-gauges is required, and immediately after the event a detailed inventory of landslides must be compiled. Many times a single event found to be very intense ("extreme" i.e., with a return period exceeding 100 years) and not representative of the local instability conditions. Thresholds based on such extreme events can underestimate the probability of failures. Hence, a long record of rainfall measurements and many events resulting from different meteorological conditions should be analyzed to define reliable rainfall thresholds. Unfortunately, information on an adequate number of events is seldom available.

Temporal probability of landslide initiation

It is assumed that the probability of occurrences of landslides is directly related to the probability of occurrence of the triggering rainfall: the threshold rainfall. The threshold is the minimum amount of rainfall needed to trigger landslides. The input of the threshold rainfall is the time series of daily rainfall $R_d(t)$, expressed in mm day^{-1}. Theoretically, for a landslide {L} to initiate, the threshold must be exceeded which in turn relates to R(t) by some function:

$$R(t) = f[R_d(t), R_{ad}(t)]$$

where, the function R(t) is the amount of rainfall in a given period (e.g. daily), and $R_{ad}(t)$ is the antecedent rainfall. This function of R defines the probability of occurrence of the landslide L: P{L}. If R_T is the threshold value of R then

$$P[L \mid R > R_T] = 1$$

$$P[L \mid R \leq R_T] = 0$$

Thus, the landslide always occurs when R exceeds R_T and does not occur when value of R is lower than or equal to R_T. In the former case, the probability of occurrences of landslide P{L} depends on the exceedance probability of $P[R > R_T]$.

$$P[L] = P[R > R_T]$$

In reality, however, the threshold may be exceeded without resulting in any landslide. This may be attributed to some other factors which locally influence the initiation of a landslide and are not fully understood (Aleotti and Chowdhury, 1999). This difference can be reduced when the final probability P_N is viewed as the conditional probability of a given threshold exceedance $[P\{R > R_T\}]$ and the probability of occurrence of a landslide [P{L}] given the exceedance (Floris and Bozzano, 2008). Thus, the probability of landslide occurrences can be given by the intersection of two probabilities

$$P\{(R>R_T)\cap L\}=P\{R>R_T\}P\{L \mid R>R_T\}$$

This means that the probability of occurrence of both $\{R > R_T\}$ and {L} is equal to the probability of $\{R > R_T\}$ multiplied by the probability of occurrence of {L}, assuming that $\{R > R_T\}$ has already occurred. The probability of $\{R > R_T\}$ can be obtained by determining the exceedance probability of threshold rainfall and probability of $\{L \mid R>R_T\}$ rely on the frequency of occurrence of landslide after the threshold has been exceeded. The annual exceedance probability (AEP) is the estimated probability that an event of specific magnitude will be exceeded in any year (Fell et al., 2005). The AEP of threshold $[P\{R > R_T\}]$ in a given rain gauge was determined using a Poisson distribution model. This model is extensively used for calculating the exceedance probability of landslides (Coe et al., 2000; Coe et al., 2004; Guzzetti et al., 2005) using landslide frequency estimates. According to the Poisson model, the exceedance probability or the probability of experiencing one or more landslides during time '*t*' is given by

$$P[N(t) \geq 1] = 1 - \exp(-t/\mu)$$

where, μ is the mean recurrence interval between successive landslides, which can be obtained from the multi-temporal landslide inventory data.

To determine the annual exceedance probability of the rainfall threshold for a particular area, the threshold rainfall (R_T) is calculated from the threshold equation and the result is subtracted from the daily rainfall (R). Each phase of continuous positive values ($R>R_T$) is considered as the period of maximum likelihood of landslide initiation and its recurrences are used in the above equation for calculating AEP. Different thresholds can be obtained for rainfall that can trigger a certain number of landslides in a given area.

Selftest

In order to evaluate whether you have understood the concepts that were presented in this session. Please make the following test, and check the answers in Blackboard.

Question: Frequency assessment
Which type of hazard does not have a clear magnitude-frequency relation for a particular location (for example, for a house)?
A) Subsidence due to collapse of underground cavities
B) Earthquakes
C) Floods
D) Rainfall

Question: frequency assessment
What is the most appropriate way for the generation of a magnitude-frequency relation for earthquakes?
A) Use the Gumbel distribution
B) Use the Gutenberg-Richter distribution
C) Use the log-Pearson distribution
D) Use a normal distribution

Question: hazard assessment
Which statement concerning statistical and an expert-based method for hazard assessment is true:
A) A statistical method uses weights derived from the correlation between past hazard events and causal factors, whereas an expert-based method tries to model the process physically.
B) A statistical method tries to model the process physically, whereas an expert-based method uses qualitative weights derived from expert opinion.
C) An expert-based method tries to find a correlation between past hazard events and causal factors, whereas a statistical method tries to model the process physically.
D) A statistical method uses weights derived from the correlation between past hazard events and causal factors, whereas an expert-based method uses qualitative weights derived from expert opinion.

Question: Climate change and risk
Which of the following statements is true? The effects of climate change on risk are expected to be highest in these areas because of:
A) Pacific islands because of changes in local risk of extremes
B) Desert areas because of changes in average climate
C) Desert areas because of changes in local risk of extremes
D) Pacific islands because of changes in average climate

Question: Methods for risk assessment
Which method for risk assessment would you recommend in the following situations (briefly explain why)
A. In case we would like to indicated the areas with the highest social vulnerability, using a hazard footprint map (without having information on return periods) and a database containing the characteristics of the population (age, gender, literacy rate etc.)
B. In case we would have three flood hazard footprints, each one with information on the return period and the water depth/flow velocity of the event, and an element at risk database with building information containing different building types.
C. In case you would have a single hazard map with qualitative classes, and a population density map (also classified into qualitative classes)

Further reading:

For more information about the concept of hazard and disaster reduction strategies, check the publications of the United Nations International Strategies for Disasters Reduction (UN-ISDR) publications: http://www.unisdr.org/eng/about_isdr/bd-isdr-publications.htm.

Other interesting definitions for concepts related to hazard and hazard assessment can be found in Coburn et Al. 1994: http://info.worldbank.org/etools/docs/library/229567/Course%20Content/Reading/Introduction%20Reading%20-%20VulnerabilityAndRiskAssessmentGuide.pdf

If you are interested in deepening your knowledge about FEMA-FIRMs program, read the following document: http://www.pdhonline.org/courses/l129/l129content.pdf.

Information related to the hazard types have been partially extracted from the US FEMA Multi-Hazard Identification and Risk Assessment (MHIRA); for further studies, the entire document can be downloaded here: http://www.fema.gov/library/viewRecord.do?id=2214

Another source of information about hazard types used in writing this guide book is the FEMA Mitigation Planning How-To Guide2, the second guide in the State and Local Mitigation Planning How-To Series: http://www.fema.gov/library/viewRecord.do?id=1880.

The Intergovernmental Panel on Climate Change (IPCC) is the official organization reporting on climate change. They have also made http://www.ipcc.ch/ipccreports/ar4-wg2.htm

The Climate Centre of the IFRC is studying the effects of climate change on disasters and focuses on climate change adaptation. They have produced an interesting summary paper on the effects of climate change: http://www.climatecentre.org/downloads/File/reports/RCRC_climateguide.pdf

Journal papers

Bates, P.D. and De Roo, A.P.J., 2000. A simple raster-based model for flood inundation simulation. Journal of Hydrology, 236(1-2): 54-77.

Coburn, A.W., Sspence, R.J.S. and Pomonis, A., 1994. Vulnerability and Risk Assessment. Cambridge Architectural Research Limited. The Oast House, Cambridge, U.K.

Dankers, R. and Feyen, L., 2008. Climate change impact on flood hazard in Europe: An assessment based on high-resolution climate simulations. J. Geophys. Res., 113.

Demeritt, D. et al., 2007. Ensemble predictions and perceptions of risk, uncertainty, and error in flood forecasting. Environmental Hazards, 7(2): 115-127.

Persson, A. and Grazzini, F., 2007. User Guide to ECMWF forecast products, Shinfield Park (UK).

Van Der Knijff, J. and De Roo, A., 2008. LISFLOOD – distributed water balance and flood simulation model, (Revised User Manual 2008).

•Choice sessions•

The following section consists of five choice sessions:

3L: Landslide hazard
3V: Volcanic hazard
3E: Earthquake hazard
3F: Flood hazard
3C: Coastal hazard

Each of these topics has a separate theory part and a separate exercise. Select one of these five sessions. You are of course free to do more then one session.

Guide book
Choice session 3.L:
Landslide susceptibility and hazard assessment

Objectives

After this session you should be able to:

- Explain impact of landslides;
- Differentiate the types of landslides, and outline the classification method;
- Explain causal factors of landslides;
- Explain the difference between inventory, susceptibility, hazard and risk for landslides
- Understand the spatial data used for landslide hazard assessment, including Remote Sensing
- Explain which method (heuristic, statistical, deterministic) can be best used in which situation;
- Use ILWIS for carrying out a basic landslide susceptibility assessment with statistical and deterministic methods;
- Understand the input needed to use landslide hazard maps in risk assessment;

This session contains the following sections and tasks:

Section	Topic	Task	Time required		
3.L.1	Introduction: showing the impact of landslides		Day 1	0.25 h	0.75 h
		3.L.1: Using World Hotspots data		0.5 h	
3.L.2	Definition and classification of landslides			0.5 h	2 h
		3.L.2: Landslide handbook		1 h	
		3.L.3: Landslide interpretation		0.5 h	
3.L.3	Processes and geomorphological setting		Day 2	0.5 h	1.25 h
		3.L.4:Landslide causes		0.25 h	
		3.L.5: Landslide videos		0.5 h	
3.L.4	Spatial data for landslide hazard assessment			1 h	2.25 h
		3.L.6: Landslide data and methods		0.25 h	
		3.L.7: Using permanent scatterers		0.25 h	
		3.L.8: Landslide inventory mapping and monitoring		0.25 h	
		3.L.9: Costs for event-based landslide maps		0.75 h	
		3.L.10: Prioritizing environmental factors		0.25 h	
3.L.5	Landslide susceptibility assessment		Day 3	1 h	10 h
		3.L.11: RiskCity exercise on statistical landslide susceptibility assessment		5 h	
		3.L.12: RiskCity exercise on deterministic landslide susceptibility assessment	Day 4	4 h	
3.L.6	From Susceptibility to hazard			0.5 h	0.5h
3.L.7	Self test	Selftest that should be submitted		1.25 h	1.25h
		Total			**16.5 h**

The session ends with a test, and the answers of this should be submitted through Blackboard.

3.L.1 Introduction

Landslides are recognized as the third type of natural disaster in terms of worldwide importance. Due to natural conditions or man-made actions, landslides have produced multiple human and economic losses. Inventories conducted between 1964–1999 show a steady increase in the number of landslides disasters worldwide. Individual slope failures are generally not so spectacular or so costly as earthquakes, major floods, hurricanes or some other natural catastrophes. This is illustrated in Table 3.L.1, which shows the statistics of landslides disasters per continent from April 1903 till January 2007 from the Emergency Disaster Database, EM-DAT, (OFDA/CRED, 2007). In this period landslides have caused 57,028 deaths and affected more than 10 million people around the world. The quantification of damage is more than US$5 billion. These losses have driven the politicians and the scientific community to produce disaster risk reduction plans for landslides, which imply first of all landslide risk assessment.

Table 3.L.1 World statistics for landslides. Source: EM-DAT database for the period 1903-2007.

Continents	Events	Killed	Injured	Homeless	Affected	Total Affected	Damage US (000's)
Africa	23	745	56	7,936	13,748	21,740	No data
Americas	145	20,684	4,809	186,752	4,485,037	4,676,598	1,226,927
Asia	255	18,299	3,776	3,825,311	1,647,683	5,476,770	1,534,893
Europe	72	16,758	523	8,625	39,376	48,524	2,487,389
Oceania	16	542	52	18,000	2,963	21,015	2,466
Total	**511**	**57,028**	**9,216**	**4,046,624**	**6,188,807**	**10,244,647**	**5,251,675**

Most of the damage and a considerable proportion of the human losses associated with earthquakes and meteorological events are caused by landslides, although these damages are attributed to the main event, which leads to a substantial underestimation in the available statistical data on landslide impact. This is illustrated in figure 3.L.1 which shows the ruined city of Beichuan in China, destroyed mainly by landslides during the earthquake in 2008. Of the total number of casualties during this earthquake (80000) one third is estimated to have been killed by landslides.

Figure 3.L.1: Illustration of the devastating effects of landslides related to the Wenchuan earthquake in 2008. The city of Beichuan was destroyed by 2 large co-seismic landslides, later on flooded by a landslide dammed lake, and the remains were destroyed later on by debris flows during the first rainy season after the earthquake.

Task 3.L.1: Landslide impact (duration 40 minutes)

The Worldbank has carried out a worldwide study on the impact of landslides and other natural hazard in the so-called Hotspots project. You can see the map results in a WebGIS browser from the following website:
http://geohotspots.worldbank.org/hotspot/hotspots/disaster.jsp
If the WebGIS doesn't work you can also consult the maps on the following website: http://www.ldeo.columbia.edu/chrr/research/hotspots/
Check out the landslide impacts in your country, region. Are these in accordance with your expectations?

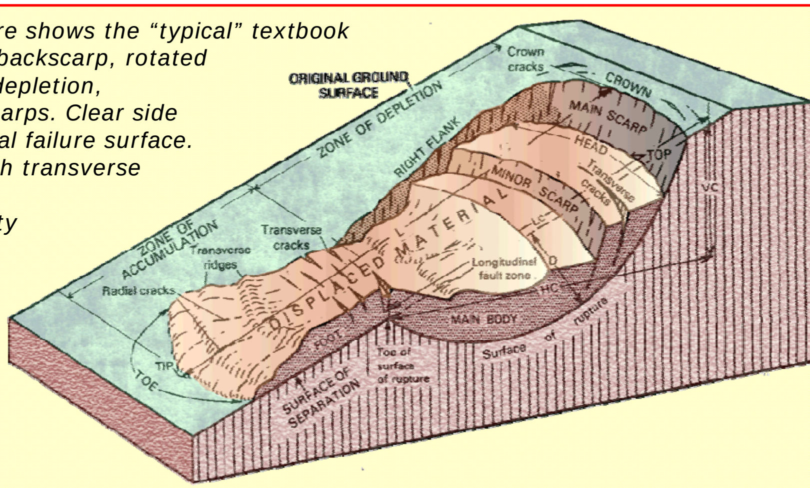
3.L.2 Definition and classification

In literature a wide variety of names have been used for the denudational process whereby soil or rock is displaced along the slope by mainly gravitational forces. The most frequently used are: *Slope movement*; *Mass movement*; *Mass wasting*; *Landslide*. In the last decades *landslide* is the term most used, though in the narrow sense of the word (sensu strictu) it only indicates a specific type of slope movement with a specific composition, form and speed.

Definition.
Landslide is the movement of a mass of rock, debris or earth, down a slope, when shear stress exceeds shear strength of the material.

The most important classification of landslides was made by Varnes in 1978, and is based on a combination of the type of movement and material type. This was adapted in a new classification of Cruden and Varnes (1996). It nominates primarily type of movement, and secondarily type of material. Factors as activity and movement type, and depth can be added as an adjective to the classification name. For example a moderately rapid, shallow, moist, active, single translational soil slide. This classification was adopted by the IAEG Commission UNESCO Working Party on World Landslide Inventory (WP/WLI). Table 3.L.2 gives an overview of the classification, and figure 3.L.2 an illustration of the main features of a landslides

Figure 3.L.2: The figure shows the "typical" textbook landslide with a clear backscarp, rotated blocks in the zone of depletion, separated by minor scarps. Clear side scarps, and a rotational failure surface. Displaced material with transverse cracks in the zone of accumulation. In reality there are many different types and many will not look like this.



The landslide classification displayed in table 3.L.2 is further illustrated with a description of the landslide activity in table 3.L.3, and Figure 3.L.3.

Figure 3.L.3: Illustration of states of activity of a landslide. See table Table 3.L.3 for explanation of the terms

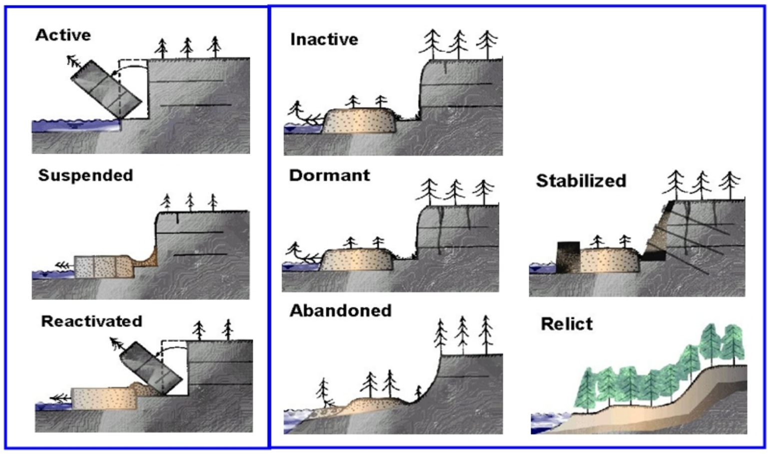


Table 3.L.4 presents examples of the landslide types and the characteristics that can be used to interpret them based on visual image interpretation. Three types of characteristics are shown: morphology, vegetation and drainage characteristics.

		Type of Material		
			Engineering Soils	
Type of Movement		Bedrock	Predominantly Coarse	Predominantly Fine
Fall		Rock Fall	Debris Fall	Earth Fall
Topple		Rock Topple	Debris Topple	Earth Topple
Slide	Rotational	Rock Slump	Debris Slump	Earth Slump
	Translational	Rock Slide / Block slide	Debris Slide	Earth Slide
Spread		Rock Spread	Debris Spread	Earth Spread
Flow		Rock Flow	Debris Flow	Earth Flow
Complex		Combination of Two or More Principal Types of Movement		

Activity		
State	Distribution	Style
Active	Advancing	Complex
Reactivated	Retrogressive	Composite
Suspended	Widening	Multiple
Inactive	Enlarging	Successive
Dormant	Confined	Single
Abandoned	Diminishing	
Stabilized	Moving	
Relict		

Description of Movement			
Rate		Water Content	Depth
Extremely Rapid	m/s	Dry	Very shallow (<2 m)
Very Rapid	m/min	Moist	Shallow (<5 m)
Rapid	m/hr	Wet	Deep (>5 m)
Moderate	m/month	Very Wet	
Slow	m/year		
Very Slow	mm/year		
Extremely Slow	< mm/year		

Table 3.L.2: Classification according to Cruden and Varnes(1996)

	State	Description
Active	Active	currently moving
	Suspended	moved within the last twelve months but is not active at present
	Re-activated	active landslide that has been inactive
Inactive: not moved within the last twelve months	Dormant	inactive landslide that can be reactivated by its original causes or other causes
	Abandoned	inactive landslide that is no longer affected by its original causes
	Stabilized	inactive landslide that has been protected from its original causes by artificial remedial measures
	Relict	inactive landslide that developed under geomorphological or climatic conditions considerably different from those at present

Distribution	Description
Advancing	the rupture surface is extending in the direction of the movement
Retrogressive	the rupture surface is extending in the direction opposite to the movement of the displaced material
Enlarging	the rupture surface of the landslide is extending in two or more directions
Diminishing	the volume of the displacing material is decreasing
Confined	there is a scarp but no rupture surface is visible at the foot of the displaced mass
Moving	the displaced material continues to move without any visible change in the rupture surface and the volume of the displaced material
Widening	the rupture surface is extending into one or both flanks of the landslide

Table 3.L.3: Landslide activity states and distribution.

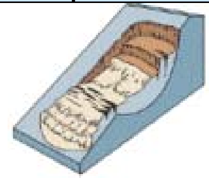
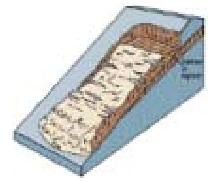
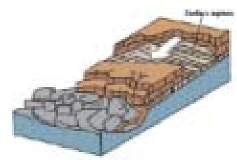
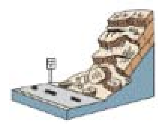
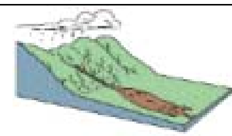
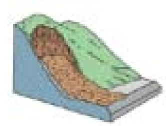
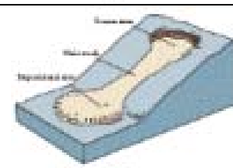
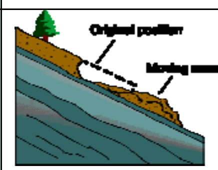
Type	Characteristics	Example
Rotational Slide	**Morphology:** Abrupt changes in slope morphology, characterized by concave (niche) - convex (run-out lobe) forms. Often step-like slopes. Semi-lunar crown and lobate frontal part. Backtilting slope facets, scarps, hummocky morphology on depositional part. D/L ratio 0.3 - 0.1 , **Vegetation:** Clear vegetational contrast with surroundings, the absence of landuse indicative for activity. Differential vegetation according to drainage conditions. **Drainage:** Contrast with not failed slopes. Bad surface drainage or ponding in niches or backtilting areas. Seepage in frontal part of run-out lobe.	
Translational slide	**Morphology:** Joint controlled crown in rockslides, smooth planar slip surface. Relatively shallow, certainly in surface mat. over bedrock. D/L ratio <0.1 and large width. Run-out hummocky rather chaotic relief, with block size decreasing with larger distance. **Vegetation:** Source area and transportational path denudated, often with lineations in transportational direction. Differential vegetation on body, in rockslides no landuse on body. **Drainage:** Absence of ponding below the crown, disordered or absence of surface drainage on the body. Streams are deflected or blocked by frontal lobe.	
Rock Block slide	**Morphology:** Joint controlled crown in rockslides, smooth planar slip surface. Relatively shallow, certainly in surface mat. over bedrock. D/L ratio <0.1 and large width. Run-out hummocky rather chaotic relief, with block size decreasing with larger distance. **Vegetation:** Source area and transportational path denudated, often with lineations in transportational direction. Differential vegetation on body, in rockslides no landuse on body. **Drainage:** Absence of ponding below the crown, disordered or absence of surface drainage on the body. Streams are deflected or blocked by frontal lobe	
Rockfall	**Morphology:** Distinct rockwall or free face in association with scree slopes (20 -30 degrees) and dejection cones. Jointed rock wall (>50 degrees) with fall chutes. **Vegetation:** Linear scars in vegetation along frequent rock fall paths. Vegetation density low on active scree slopes. **Drainage:** No specific characteristics.	
Debrisflow	**Morphology:** Extensive coverage of materials with high content of mud and boulders in a fan shaped form, either deposited on alluvial fans at the outlet of valleys, or on the foot of a slope. **Vegetation:** absence of vegetation everywhere; sometimes large trees still stand and are engulfed in flow, or tree stumps still there. **Drainage:** disturbed on body; original streams blocked or deflected by flow.	
Debris avalanche	**Morphology:** relatively small, shallow niches on steep slope (>35 degrees) with clear linear path; body frequently absent as it eroded away by stream **Vegetation:** Niche and path are denuded or covered by secondary vegetation. **Drainage:** Shallow linear gully can originate on path of debris aval.	
Earthflow	**Morphology:** One large or several smaller concavities, with hummocky relief in the source area. Main scars and several small scars resembles slide type of failure. Path following streamchannel and body is infilling valley, contrasting with V shaped valleys. Lobate convex frontal part. Irregular micromorphology with pattern related to flow- structures. D/L ratio very small **Vegetation:** Vegetational on scar and body strongly contrasting with surroundings, landuse absent if active. Linear pattern in direction of flow. **Drainage:** Ponding frequent in concave upper part of flow. Parallel drainage channels on both sides of the body in the valley. Deflected or blocked drainage by frontal lobe.	
Flowslide	**Morphology:** Large bowlshaped source area with step-like or hummocky internal relief. Relative great width. Body displays clear flowstructures with lobate convex frontal part (as earthflow). Frequent associated with cliffs (weak rock) or terrace edges. **Vegetation:** Vegetational pattern are enhancing morphology of scarps and blocks in source area. Highly disturbed and differential vegetation on body. **Drainage:** As on earthflows, ponding or deranged drainage at the rear part and deflected or blocked drainage by frontal lobe.	

Table 3.L.4: Main landslide types and characteristics as can be observed from image interpretation.

Task 3.L.2: Landslide information (duration 60 minutes)
Download the landslide handbook published by USGS and CGS: Highland, L.M., and Bobrowsky, Peter, 2008, The landslide handbook—A guide to understanding landslides: Reston, Virginia, U.S. Geological Survey Circular 1325, 129 p. Link: http://pubs.usgs.gov/circ/1325/

Interpreting landslides through visual image interpretation

The characteristics indicated in the table before cannot all be directly interpreted from image interpretation. Also in the field it is sometimes difficult to determine these afterwards. Therefore, when doing image interpretation often a simplified checklist is used which is illustrated in figure 3.L.4. A simplified checklist that can be used in image interpretation is given below. The figure also shows an example of a landslide and the way it is interpreted using polygons with identifiers and an associated attribute table.

Figure 3.L.4: Example of the use of a simple checklist used in image interpretation.

Interpreted image

Checklist for landslide interpretation

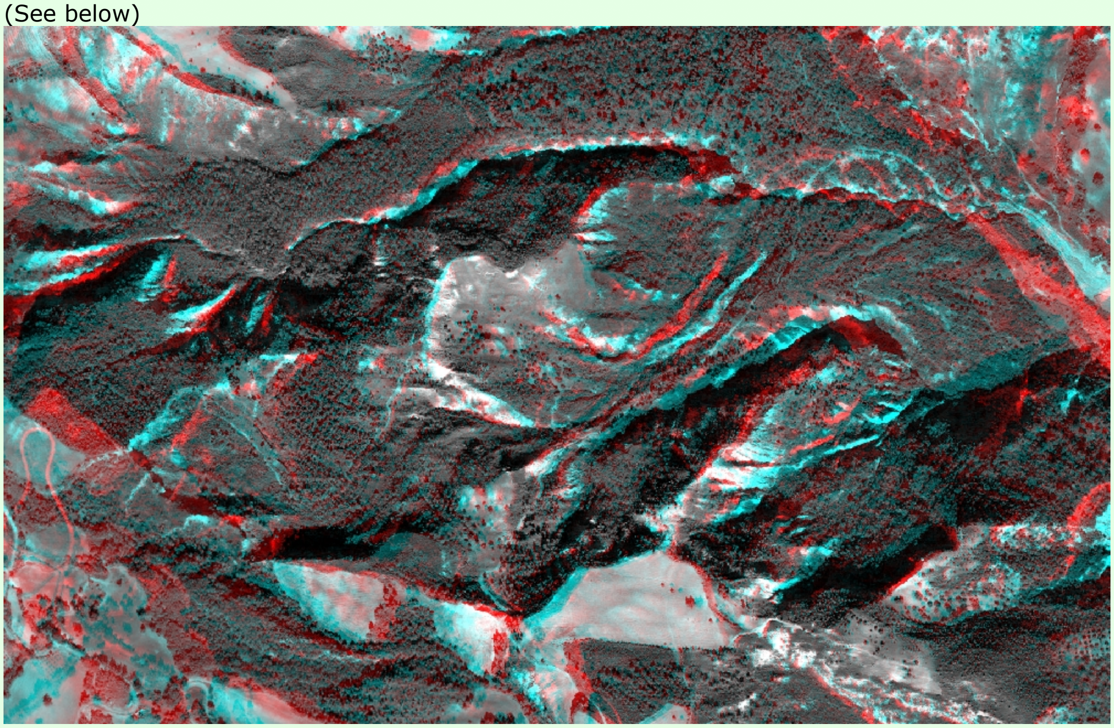
Type	Subtype	Activity	Depth	Body
Fall Topple Slide Spread Flow	Rotational Translational Complex Unknown	Stable Dormant Active	Surficial Deep	Scarp Body

Attribute table linked to interpreted image

Slide	Part	Type	Subtype	Activity	Depth	Body
001	01	Slide	Rotational	Active	Deep	Body
001	02	Slide	Rotational	Active	Deep	Scarp

Task 3.L.3: Landslide interpretation (duration 30 minutes)

Below you see an anaglyph image of a landslide area in Italy. Use the red-blue glasses provided to you for the course and interpret the landslides. Try to use the same approach as indicated in the figure above. Map a few landslides in this way, and describe their characteristics in a table (See below)

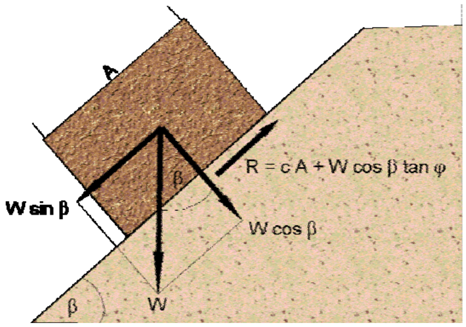


Slide	Part	Type	Subtype	Activity	Depth	Body

3.L.3 Processes and geomorphological setting

The occurrence of landslides is the consequence of a complex field of forces (stress is a force per unit area) that is active on a mass of rock or soil on the slope.

Figure 3.L.5: Forces involved in mass movement.



A = Shear surface [m2];
W = Gravitational force [N];
Wsinβ/A = shear stress [KPa=kN/m2];
s = c + σ tan ϕ : Shear strength
σ = normal stress = W cos β / A
c = cohesion (KPa)
ϕ = angle of internal friction (degrees)

The relationship $s = c + \sigma \tan \phi$ *is what is called the Mohr-Coulomb relationship*
The degree of slope hazard can be expressed by the Safety Factor (F) which is the ratio of the forces that make a slope fail and those that prevent a slope from failing. This is shown in the equation below.

$$F = \frac{cA + W \cos \beta \tan \phi}{W \sin \beta}$$

F < 1 unstable slope conditions,
F = 1 slope is at the point of failure,
F > 1 stable slope conditions.

This is the very basic equation, which doesn't take many additional factors into account such as the effect of soil moisture, groundwater table, differences in material types, and seismic acceleration. Basically, slopes become unstable when one of the two components changes, as shown in table 3.L.5.

Table 3.L.5: Major contributing factors to instability.

Increase of shear stress	**Decrease of material strength**
Removal of lateral and underlying support (erosion, previous slides, movement of adjacent areas, road cuts and quarries)	A decrease of material strength (weathering, change in state of consistency)
An increase of load (weight of rain/snow, fills, vegetation, buildings)	Changes in intergranular forces (pore water pressure, solution)
An increase of lateral pressures (hydraulic pressures, roots, crystallization, swelling of clay)	Changes in material structure (decrease of the strength of the failure plane, fracturing due to unloading)
Transitory stresses (earthquakes, vibrations of trucks, machinery, blasting)	
Regional tilting (geological movements)	

The overall component of forces, linked with slope morphology and geotechnical parameters of the material, defines the specific type of landslide that may occur.
The potential causes of landslide can be subdivided into geological causes, morphological causes, physical causes, and human causes. Landslides can also be seen as controlled by **internal factors** that make the slope favourable to instability and **triggering factors** that actually trigger the landslide to happen.

Task 3.L.4: Landslide causes (duration 15 minutes)

Mention some examples of landslide causes?
Differentiate between internal factors and triggering factors.

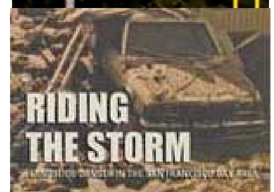
In this section also some examples are given of landslides together will illustrations and videos. The videos can be seen on Youtube, but are also available on the course DVD.

Introduction to landslides

This is a National Geographic movie which give a good introduction into landslides and the factors that cause them.
http://www.youtube.com/watch?v=mknStAMia0Q&NR=1

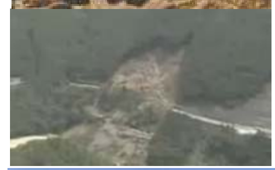
Riding the storm

This is a video by the USGS explaining the landslide problems in the San Francisco Bay region, with examples of how landslides affect the daily lives of the inhabitants of the region. A short version can be seen at: http://www.youtube.com/watch?v=2-e2JjktQ6A You can download the full version of the movie at: http://landslides.usgs.gov/learning/movie/



Translational landslide example from Japan

This is an example of a translational landslide, which was predicted to occur. That is why video teams were able to film the event. From this movie the movement of the landslide as if displaced along a conveyor belt is very striking.
http://www.youtube.com/watch?v=ManGanavlL8



Landslides and debrisflows in Sarno, Italy

On May 5 1998 a series of landslides were triggered due to heavy rainfall in pyroclastic deposits in the province of Avellino and Salerno in the Campania region of Southern Italy. The landslides turned into a series of debrisflows, which hit number of towns in the area, especially the town of Quindici, causing around 140 casualties.
http://www.youtube.com/watch?v=7iZzNL1VUWU&feature=related

SLIDE

A very nice internet site with videos on various landslides from British Columbia in Canada. It uses Flash player, and you need a fairly high speed internet connection to view it. It also contains a summary of information on the tools to investigate landslides (Geologist's tool). Other sections are on landslide types and on planning and safety.
http://www.knowledgenetwork.ca/slide/

Wikipedia on landslides

Find out what Wikipedia has on landslide, in particular related to historical landslides. Check out the website: http://en.wikipedia.org/wiki/Landslide

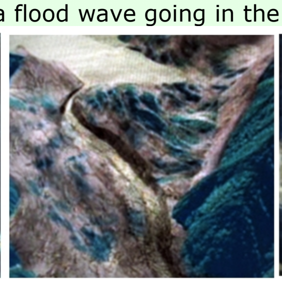
Massive landslide causing lake breakout in Malaysia.

http://www.youtube.com/watch?v=H6Ma0SVjMHA&feature=related

Task 3.L.5: Landslide examples (duration 30 minutes)
Check out the landslide videos by following the indicated links above.
Find also other landslide related videos.
You can also find several related landslide videos on the DVD of the course, in:
Background materials\session 03\ landslides
The following videos are there:

- Debrisflows and landslides in Japan
- Rockfall and landslides in the US
- Rock avalanche in Italy
- Simulation of an earthquake induced landslide causing damming of a river, followed by a break of the dam and a flood wave going in the downstream area.


Earthquake induced landslide damming the river


Landslide dam eroded and broken causing flood wave


Massive flooding in downstream area

3.L.4. Spatial data for landslide hazard assessment

The first extensive papers on the use of spatial information in a digital context for landslide susceptibility mapping date back to the late seventies and early eighties of the last century. Nowadays, practically all research on landslide susceptibility and hazard mapping makes use of digital tools for handling spatial data such as GIS, GPS and Remote Sensing. These tools also have defined, to a large extent, the type of analysis that can be carried out. It can be stated that GIS has determined, to a certain degree, the current state of the art in landslide hazard and risk assessment. Figure 3.L.6 gives a schematic overview of the various components of landslide risk assessment.

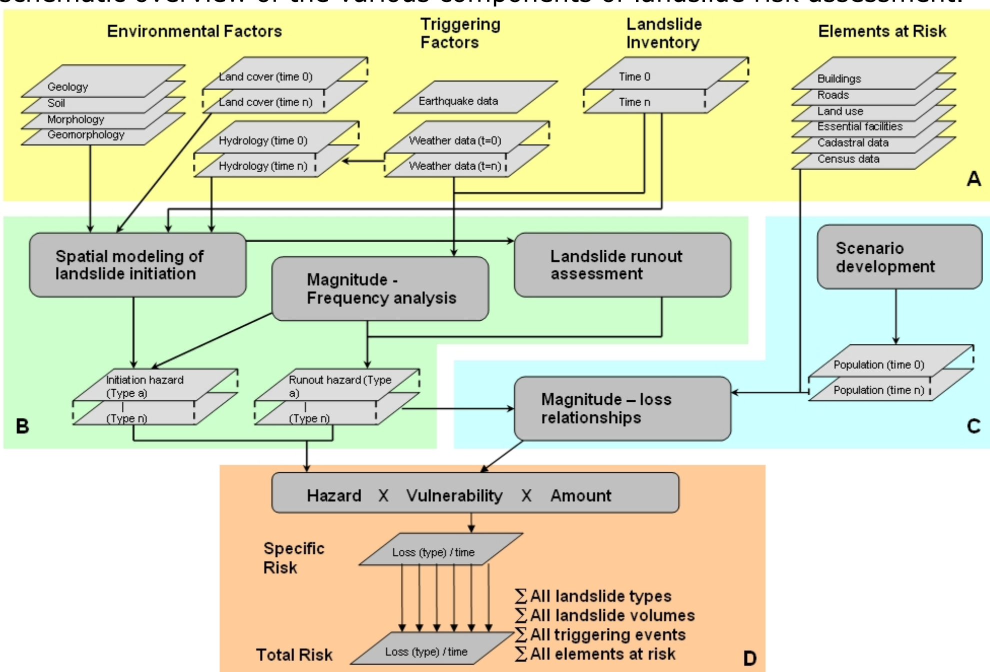


Figure 3.L.6: Schematic representation of the landslide risk assessment procedure. A: Basic data sets required, both of static, as well as dynamic (indicated with "time…") nature, B: Susceptibility and hazard modeling component, C: Vulnerability assessment component, D: Risk assessment component, E: Total risk calculation in the form of a risk curve. See text for further explanation

Table 3.L.7 gives a schematic overview of the main data layers required for landslide susceptibility, hazard and risk assessment (indicated in the upper row of Figure 3.L.6). These can be subdivided into four groups: landslide inventory data, environmental factors, triggering factors, and elements at risk. Of these, the landslide inventory is by far the most important, as it should give insight into the location of landslide phenomena, the types, failure mechanisms, causal factors, frequency of occurrence, volumes and the damage that has been caused. Landslide inventory databases should display information on landslide activity, and therefore require multi-temporal landslide information over larger regions. The environmental factors are a collection of data layers that are expected to have an effect on the occurrence of landslides, and can be utilized as causal factors in the prediction of future landslides. The list of environmental factors indicated in figure 3.L.7 is not exhaustive, and it is important to make a selection of the specific factors that are related to the landslide types and failure mechanisms in each particular environment. It is not possible to give a prescribed uniform list of causal factors. The selection of causal factors differs, depending on the scale of analysis, the characteristics of the study area, the landslide type, and the failure mechanisms. The basic data can be subdivided into those that are more or less static, and those that are dynamic and need to be updated regularly (See figure 3.L.7). Examples of static data sets are related to geology, soil types, geomorphology and morphography. The time frame for the updating of dynamic data may range from hours to days, for example for meteorological data and its effect on slope hydrology, to months and years for land use

and population data (see figure 3.L.7). Landslide information needs to be updated continuously, and land use and elements at risk data need to have an update frequency which may range from 1 to 10 years, depending on the dynamics of land use change in an area. Especially the land use information should be evaluated with care, as this is both an environmental factor, which determines the occurrence of new landslides, as well as an element at risk, which may be affected by landslides.

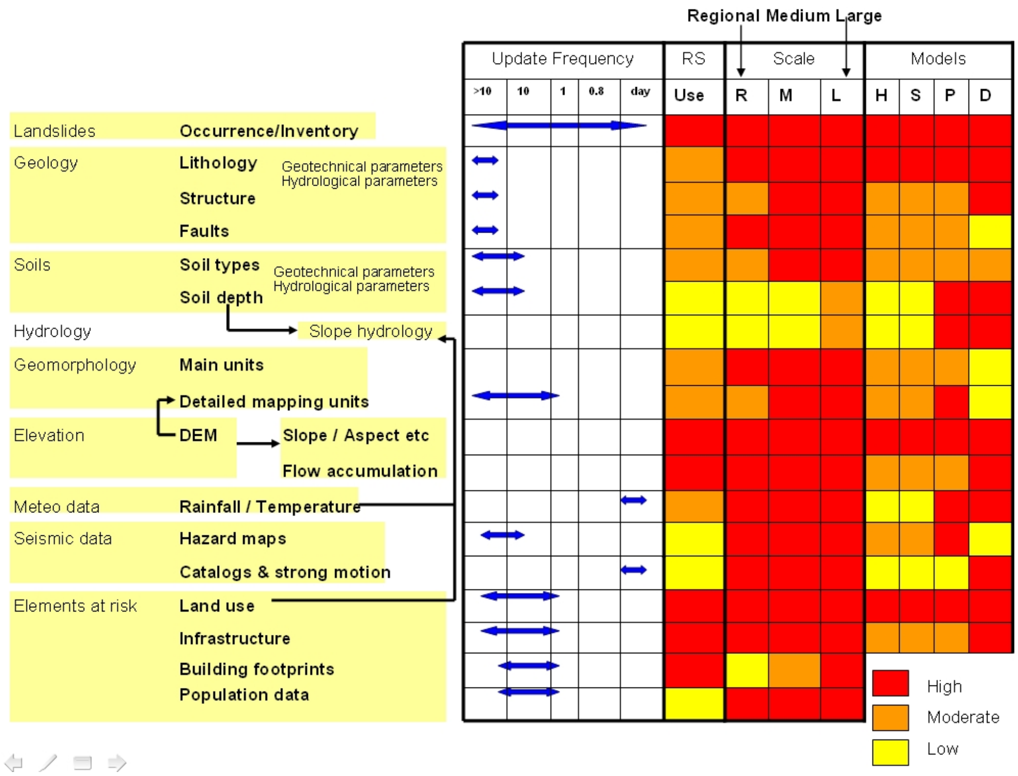


*Figure 3.L.7: Schematic representation of basic data sets for landslide susceptibility, hazard and risk assessment. **Left**: indication of the main types of data, **Middle**: indication of the ideal update frequency, **RS**: column indicating the usefulness of Remote Sensing for the acquisition of the data, **Scale**: indication of the importance of the data layer at small, medium, large and detailed scales, related with the feasibility of obtaining the data at that particular scale, **Hazard models**: indication of the importance of the data set for heuristic models (H), statistical models (S), deterministic models (D), and probabilistic models (P)*

Figure 3.L.7 also gives an indication of the extent to which remote sensing data can be utilized to generate the various data layers. For a number of data layers the main emphasis in data acquisition is on field mapping, field measurements or laboratory analysis, and remote sensing imagery is only of secondary importance. This is particularly the case for the geological, geomorphological, and soil data layers. The soil depth and slope hydrology information, which are very important in physical modeling of slope stability are also the most difficult to obtain, and remote sensing has not proven to be a very important tool for these. On the other hand, however, there are also data layers for which remote sensing data can be the main source of information. This is particularly so for landslide inventories, digital elevation models, and land use maps.

Task 3.L.6: Landslide data and methods (duration 15 minutes)
If you look closely to figure 3.3.L.7

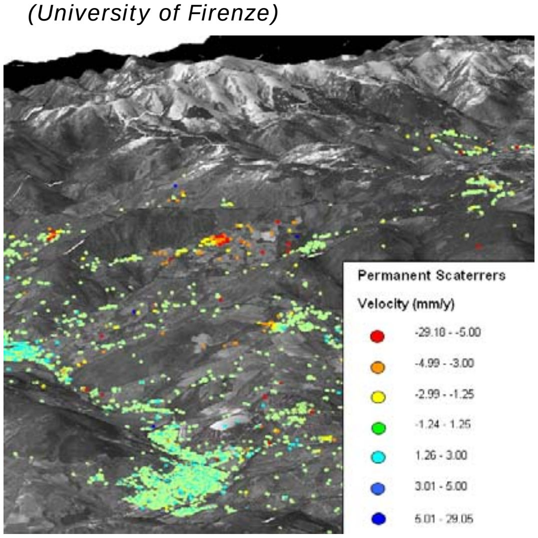
- What is the update frequency of slope hydrology information?
- what do you think will be the most limiting datatypes for the application of Deterministic methods (D) in medium and small scales ?

Landslide inventory mapping

For visual interpretation of landslides, stereoscopic imagery with a high to very high resolution is required. Optical images with resolutions larger than 3 meters (e.g. SPOT, LANDSAT, ASTER, IRS-1D), as well as SAR images (RADARSAT, ERS, JERS, ENVISAT) have proven to be useful for visual interpretation of large landslides in individual cases, but not for landslide mapping on the basis of landform analysis over large areas. Very high resolution imagery (QuickBird, IKONOS, CARTOSAT-1, CARTOSAT-2) has become the best option now for landslide mapping from satellite images. Figure 3.L.8 gives an example of the use of different types of imagery for landslide mapping in RickCity. Another interesting development is the visual interpretation of landslide phenomena from shaded relief images produced from LiDAR DEMs, from which the objects on the earth surface have been removed; so called bare earth DEMs. The use of shaded relief images of LiDAR DEMs also allows a much more detailed interpretation of the landslide mechanism as the deformation features within the large landslide are visible, and landslide can be mapped in heavily forested areas. However, in practice, aerial photo interpretation still remains the most used technique for landslide mapping.

Automated landslide mapping from satellite images has only proven to be possible for recent landslides, with unvegetated scars, e.g. using multi-spectral images such as SPOT, LANDSAT, ASTER and IRS-1D LISS3. Many methods for landslide mapping make use of digital elevation models of the same area from two different periods. The subtraction of the DEMs allows visualizing where displacement due to landslides has taken place, and the quantification of displacement volumes. Satellite derived DEMS from SRTM, ASTER and SPOT do not provide sufficient accuracy, but high resolution data from Quickbird, IKONOS, PRISM (ALOS) and CARTOSAT-1 are able to produce highly accurate DEMs that might be useful in automatic detection of large and moderately large landslides. Light Detection and Ranging (LiDAR) or laser scanning can provide high resolution topographic information (<1 m horizontal and a few cm vertical accuracy), depending on the flying height, point spacing and type of terrain, and may be as low as 100 cm in difficult terrain. Interferometric Synthetic Aperture Radar (InSAR) has been used extensively for measuring surface displacements. Unfortunately, in most environments InSAR applications are limited by problems related to geometric noise due to the different look angles of the two satellite passes and temporal de-correlation of the signal due to scattering characteristics of vegetation, as well as by atmospheric variability in space and time. To overcome these problems, the technique of Persistent Scatterer Interferometry (PSI), or Permanent Scatterers was introduced that uses a large number of radar images and works as a time series analysis for a number of fixed points in the terrain with stable phase behavior over time, such as rocks or buildings.

Figure 3.L.8: Results of a study on landslide displacements using permanent scatterers. (University of Firenze)



Task 3.L.7: Landslide applications from permanent scatterers (duration 15 minutes)

If you look closely to figure 3.3.L.8. The displacement information using this technique can only be done for objects like buildings and large rock blocks.

- How could you use this kind of information for landslide hazard assessment?
- What are the limitations of this technique, if you want to apply this in your own country?

Table 3.L.6: Overview of techniques for the collection of landslide information. Indicated is the applicability of each technique for regional (R), medium (M), large (L) and detailed (D) mapping scales. (H= highly applicable, M= moderately applicable, and L= Less applicable)

Group	Technique	Description	Scale			
			R	M	L	D
Image interpretation	Stereo aerial photographs	Analog format or digital image interpretation with single or multi-temporal data set	M	H	H	H
	High Resolution satellite images	With monoscopic or stereoscopic images, and single or multi-temporal data set	M	H	H	H
	LiDAR shaded relief maps	Single or multi-temporal data set from bare earth model.	L	M	H	H
	Radar images	Single data set	L	M	M	M
(Semi) automated classification : spectral characteristics	Aerial photographs	Image ratioing, thresholding	M	H	H	H
	Medium resolution multi spectral images	Single data images, with pixel based image classification or image segmentation	H	H	H	M
		Multiple date images, with pixel based image classification or image segmentation	H	H	H	M
	Using combinations of optical and radar	Either use image fusion techniques or multi-sensor image classification, either pixel based or object based	M	M	M	M
(Semi) automated classification : altitude characteristics	InSAR	Radar Interferometry for information over larger areas	M	M	M	M
		Permanent scatterers for pointwise displacement data	H	H	H	H
	LiDAR	Overlaying of LiDAR DEMs from different periods	L	L	M	H
	Photogrammetry	Overlaying of DEMs from airphotos or high resolution satellite images for different periods	L	M	H	H
Field investigation methods	Field mapping	Conventional method	M	H	H	H
		Using Mobile GIS and GPS for attribute data collection	L	H	H	H
	Interviews	Using questionnaires, workshops etc.	L	M	H	H
Archive studies	Newspaper archives	Historic study of newspaper, books and other archives	H	H	H	H
	Road maintenance organizations	Relate maintenance information along linear features with possible cause by landslides	L	M	H	H
	Fire brigade/police	Extracting landslide occurrence from logbooks	L	M	H	H
Dating methods for landslides	Direct dating	Dendrochronology, radiocarbon dating etc.	L	L	L	M
	Indirect dating	Pollen analysis, lichenometry, other indirect methods,	L	L	L	L
Monitoring networks	Extensometer etc.	Continuous movement velocity using extensometers, surface tiltmeters, inclinometers, piezometers	-	-	L	H
	EDM	Network of Electronic Distance Measurements	-	-	L	H
	GPS	Network of Differential GPS measurements	-	-	L	H
	Total stations	Network of theodolite measurements	-	-	L	H
	Groundbased InSAR	Using ground-based radar with slide rail	-	-	L	H
	Terrestrial LiDAR	Using terrestrial laser scanning, repeated regularly	-	-	L	H

Task 3.L.8: Landslide inventory mapping and monitoring (duration 15 minutes)

If you look closely to the table 3.3.L.6. Which method of landslide mapping would you recommend in the following cases?

- Mapping old landslides that are covered by forest.
- Fast mapping of hundreds of landslides caused by a hurricane in remote and inaccessible areas?
- Monitoring the movements of a town that is built on a slow moving landslide?
- Regular mapping of an area of 1000 km2 for landslide hazard assessment?

The techniques described above are intended to support the generation of landslide databases. The difficulties involved in obtaining a complete landslide database, and its implications for landslide hazard assessment are illustrated in Figure 3.L.9, with a graph indicating a hypothetical landslide frequency in the period 1960-2006, and the main triggering events (either earthquakes or rainfall events) with the return period indicated. For the area, five different sets of imagery are available (indicated in Figure 3.L.9 with A to E). In order to be able to capture those landslides related with a particular triggering event, it is important to be able to map these as soon as possible after the event occurred. For example the imagery of C and E can be used to map the landslides triggered by rainfall events with different return periods. The imagery of B and D however, are taken either some time after the triggering event has occurred, so that landslide scarps will be covered by vegetation and are difficult to interpret, or they occur after a sequence of different triggering mechanisms, which would make it difficult to separate the landslide distributions. This is also illustrated for the Tegucigalpa area in figure 2, where the landslide inventory of past events is limited by the availability of historical imagery. For instance, if image C in figure 2 (taken directly after the occurrence of Hurricane Mitch) would not have been available, it would have been very difficult to identify the landslide type and mechanism on the later imagery (e.g. D).

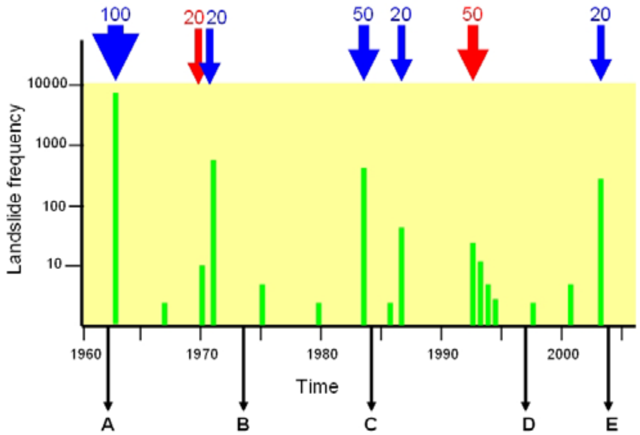


Figure 3.L.9: Schematic presentation of landslide frequency in relation to triggering events and dates of imagery. On top of the graph the rainfall events (in black) and earthquakes (in gray) are indicated as arrows, with an indication of their return periods. The black arrows below the graph (A to E) refer to dates of available remote sensing imagery for landslide inventory mapping.

Task 3.L.9: Costs for event-based landslide maps (duration 45 minutes)

Suppose you wouldn't have any of the sets of data (A to E) as indicated in the graph above. Your study area is 100 km^2. You would have a budget of 50,000 Dollars. Buying Ikonos images costs you 1435 Dollars per image. One IKONOS covers 62 km^2. Buying aerial photo's at 1:10.000 scale costs you 20 $ each. One airophoto is 23*23 cm. Buying ASTER data costs you 60 Dollars per image, and one ASTER image covers 500 km^2. For stereo you need 50 percent overlap, so basically twice as many images. Suppose the mapping department has many flights available, say every even year.

- What is the cost for having a full coverage of the area for one set of airphotos and for one set of Quickbird images? Make the calculation in a spreadsheet.
- How would you spend your budget optimally in order to get the best information on the temporal occurrence of landslide in relation with return periods of rainfall and earthquakes?
- How many acquisitions could you do if you would include interpreter costs (2.5 hour/photo and 5/image at 20 $/hour) ?

This is based on the paper Nichol, J.E., Shaker, A. and Man-Sing Wong, Application of high-resolution stereo satellite images to detailed landslide hazard assessment. Geomorphology 76 (2006) 68– 75
You can use the set-up for the Excel sheet as indicated below.
The results can be found in an Excel sheet on Blackboard after 1 day.

Landslide hazard						
Task	3.3.L.9					
Budget	50000	Dollars				
Size of study area	1000	km2				
Only acquisition						
Airphotos			Quickbird images		Aster images	
Airphoto scale			Size of image		Size of image	
1 cm is equal to		km				
23 cm is equal to		km				
1 photo area		km2				
photos no stereo		nr	images no stereo		images no stereo	
photos with stereo		nr	images stereo		images stereo	
Costs per photo		Dollars	Cost per image		Cost per image	
Costs per flight			Cost for 1 time		Cost for 1 time	
Possible acuisitions			Possible acquisitions		Possible acquisitions	
With interpretation						
Airphotos			Quickbird images		Aster images	
time for 1 photo		hours	time per image		time per image	
total time for interpretation			total time for interpretation		total time for interpretation	
Cost per hour		dollars	Cost per hour		Cost per hour	
Interpretation costs		dollars	Interpretation costs		Interpretation costs	
Total costs			Total costs		Total costs	
Possible acuisitions			Possible acquisitions		Possible acquisitions	

Environmental factors

As indicated in Figure 3.L.7, the next block of spatial information required for landslide susceptibility, hazard and risk assessment consists of the spatial representation of the factors that are considered relevant for the prediction of the occurrence of future landslides. Table 3.L.7 provides more details on the relevance of these factors for heuristic, statistical and deterministic analysis. It is clear from this table that the three types of analysis use different types of data, although they share also common ones, such as slope gradient, soil and rock types, and land use types. The selection of the environmental factors that are used in the susceptibility assessment depends on the type of landslide, the type of terrain and the availability of existing data and resources. A good understanding of the different failure mechanisms is essential. Often different combinations of environmental factors should be used, resulting in separate landslide susceptibility maps for each failure mechanism.

Table 3.L.7: Overview of environmental factors, and their relevance for landslide susceptibility and hazard assessment. (H= highly applicable, M= moderately applicable, and L= Less applicable).

Group	Data layer and types	Relevance for landslide susceptibility and hazard assessment	Scales of analysis			
			R	M	L	D
Digital Elevation Models	Slope gradient	Most important factor in gravitational movements	L	H	H	H
	Slope direction	Might reflect differences in soil moisture and vegetation	H	H	H	H
	Slope length/shape	Indicator for slope hydrology	M	H	H	H
	Flow direction	Used in slope hydrological modeling	L	M	H	H
	Flow accumulation	Used in slope hydrological modeling	L	M	H	H
	Internal relief	In small scale assessment as indicator for type of terrain.	H	M	L	L
	Drainage density	In small scale assessment as indicator for type of terrain.	H	M	L	L
Geology	Rock types	Based on engineering properties on rock types	H	H	H	H
	Weathering	Depth of profile is an important factor	L	M	H	H
	Discontinuities	Discontinuity sets and characteristics	L	M	H	H
	Structural aspects	Geological structure in relation with slope angle/direction	H	H	H	H
	Faults	Distance from active faults or width of fault zones	H	H	H	H
Soils	Soil types	Engineering soils with genetic or geotechnical properties	M	H	H	H
	Soil depth	Soil depth based on boreholes, geophysics and outcrops	L	M	H	H
	Geotechnical prop.	Grainsize, cohesion, friction angle, bulk density	L	M	H	H
	Hydrological prop.	Pore volume, saturated conductivity, PF curve	L	M	H	H
Hydrology	Water table	Spatially and temporal depth to ground water table	L	L	M	H
	Soil moisture	Spatially and temporal soil moisture content	L	L	M	H
	Hydrologic components	Interception, Evapotranspiration, throughfall, overland flow, infiltration, percolation etc.	M	H	H	H
	Stream network	Buffer zones around streams	H	H	H	L
Geomorpho -logy	Physiographic units	First subdivision of the terrain in zones	H	M	L	L
	Terrain Mapping Units	Homogeneous units of lithology, morphography and processes	H	M	L	L
	Geomorpholy	Genetic classification of main landform building processes	H	H	M	L
	Slope facets	Geomorphological subdivision of terrain in slope facets	H	H	H	L
Landuse	Land use map	Type of land use/ land cover	H	H	H	H
	Land use changes	Temporal varying land use/ land cover	M	H	H	H
	Vegetation	Type, canopy cover, rooting depth, root cohesion, weight	L	M	H	H
	Roads	Buffers around roads in sloping areas with road cuts	M	H	H	H
	Buildings	Slope cuts made for building construction	M	H	H	H

Task 3.L.10: Prioritizing environmental factors (duration 30 minutes)

1. *Select a scale of analysis (Regional, medium, small, detailed)*
2. *Make a ranking of the 15 most important factors for that scale*

3.L.5. Landslide susceptibility assessment

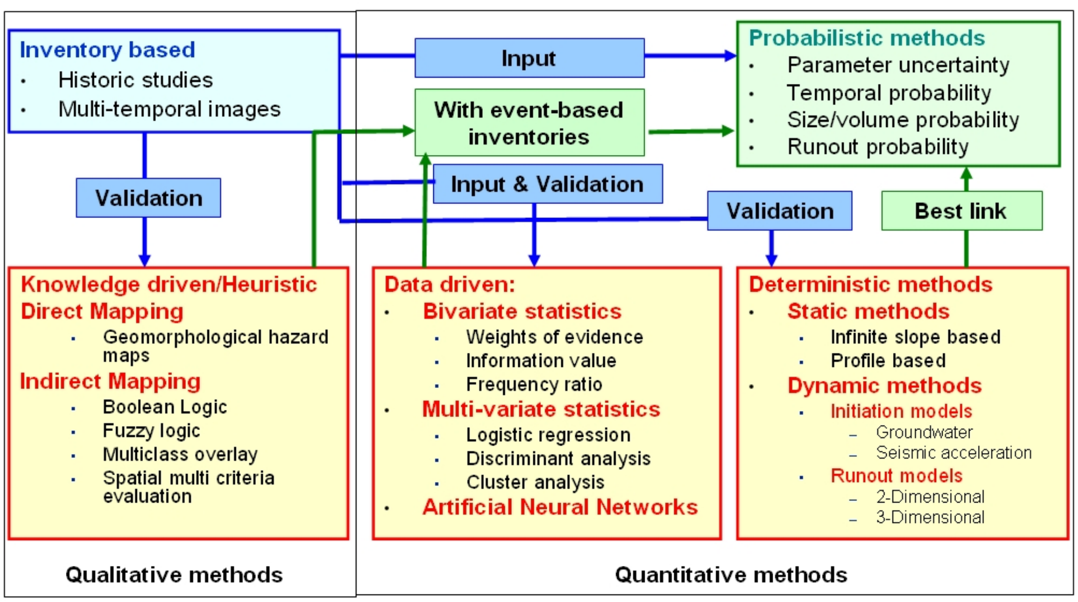
There is a clear difference between landslide susceptibility and hazard assessment, as given by the following definitions (from Fell et al, 2008):

Landslide Susceptibility: the classification, volume (or area), and spatial distribution of landslides which exist or potentially may occur in an area. Susceptibility may also include a description of the velocity and intensity of the existing or potential landsliding.
This looks basically at the relative spatial likelihood of landslide occurrence.
Landslide Hazard: A condition with the potential for causing an undesirable consequence. The description of landslide hazard should include the location, volume (or area), classification and velocity of the potential landslides and any resultant detached material, and the likelihood of their occurrence within a given period of time. Landslide hazard includes landslides which have their source in the area, or may have their source outside the area but may travel onto or regress into the area.
A complete quantitative landslide hazard assessment includes:

- **spatial probability**: the probability that a given area is hit by a landslide
- **temporal probability**: the probability that a given triggering event will cause landslides
- **size/volume probability**: probability that the slide has a given size/volume
- **runout probability**: probability that the slide will reach a certain distance downslope.

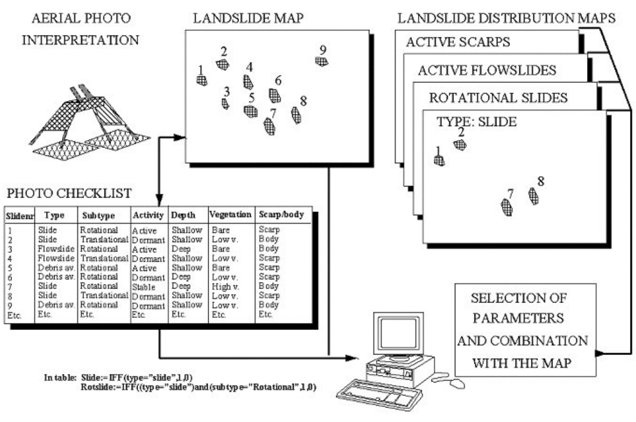
The methods for landslide susceptibility assessment are shown in the figure below. The methods are subdivided in qualitative ones (landslide inventory analysis, and knowledge driven methods) and quantitative ones (data driven, deterministic, and probabilistic methods). The inventory based methods are also required as a first step for all other methods, as they form the input and are used for validating the resulting maps. The probabilistic methods use the inputs from the lower three. In the case of dynamic models the results can be used directly in a probabilistic analysis. For the other methods a link is made with event-based landslide inventory maps.

Figure: 3.L.10: Methods for susceptibility and hazard assessment. Blue relates to landslide inventories. Red to susceptibility and Green to Landslide hazard.



Landslide inventory analysis

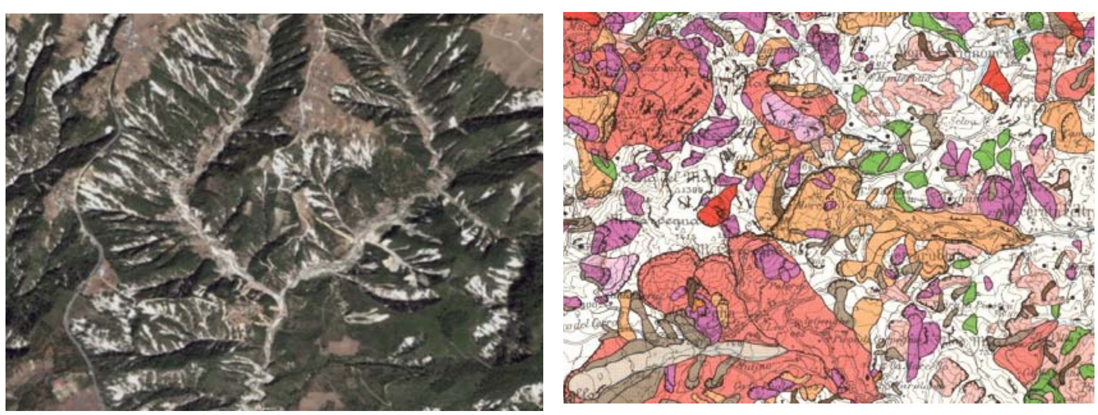
Figure 3.L.11: Landslide inventory method



The most straightforward approach to landslide hazard zonation is a landslide inventory based on aerial photo interpretation, ground survey, and/or historical data of landslide occurrences. The final product gives the spatial distribution of mass movements, represented either at scale or as points.

Mass movement inventory maps are the basis for most of the other landslide hazard zonation techniques. They can, however, also be used as an elementary form of hazard map, because they display where in an area a particular type of slope movement has occurred. See figure 3.L.11. Landslide inventories are either continuous in time, or provide so-called event-based landslide inventories, which are inventories of landslides that happened on the same day due to a particular triggering event (rainfall, earthquake). By correlating the density of landslides with the frequency of the trigger, it is possible to make a magnitude-frequency relation, required for hazard assessment.

Figure 3.L.12: Left: example of a high resolution image taken after a major rainfall event causing hundreds of landslides in the same area. Right: a fragment of a detailed landslide inventory map, with differentiation of type and age of landslides.

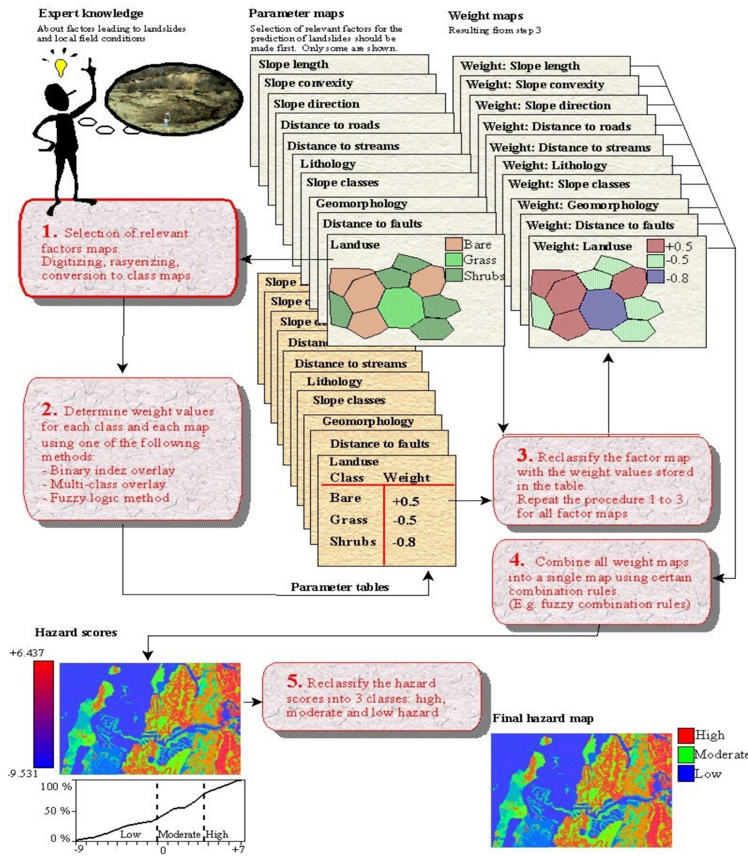


The landslide distribution can also be shown in the form of a density map within administrative units or to use counting circles for generating landslide density contours.

Heuristic landslide hazard assessment methods

In heuristic methods expert opinion plays a decisive role, that is why they are also called knowledge driven method. A landslide susceptibility map can be directly mapped in the field by expert geomorphologist. Very often, however, landslide maps are made indirectly, by combining a number of factor maps, that are considered to be important for landslide occurrence. The mapping of mass movements and their geomorphological setting is the main input factor for hazard determination. From this the experts learn the relative importance of the various factor maps used. Figure 3.L.13 gives a schematic flowchart of the use of knowledge driven methods for landslide susceptibility assessment. In a qualitative map combination, the earth scientist uses his/her expert knowledge to assign weight values to series of parameter maps. The terrain conditions are summated according to these weights, leading to susceptibility values, which can be grouped into hazard classes. This method of qualitative map combination has become widely used in slope instability zonation. Several techniques can be used such as Boolean overlay, Fuzzy logic, multi-class overlay and Spatial Multi-Criteria Evaluation. The drawback of this method is that the exact weighting of the various parameter maps is difficult. These factors might be very site specific and cannot be simply used in other area. They should be based on extensive field knowledge and be assigned by real experts with sufficient field knowledge of the important factors. The methods are subjective, but the weights assigned to the factors are transparent and can be discussed among experts, and defended against end users/decision makers.

Figure 3.L.13: Scheme for Qualitative landslide hazard assessment



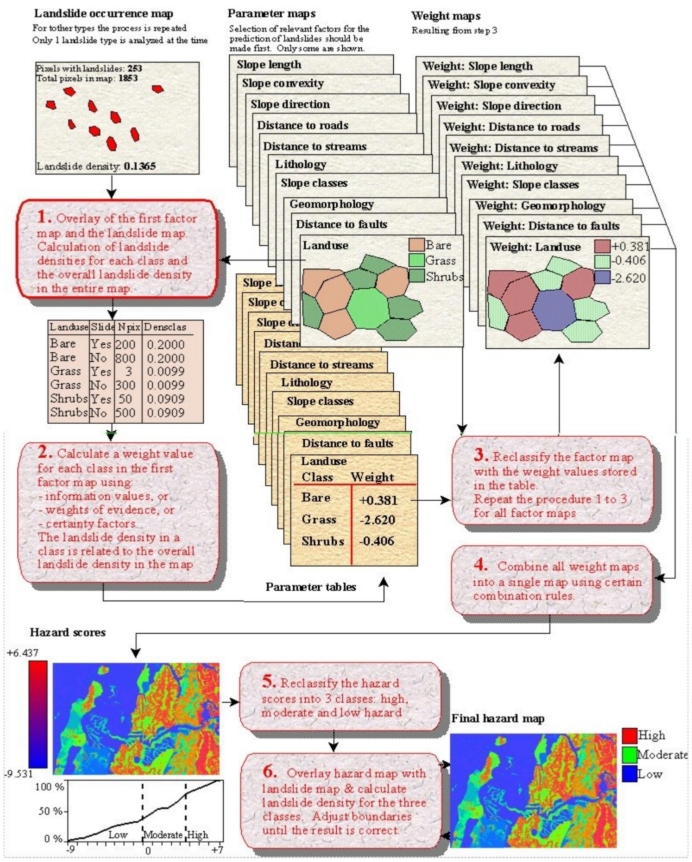
Statistical landslide susceptibility assessment methods

In statistical landslide hazard analysis, the combinations of factors that have led to landslides in the past are evaluated statistically and quantitative predictions are made for landslide free areas with similar conditions. The method assumes that similar conditions that have lead to landslides in the past will do so in future. Two main statistical approaches are used in landslide hazard analysis Bivariate and multi-variate methods (see Figure 3.L.13).

In a bivariate statistical analysis, each factor map (slope, geology, land use etc.) is combined with the landslide distribution map, and weight values, based on landslide densities, are calculated for each parameter class (slope class, lithological unit, land use type, etc). Several statistical methods can be applied to calculate weight values, such as landslide susceptibility, the information value method, weights of evidence modeling, Bayesian combination rules, certainty factors, the Dempster-Shafer method and fuzzy logic. Bivariate statistical methods are a good learning tool for the analysist to find out which factors or combination of factors plays a role in the initiation of landslides. The method is mostly done on a grid level.

Multivariate statistical models look at the combined relationship between a dependent variable (landslide occurrence) and a series of independent variables (landslide controlling factors). In this type of analysis all relevant factors are sampled either on a grid basis, or in morphometric units. For each of the sampling units also the presence or absence of landslides is determined. The resulting matrix is then analyzed using multiple regression, logistic regression or discriminant analysis. With these techniques, good results can be expected. Since statistical methods required a nearly complete landslide inventory and a series of factor maps, they cannot be applied easily over very large areas. These techniques have become standard in medium scale landslide susceptibility assessment.

Figure 3.L.14: Bivariate statistical analysis



One example of a simple bi-variate statistical analysis is the hazard index method: This method is based upon the following formula:

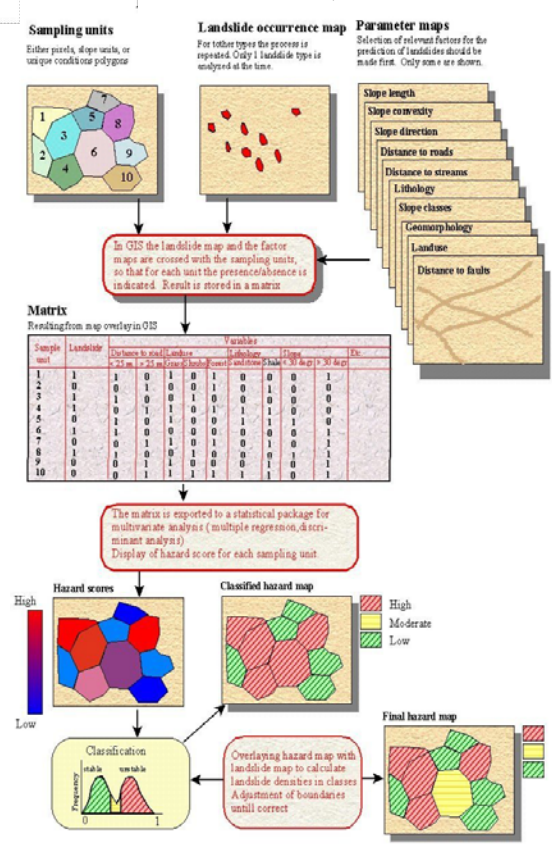
$$W_i = \ln\left(\frac{Densclas}{Densmap}\right) = \ln\left(\frac{\frac{Area(Si)}{Area(Ni)}}{\frac{\sum Area(Si)}{\sum Area(Ni)}}\right)$$

where,
Wi = the weight given to a certain parameter class (e.g. a rock type, or a slope class).
Densclas = the landslide density within the parameter class.
Densmap = the landslide density within the entire map.
Area(Si) =area, which contain landslides, in a certain parameter class.
Area(Ni) = total area in a certain parameter class.

Task 3.L.11: RiskCity exercise on statistical landslide susceptibility assessment (duration 5 hours)

In order to see how statistical methods can be applied in landslide susceptibility assessment we have prepared a GIS exercise on the use of a simple bi-variate statistical method (information value method). You can find the exercise description in the RiskCity exercise book.

Figure 3.L.15: Flowchart of multivariate statistical analysis.



Deterministic landslide hazard analysis

Deterministic methods are based on modeling the processes of landslides using physically-based slope stability models (figure 3.L.16). They are increasingly used in hazard analysis, especially with the aid of geographic information systems safety factors over large areas can be calculated. The methods are applicable only when the geomorphological and geological conditions are fairly homogeneous over the entire study area and the landslide types are simple. They can be subdivided in static models that do not include a time component, and dynamic models, which use the output of one time step as input for the next time step. Especially the use of dynamic models using GIS software such as PCraster (http://pcraster.geo.uu.nl/) is very powerful. It allows modeling soil moisture changes in the slope over time, and combine this with a slope stability model. Some examples combined slope hydrology and slope stability software are: Shalstab, TRIGRS, SINMAP and STARWARS/PROBSTAB. The advantage of these models is that they are based on slope stability models, allowing the calculation of quantitative values of stability (safety factors). The main drawbacks of this method are the high degree of oversimplification and the need for large amounts of reliable input data. This method is usually applied for translational landslides using the infinite slope model. The methods generally require the use of groundwater simulation models. Stochastic methods are sometimes used for selection of input parameters.

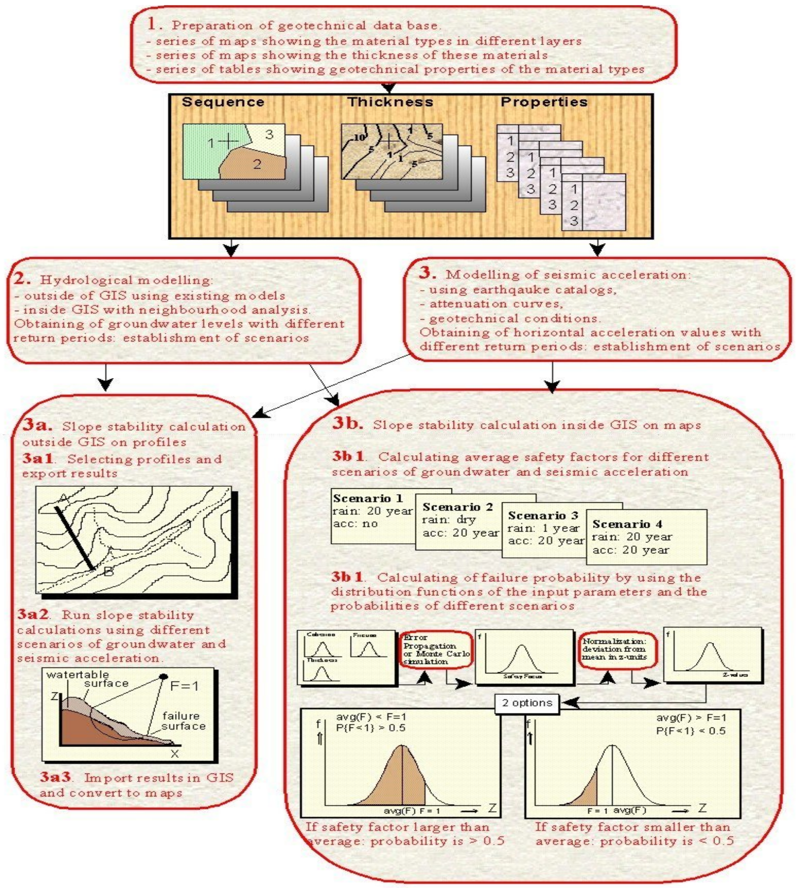


Figure 3.L.16: Deterministic approach to landslide hazard zonation

Task 3.L.12: RiskCity exercise on deterministic landslide susceptibility assessment (duration 5 hours)

In order to see how deterministic methods can be applied in landslide susceptibility assessment we have prepared a GIS exercise on the use of a simple infinite slope model under different scenarios of groundwater levels. You can find the exercise description in the RiskCity exercise book.
The exercise is based on the following formula:

$$F = \frac{c\,A + W \cos\beta \tan\phi}{W \sin\beta}$$

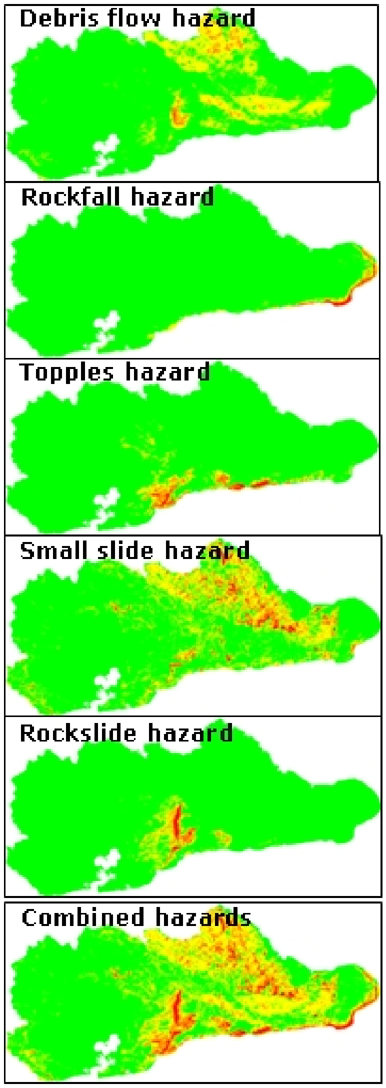
c = cohesion (Pa= N/m^2). A = length of the block (m).
W = weight of the block (kg). β = slope surface inclination (°).
ϕ = angle of shearing resistance (°)

Selecting the best method of analysis.
There is a clear link between the scale of analysis and the type of method that can be used, basically related to the possibility of obtaining the required input data. Table 3.L.8 gives a summary.

Table 3.L.8: Applicability of the methods at different scales.

Scale	Qualitative methods		Quantitative methods		
	Inventory	**Heuristic Methods**	**Statistical Methods**	**Deterministic methods**	**Probabilistic methods**
Large > 1:10000	Yes	Yes	No	Yes	Yes
Medium 25000–50000	Yes	Yes	Yes	No	Yes
Regional > 1:100000	Yes	Yes	Yes/No	No	No

There are several pitfalls in this process that should be avoided:



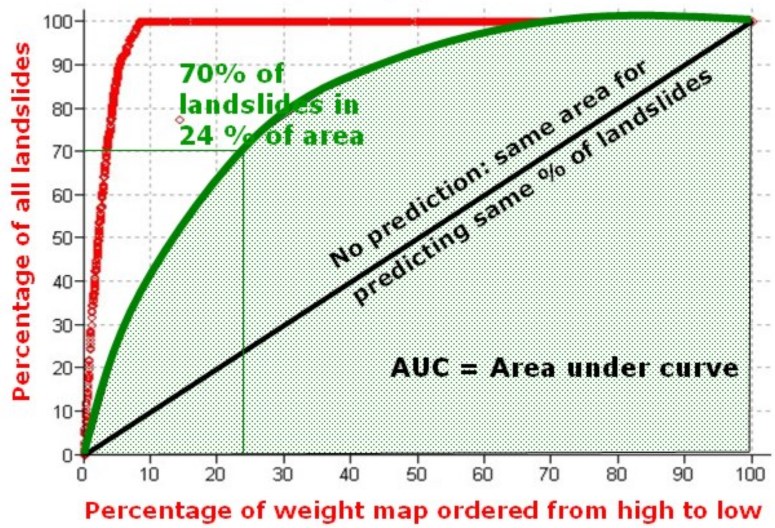
- Selection of a method that does not suit the available data and the scale of the analysis. For instance, selecting a physical modeling approach at small scales with insufficient geotechnical and soil depth data. This will either lead to large simplifications in the resulting hazard and risk map, or to endless data collection.
- Use of incomplete landslide inventories, either in temporal aspect, or in the landslide classification. It is important to keep in mind that different landslide types are controlled by different combinations of environmental and triggering factors.
- Using the same type of data and method of analysis for entirely different landslide types and failure mechanisms. The inventory should be subdivided into several subsets, each related to a particular failure mechanism, and linked to a specific combination of causal factors (See figure 3.?.?). Also only those parts of the landslides should be used that represent the situation of the slopes that failed.
- Use of data with a scale or detail that is not appropriate for the hazard assessment method selected. For instance, using an SRTM DEM to calculate slope angles used in statistical hazard assessment.
- Selection of easily obtainable landslide causal factors, such as DEM derivatives from SRTM data on a medium or large scale, or the use of satellite derived NDVI values as a causal factor instead of generating a land cover map.
- Use factor maps that are not from the period of the landslide occurrence. For instance, in order to be able to correlate landslides with landuse/landcover changes, it is relevant to map the situation that existed when the landslide occurred, and not the situation that resulted after the landslide.
- Much of the landslide susceptibility and hazard work is based on the assumption that “the past is key to the future”, and that historical landslides and their causal relationships can be used to predict future ones. However, one could also follow the analogy of the investment market in stating that “results obtained in the past are not a guarantee for the future”. Conditions under which landslide happened in the past change, and the susceptibility, hazard and risk maps are made for the present situation. As soon as there are changes in the causal factors (e.g. a road with steep cuts is constructed in a slope which was considered as low hazard before) or changes in the elements at risk (e.g. city growth) the hazard and risk information needs to be adapted.

Validation of susceptibility maps

The most important question to be asked for each hazard study is related to the degree of accuracy. The terms accuracy and reliability are used to indicate whether the hazard map makes a correct distinction between landslide free and landslide prone areas. The accuracy of a hazard prediction depends on a large number of factors such as the models, the input data, the experience of the earth scientists involved, and the size of the study area. The evaluation of the accuracy of a susceptibility map is generally very difficult. In reality a hazard prediction can only be verified by observing if the event

takes (or has taken) place in time ("wait and see"), but this is not a very useful method, for obvious reasons.
Depending on the method used there are several ways to validate the landslide susceptibility maps. In the case of deterministic landslide hazard assessment, using dynamic models, it is possible to compare the predicted unstable pixels with the actual landslides that have taken place. This could even be done to predict them both in space and time. For statistical and knowledge driven method the best way is to use success rate curves.
The success rate is a statistical method to determine how well the resulting hazard map has classified the areas of existing landslides as high hazard areas.
The method first divides the area of the hazard map in equal classes of the histogram, ranging from the highest to the lowest scores. Then for each of these classes the percentage of the landslides that occur in that class is calculated. The result is plotted as the percentage of the map on the X-axis, ad the percentage of the landslides on the Y-axis (see figure 3.L.17).
This method is often unjustly presented as a check of the predicting power of the hazard map. It is merely a method that allows checking how many of the landslides occur in the high hazard areas (well classified) and how many occur in the low hazard areas (wrongly classified). To some extent this is circular reasoning, since the same landslides that are used to calculate the hazard, are used later to check it. This can be avoided by separating the landslide set into two populations: one used for generating the hazard map, and the other for checking it. This can be done by using a random selection of the landslides, or by dividing the area in a checkerboard pattern, and use the landslide falling in the “white” blocks for the generation of the hazard map, while using the ones in the “black” bocks for checking it. When you are using two temporally different inventory maps, the success rate actually becomes a prediction rate. The objective of the prediction rate is to check how well the hazard map can predict the future occurrence of landslides. The hazard prediction, based on an older distribution map, can then be checked with a younger distribution.
The comparison of hazard maps, made by different methods (for example statistical and deterministic methods) may give a good idea of the accuracy of the prediction as well.

Figure 3.L.17: Success rate: plotting the percentage of the susceptibility map ordered from high to low values against the percentage of landslides. The diagonal is the line where no prediction is made. The AUC (Area under the curve) gives a measure of the accuracy. For the diagonal line AUC=0.5, in case of complete prediction: AUC=1.



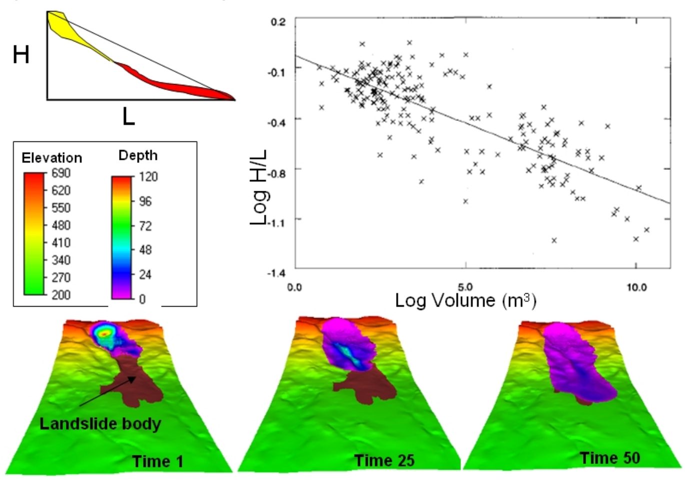
Runout assessment

As shown in figure 3.L.6 the methods explained above are intended for landslide initiation modeling. These will serve as input in the prediction of the run out behavior of landslides, where information is required on run out distance, run out width, velocity, pressure, depth of the moving mass;, depth of deposits.

A variety of techniques have been developed to assess the travel distance and the velocity of mass movements. They can be classified into the following groups:

- *Empirical models*. These are based on empirical relationship between the runout length and other factors. For instance the mass-change method is based on the fact that the landslide stops when the volume of the actively moving debris becomes negligible. The average mass/volume-change rate of landslide debris was established by dividing the volume of mobilized material from the landslide by the length of the debris trail. The angle of reach, defined as the angle of the line connecting the crest of the landslide source to the distal margin of the displaced mass, shows a linear correlation with volume for all types of failures (see figure 3.L.18). The angle of reach method is a very generalized method and can only be used as a general indication. Empirical methods are generally simple and relatively easy to use, and they do no used complicated input data.

Figure 3.L.18: Runout modeling. Above: Empirical angle of reach/volume relationship (Corominas, 1996). Below: three time slices of a numerical runout simulation (Castellanos, 2008).



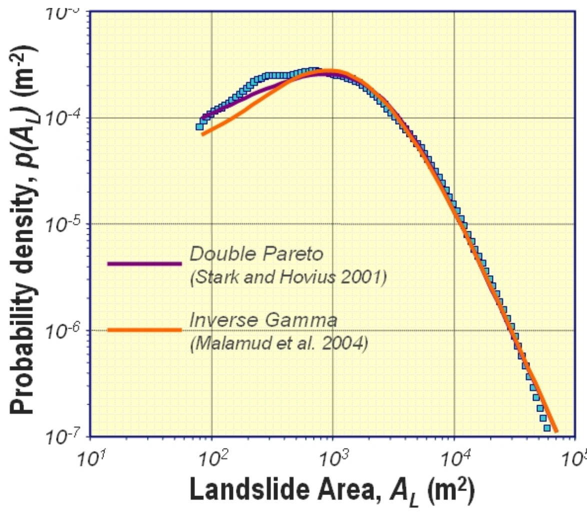
- *Analytical models* are based on energy considerations. They include different formulations based on lumped mass approaches in which the debris mass is assumed as a single point. Observation of the superelevation of the flow around the bends and run-up of the flow against an obstacle also allow an estimate of the velocity.
- *Numerical models*. Numerical methods for modeling run out behavior of landslide debris mainly include fluid mechanics models and distinct element methods. Continuum fluid mechanics models utilize the conservation equations of mass, momentum and energy that describe the dynamic motion of debris, and a rheological model to describe the material behavior of debris. By solving a set of governing equations with a selected rheological model describing the flow properties of the debris, the velocity, acceleration and run out distance of debris can be predicted. Rheological models have to be selected, and the required rheological parameters have to be determined by back-analysis from the landslide cases. After determining the probability of landsliding and the areal extent that would be potentially affected by the landslide, landslide hazard can be delimited, and elements at risk can be defined. Wellknown models are DAN, DAN-3D, RAMMS, FLO-2D, MASSMOV2D etc.

Run out modeling is complicated because of the various physical processes that occur during an event. These depend on the initial composition, the characteristics of the path and the material incorporated during the flow. Runout models for rockfall have been well developed. For landslides and debrisflow runout modeling there are many uncertainties involved related to the spatial and temporal distribution of the release areas, the volume of the release mass, and the input parameters of the rheological model.

3.L.6 From susceptibility to hazards

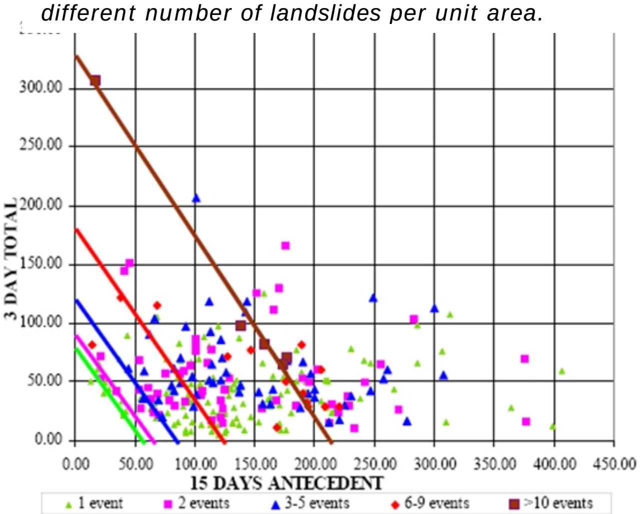
As indicated in section 3.L.5 the difference between susceptibility and hazard is the inclusion of probability (temporal, spatial and size probability). Size probability is the probability that the landslide will be of a particular minimum size. This is done by plotting the size/frequency distribution (See figure 3.L.19).

Figure 3.L.19: Size probability estimation (Guzetti. 2006).



Temporal probability can be established using different methods. A relation between triggering events (rainfall or earthquakes) and landslide occurrences is needed in order to be able to assess the temporal probability. Temporal probability assessment of landslides is either done using rainfall threshold estimation, through the use of multi-temporal data sets in statistical modeling, or through dynamic modeling. Rainfall threshold estimation is mostly done using antecedent rainfall analysis, for which the availability of a sufficient number of landslide occurrence dates is essential. If distribution maps are available of landslides that have been generated during the same triggering event, a useful approach is to derive susceptibility maps using statistical or heuristic methods, and link the resulting classes to the temporal probability of the triggering events. The most optimal method for estimating both temporal and spatial probability is dynamic modeling, where changes in hydrological conditions are modeled using daily (or larger) time steps based on rainfall data. However, more emphasis should be given to the collection of reliable input maps, focusing on soil types and soil thickness. The methods for hazard analysis should be carried out for different landslide types and volumes, as these are required for the estimated damage potential. Landslide hazard is both related to landslide initiation, as well as to landslide deposition, and therefore also landslide run-out analysis should be included on a routine basis.

Figure 3.L.20: Rainfall threshold generation. Plot of antecedent rainfall and threshold lines for different number of landslides per unit area.



A good understanding and quantification of the different hazard aspects (temporal and spatial probability of initiation, magnitude-frequency relation and run-out potential) is essential in order to be able to make further advancements in landslide vulnerability and risk assessment. Also more emphasis could be given to the collection of historic landslide damage information for different elements at risk, and relate these to the characteristics of the landslides that caused the damage (e.g. volume, speed, run-out length).

Eventually, it is the spatial data availability that is the limiting factor in landslide hazard and risk assessment.

3.L.7 Selftest

Self test
In order to evaluate whether you have understood the concepts that were presented in this session. Please make the following test, and check the answers in Blackboard.

Question 1: Landslide hazard assessment
Which statement concerning statistical and an expert-based method for landslide hazard assessment is true:

A) A statistical method uses weights derived from the correlation between past hazard events and causal factors, whereas an expert-based method tries to model the process physically.
B) A statistical method tries to model the process physically, whereas an expert-based method uses qualitative weights derived from expert opinion.
C) An expert-based method tries to find a correlation between past hazard events and causal factors, whereas a statistical method tries to model the process physically.
D) A statistical method uses weights derived from the correlation between past hazard events and causal factors, whereas an expert-based method uses qualitative weights derived from expert opinion.

Explain your answer:

Question 2: Landslide hazard assessment
For landslide hazards it is very difficult to estimate the probability of occurrence. The most important reason for that is:

A) Most landslide types do not have a magnitude –frequency relation for a particular location, and you cannot say that the same location will be affected often by small landslides, and less often by large landslides.
B) Landslides are mostly occurring as a result of a triggering event, such as rainfall or earthquakes, and these have no clear magnitude-frequency relation
C) Landslides occur randomly, and cannot be predicted in space or time.
D) Landslides never occur twice at the same location.

Explain your answer:

Question 3: Landslide inventory mapping
Which method of landslide mapping would you recommend in the following cases?

- Mapping old landslides that are covered by forest.
- Fast mapping of hundreds of landslides caused by a hurricane in remote and inaccessible areas?
- Monitoring the movements of a town that is built on a slow moving landslide?
- Regular mapping of an area of 1000 km2 for landslide hazard assessment?

Question 4: Statistical susceptibility assessment

Below a number of possible factor maps are indicated that can be used in a bivariate statistical analysis for landslide susceptibility. Indicate for each of the maps:

- Why this could be a good / not so good / bad indicator for landslide occurrence?
- What would be the expected order of magnitude of the weights that are used in the hazard index method.

Slope class of 0-10 degrees.

Distance from faults (indicate which distance range you would use)

Landuse type unvegetated terrain.

Further reading:

If you are new to landslides, one of the best internet sites to look for landslide related information is the USGS landslide website: http://landslides.usgs.gov/learning/

On this site you can also download the following introductory handbook: Highland, L.M., and Bobrowsky, Peter, 2008, The landslide handbook—A guide to understanding landslides: Reston, Virginia, U.S. Geological Survey Circular 1325, 129 p. Link: http://pubs.usgs.gov/circ/1325/

Guidelines for landslide inventory, hazard and risk assessment can be found in:

Fell, R., Corominas, J. Bonnard, C., Cascini, L. ,Leroi, E., Savage, W. on behalf of the JTC-1 Joint Technical Committee on Landslides and Engineered Slopes. Guidelines for landslide susceptibility, hazard and risk zoning for land-use planning. Engineering Geology 102 (2008) : 85-98 and commentary on 99-111

AGS, 2000. Landslide risk management concepts and guidelines, Australian Geomechanics Society (AGS), Sub-committee on landslide risk management. This report can be downloaded from: http://www.australiangeomechanics.org/LRM.pdf

Castellanos Abella, E.A., de Jong, S.M. (promotor) , van Westen, C.J. (promotor) and van Asch, W.J. (promotor) (2008) Multi - scale landslide risk assessment in Cuba. Enschede, Utrecht, ITC, University of Utrecht, 2008. ITC Dissertation 154, 272 p. ISBN: 978-90-6164-268-8 http://www.itc.nl/library/papers_2008/phd/castellanos.pdf

For those familiar with landslides that want to know more about the methods for landslide hazards and risk assessment, the following materials can be recommended:

Carrara, A., Guzzetti, F., Cardinali, M., Reichenbach, P., 1999. Use of GIS Technology in the Prediction and Monitoring of Landslide Hazard. Natural Hazards 20, 117-135.

Castellanos, E. and Van Westen, C.J., 2007. Qualitative landslide susceptibility assessment by multicriteria analysis; a case study from San Antonio del Sur, Guant´anamo, Cuba. Geomorphology DOI: 10.1016/j.geomorph.2006.10.038.

Cruden, D.M., Varnes, D.J., 1996. Landslide types and processes. In: Turner, A.K., and Schuster, R.L., (Eds.), Landslides, Investigation and Mitigation. Transportation Research Board, Special Report 247, Washington D.C., USA, pp. 36-75.

Glade, T., Crozier, M.J., 2005. A review of scale dependency in landslide hazard and risk analysis. In: Glade, T., Anderson, M., and Crozier, M.J., (Eds.), Landslide Hazard and Risk. John Wiley and Sons Ltd., West Sussex, England, pp. 75-138 .

Guzzetti, F., Reichenbach, P., Cardinali, M., Galli, M., Ardizzone, F., 2005. Probabilistic landslide hazard assessment at the basin scale. Geomorphology 72, 272-299.

IAEG-Commission on Landslides, 1990. Suggested nomenclature for landslides. Bulletin of the International Association of Engineering Geology 41, 13-16.

IGOS, 2003. Marsh, S., Paganini, M., Missotten, R., (Eds.), Geohazards Team Report. http://igosg.brgm.fr/. Accessed on 30th June 2007.

IUGS-Working group on landslide, 1995. A suggested method for describing the rate of movement of a landslide. Bulletin of the International Association of Engineering Geology 52, 75-78.

IUGS-Working group on landslide, 2001. A suggested method for reporting landslide remedial measures. Bulletin of Engineering Geology and Environment 60, 69-74.

JTC-1 Joint Technical Committee on Landslides and Engineered Slopes, 2008. Guidelines for landslide susceptibility, hazard and risk zoning, for land use planning. Engineering Geology (this volume).

Mantovani, F., Soeters, R., Van Westen, C. J., 1996. Remote sensing techniques for landslide studies and hazard zonation in Europe, Geomorphology 15 (3-4), 213-225.

Metternicht, G., Hurni, L., Gogu, R., 2005. Remote sensing of landslides: An analysis of the potential contribution to geo-spatial systems for hazard assessment in mountainous environments. Remote Sensing of Environment 98 (23), 284-303.

Soeters, R., Van Westen, C.J., 1996. Slope instability recognition, analysis and zonation. In: Turner, A.K., Schuster, R.L., (Eds.), Landslides, Investigation and Mitigation. Transportation Research Board, National Research Council, Special Report 247, National Academy Press, Washington D.C., U.S.A., pp. 129-177.

UNESCO-WP/WLI, 1993a. Multilingual Landslide Glossary. Bitech Publishers Ltd., Richmond, Canada, 34 pp.

UNESCO-WP/WLI, 1993b. A suggested method for describing the activity of a landslide. Bulletin of the International Association of Engineering Geology 47, 53-57.

UNESCO-WP/WLI, 1994. A suggested method for reporting landslide causes. Bulletin of the International Association of Engineering Geology 50, 71-74.

Van Westen, C.J., Van Asch, T.W.J., Soeters, R., 2005. Landslide hazard and risk zonation; why is it still so difficult? Bulletin of Engineering geology and the Environment 65 (2), 167-184.

Guide book
Choice Session 3.V:
Volcanic hazard assessment

Objectives

After session 3.V you should be able to:

- List different volcanic hazard types
- Understand their varying spatial and temporal characteristics
- Understand the basics of volcanic hazard assessment
- Explain in broad terms how optical, thermal, radar and ground-based remote sensing can be used to monitor volcanoes
- Understand how multi-temporal studies can be used to map and assess changes (e.g. in gas emissions, topography etc.)

This session contains the following sections and tasks

Section	Topic	Task	Time required		
3.V.2	What is volcanic hazard?	3.V.1 Visit the Volcano World website and watch a YouTube video on different volcano types		0.5 h	1.0 h
		3.V.2 Visit the website of the US Geological Survey and learn more about hazard assessment and find currently active volcanoes		0.5 h	
3.V.3	Assessing volcanic hazards	3.V.3 Learn about different volcanic subhazards and the spatial reach		0.25 h	0.45 h
		3.V.4 Learn about supervolcanoes		0.30 h	
3.V.4	Remote sensing of volcanic hazards	3.V.5 Google Earth volcanic hazard assessment		0.5 h	1.5 h
		3.V.6 Use the MODVOLC page to find currently active volcanoes		0.5 h	
		3.V.7 Design a simple volcano monitoring strategy		0.5 h	
		Total			**3.25 h**

3.V.1 Introduction to volcanic hazards

No other natural process tends to awe and fascinate people as much as a volcanic eruption. For anyone who has seen footage of an eruption on TV, or even witnessed in person huge eruption clouds or lava flows snaking down a mountain, such display of nature’s power will likely seem unparalleled. Volcanic activity is also one of the few hazards where a clear positive side is widely recognised. Just like an annual flood adding nutrients to agricultural fields and thus being seen as a necessary price to pay for a good harvest by societies where such flooding has become part of the culture, volcanic activity creates highly fertile lands, which explains why volcanic slopes tend to be intensively farmed. This combination of threat and benefit has frequently led to reverence towards volcanoes, with divine attributes being attached to those structures. In this section we introduce volcanic hazard, explain its characteristics relevant from a geoinformatics perspective, and explain in detail how remote sensing and GIS can be of use to understand and monitor the hazard.

3.V.2 What is volcanic hazard?

Approximately 50-60 subaerial volcanoes (i.e. on land instead of under water) erupt worldwide every year, posing substantial risks to surrounding communities, the environment and the aviation industry, as well as occasionally affecting the global climate. In total some 1,500 potentially active volcanoes exist in the world. As they tend to occur in well-understood locations, such as along plate boundaries (e.g. the Pacific Ring of Fire), or where known so-called hotspots exist, it seems like we have pretty good knowledge on the source of the hazard. After all, we do not expect new volcanoes to appear overnight (although the growth of a new volcano over the course of a few weeks has happened before!), or for them to move their location (although that too happens, slowly, when a hotspot moves, or the continental plate above it). What is more difficult to determine is whether a volcano is just dormant (sleeping) or actually extinct, and when it will erupt again if still active or just dormant. For people who wish to move to a fertile volcanic area it can be rather important to know whether a volcano might suddenly re-awake. Although volcanoes only account for some 2% of all natural disasters, more than 220,000 documented human fatalities have been attributed to volcanic activity over the last 200 years.

Task 3.V.1: Internet exercise (duration 30 minutes)
Go to Volcano World (http://volcano.oregonstate.edu/volcanoes/index.html) to learn more about volcanoes. In particular check out the "Find a volcano" section to learn more about where volcanoes are concentrated. The watch the following short video on YouTube: http://www.youtube.com/watch?v=DnBggrCdkN0 (3:26).

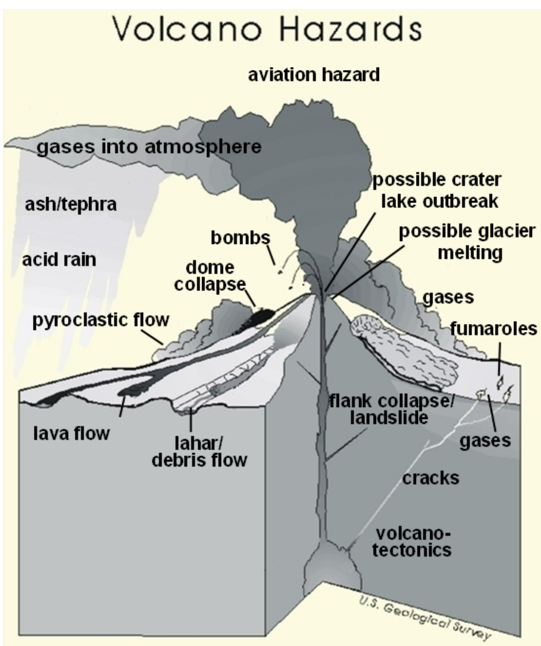


Figure 3.V.1: overview of the different hazards a volcano can pose (modified from United States Geological Survey).

A look at volcanic hazard reveals that we are not actually dealing with a single hazard, thus the term "volcanic hazard" is too unspecific and should always be qualified. Think for a moment about a volcano and consider different hazard aspects – surely more than just lava flows will come to mind. In fact, from a hazard perspective a volcano is the most diverse phenomenon we will address in this course. Figure 3.V.1 gives an overview of the various hazards a volcano can pose – a total of 17 distinct hazards is listed! Several of those are well-known, such as ash fall or lava flows, perhaps even gas emissions or pyroclastic flows. However, in addition there are lesser known hazards, such as volcano-tectonic seismicity (when magma rises within the edifice, leading to earthquakes), acid rain or crater lake outbreaks. Many of those can occur simultaneously during the eruption of a given volcano. Some actually precede an eruption, while others are not even associated with what we consider to be volcanic activity. For example, an extinct volcano may have a crater lake. If the rim that contains the lake becomes unstable because of erosion or seismic activity, a crater lake breakout can occur, leading to vast quantities of water rushing down the mountain, picking up ash and other material, and forming a mudflow that can be deadly for tens of kilometres. At other times volcanic activity has consequences even further away from the edifice. For example, the famous 1991 eruption of Mount Pinatubo in the Philippines ejected more than 20 million tons of sulphur dioxide (SO_2) into the atmosphere, leading to global cooling of about 0.5ºC. An even larger eruption at Tambora (Indonesia) in 1815 cooled the Earth by as much as 3ºC, and leading to a "year without a summer" in Europe and North America. Thus harvests lost there were a consequence of a volcanic hazard originating thousands of kilometres away.

Task 3.V.2: Internet exercise (duration 30 minutes)
Go to the USGS Volcano Hazards Program website (http://volcanoes.usgs.gov/) that provides detailed background information of different volcanic hazards, as well as status information on currently active volcanoes. Explore what information is available, both as background and in real time. Summarise briefly how hazard information is being communicated. Who seem to be the users of such information?

3.V.3 Assessing volcanic hazards

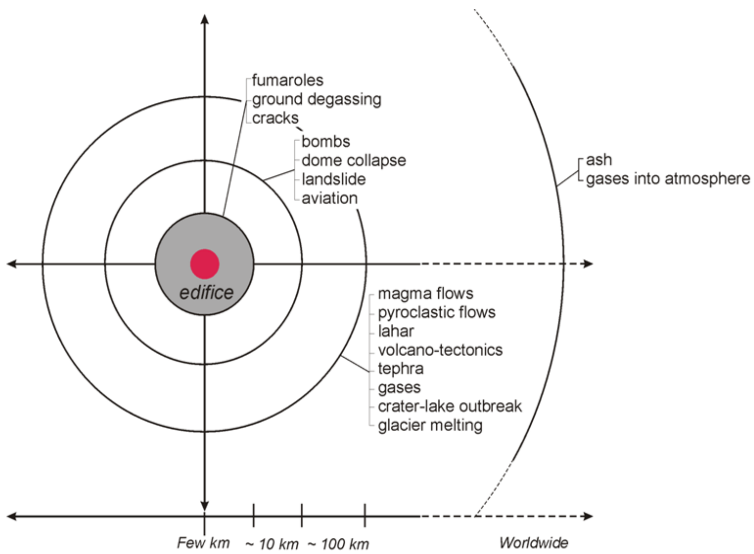


Figure 3.V.2: Spatial reach of different volcanic hazards.

This course deals with multi-hazard risk assessment. Hence, to understand the risk as a precondition to reduce or manage it a detailed understanding of the hazard is needed. Here we face a challenge. Unlike, for example, a river, where we model how high and how fast the water will rise given information on the topography, surface roughness and the rate of rainfall in the catchment, we do not have a single hazard here. In principle each of the 17 sub-hazards has to be considered separately. There are, however, possibilities to reduce this problem somewhat. For example, if a volcano has no glacier or crater lake, there can be no flooding or mudflow formation, except for cases of extreme rainfall. We can also consider the hazards in terms of their reach (Figure 3.V.2). Several hazard types clearly have a very limited impact field. For example, fumaroles (volcanic gases emitted through cracks in the edifice) or crack formation are a problem for buildings standing right on the flank of the volcano, or for cattle and people, but do not reach further. An eruption, however, can fling volcanic bombs more than 1 km away from the crater. During a dome collapse (when parts of a magma plug break up) or a volcanic landslide an area a few kilometres away can still be buried by material, which also happens due to tephra fall. This is still far less though than the reach of magma or pyroclastic flows, as well as volcanic mudflows (lahars) that have been documented to travel up to 100 km when channelled by topography. For example, following the 1985 eruption of Nevado del Ruiz in Colombia, a lahar formed due to melted glaciers, and destroyed the town of Armero 74 km away from the crater, killing more than 23,000 people. Thus seemingly local events (e.g. glacier melting) can have far-reaching consequences. Volcanic gases can also travel great distances. For example, at Masaya volcano in Nicaragua, SO_2 concentrations recorded during non-eruptive times were highest at a ridge 14 km from the crater. In fact, when we talk about volcanic gases as a hazard, we could subdivide it further, as not only SO_2 is dangerous. In 1986 vast amounts of carbon dioxide (CO_2) were released from the Nyos crater lake in Cameroon, travelled some 25 km, and asphyxiated more than 1,700 people in their sleep. As CO_2 is heavier than air it concentrates near the ground, thus leading to deadly concentrations. SO_2, on the other hand, can rise into the stratosphere and remain there for weeks or months, eventually circling the planet and, after conversion to sulphuric acid, leading to the cooling already mentioned. One sub-hazard is rather unique, in that it works in the vertical direction: aviation hazard. If a plane flies into an eruption cloud, the ash entering the engines is melted to glass, which can lead to loss of engine power and planes crashing.

The size of an area a given hazard can affect is only one part of a hazard assessment. It is also important to know the return periods. As for other hazards that occur rarely or infrequently this can be a major challenge. We wish it was as easy as with the so-called *Lighthouse of the Mediterranean* – Stromboli volcano. For 2,600 years this volcano has been continuously active, emitting several small bursts per hour (and only rarely a little more violently). However, often we observe that a volcano "sleeps" for centuries before erupting again, leading to a situation where people do not even recognise a volcano as such, but only think of it as a mountain (e.g. Pinatubo before the 1991 eruption)! Thus for many volcanoes we have a very poor understanding of their history for the different hazard types. While it is possible to carry out detailed stratigraphic analysis around a volcano, to determine date, size and type of a volcanic deposit (e.g. lava, tephra, ash), this has only been done at few volcanoes, and often only after a disaster has happened. As we will discuss below, remote sensing can help here. Another important source of information is historical records. Large eruptions tend to be recorded, sometimes in great detail. For example, the eruption of Vesuvius in Italy that famously destroyed the town of Pompeii in 79AD was meticulously described. Especially for areas that have been inhabited for millennia (such as Italy), we tend to have a seamless record of activity. In the "New World" far fewer data exist, and we have to make do with what we can find in the stratigraphic record. Also for other hazards, such as landslides, crater-lake outbursts or historic gas emissions, typically records are very sketchy.

Task 3.V.3: Exercise (duration 15 minutes)

Figure 3.3.V.2 shows how different subhazard types can affect areas at different distances. Explain why the circular shape used here may not always be appropriate?

Often what we are left with is trying to understand the onset times and durations of different hazards. For example, a volcano gives off certain signs that can signal an impending eruption. Thus even if we do not have sufficient information about historic eruptions, observing such signs can be useful for early warning and to update hazard maps. Also important is the duration of a hazardous event. For example, a small volcano-tectonic shock may crack some roads or building walls that are readily fixed. Another matter is long-lasting missions of gas or ash. A good example is a new "mud volcano" near Surabaya in Indonesia. Since May 2006, a new volcano has been emitting more than 100,000 m^3 of hot mud per day, displacing thousands of people. Figure 3.V.3 gives an overview of the onset times and durations of various volcanic sub-hazards.

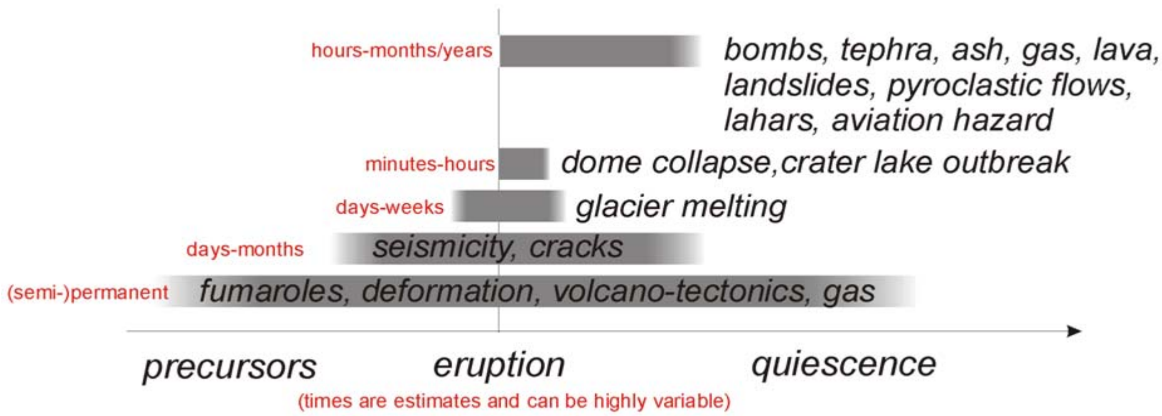


Figure 3.V.3: onset times and duration of different volcanic hazards.

We see that we can distinguish a precursor period, the eruption, as well as quiescence. While the times shown are estimates, they give an idea of when a certain hazard is likely to occur, and how long it might last. For example, fumaroles or low-level gas emissions can occur for very long times. Volcanic seismicity or cracks in the edifice, on the other hand, are associated with ascending magma and can thus signal a coming eruption, but they can also result from the collapse of an empty magma chamber after an eruption. For glaciers to melt, we already need a significant heat source near the summit, though the melting can then last for weeks. Other events, such as a dome collapse, only occur after an eruption has begun, but may only last minutes or hours. If the volcano then remains active, as is often the case, the hazard from tephra falls, degassing lava flows etc. can then persist for months or years.

To understand a hazard fully we also need to consider what impact it might have on people or infrastructure. In terms of infrastructure this is rather easy. Direct contact with lava or a pyroclastic flow will likely lead to a total loss. For a lahar it depends on the height and the speed of the flow, ad we can model the force for a given scenario and whether a structure can withstand it. Similarly, we can calculate the weight of a certain amount of ash on a roof, and up to which point a building can withstand the pressure. Figure 3.V.4 shows how we can conceptualise the impact of volcanic activity on people. Broadly speaking, it can lead to death (e.g. in direct contact with lava or pyroclastic flows), or to traumatic of chronic injuries. Traumas occur when falling volcanic bombs or tephra,

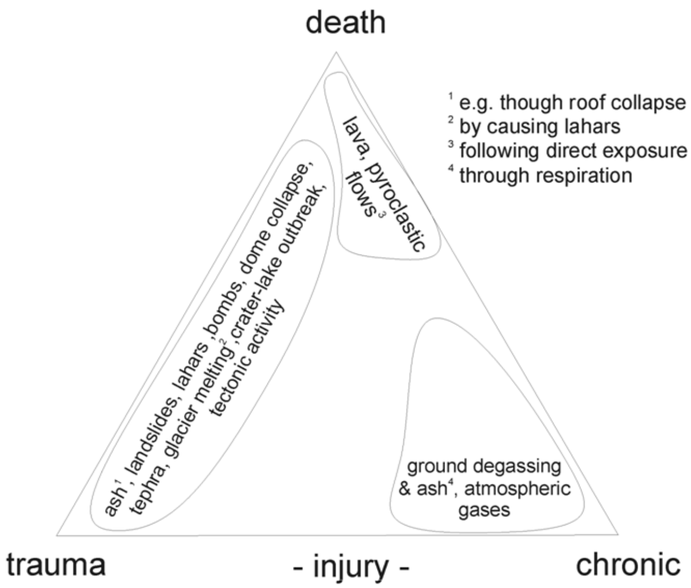


Figure 3.V.4: Impact of volcanic hazard on people.

or for example collapsing roofs injure people who later recover. Inhaling of volcanic gases or ash, on the other hand, can lead to chronic respiratory illness.

We can thus conclude that there is no single volcanic hazard, but rather that there are many sub-hazard types, each with its own spatio-temporal characteristics as well as consequences for people and infrastructure. These various hazards can also occur with variable relation to eruptive activity, compound or reinforce each other, and some can also occur without any eruption activity at all. In the following section we review how remote sensing can help us to map and understand these volcanic hazards.

Task 3.V.4: Exercise (duration 30 minutes)
One volcano type we have not mentioned so far is a supervolcano. Use the internet to find out what this is. Why do you think we do not consider them here?

3.V.4 Remote sensing of volcanic hazards

Volcanoes probably always produce precursory signals prior to eruption, though in many cases these go unobserved. These include changes in quantity and composition of emitted gases such as SO_2, an increase in temperature of (parts of) the edifice or crater lakes, and seismic activity and bulging as signs of ascending magma. While all of those signs are readily detected with *in situ* instrumentation, the cost and risk associated with such efforts has precluded widespread implementation of available technology. However, with the exception of seismic activity, all the above signs can be detected with remote sensing technology. Volcanoes are in fact wonderfully expressive entities, broadcasting much useful information. What we need is to adjust our monitoring means – e.g. through remote sensing – to pick up those signals.

As was explained already in the guidance notes on spatial data sources (and the background box on remote sensing), we need to adjust our monitoring in terms of appropriate spatial, spectral and temporal resolution. This means that we need to understand all sub-hazard types we wish to consider in this respect. This means that for some hazards the low temporal resolution (several days to weeks) of a polar orbiter is sufficient, when it provides a good regular overview of the entire volcano. For other, more dynamic hazards, such as variable magmatic activity, frequent thermal monitoring may be needed. Below we briefly review the main types of remote sensing of different volcanic hazards.

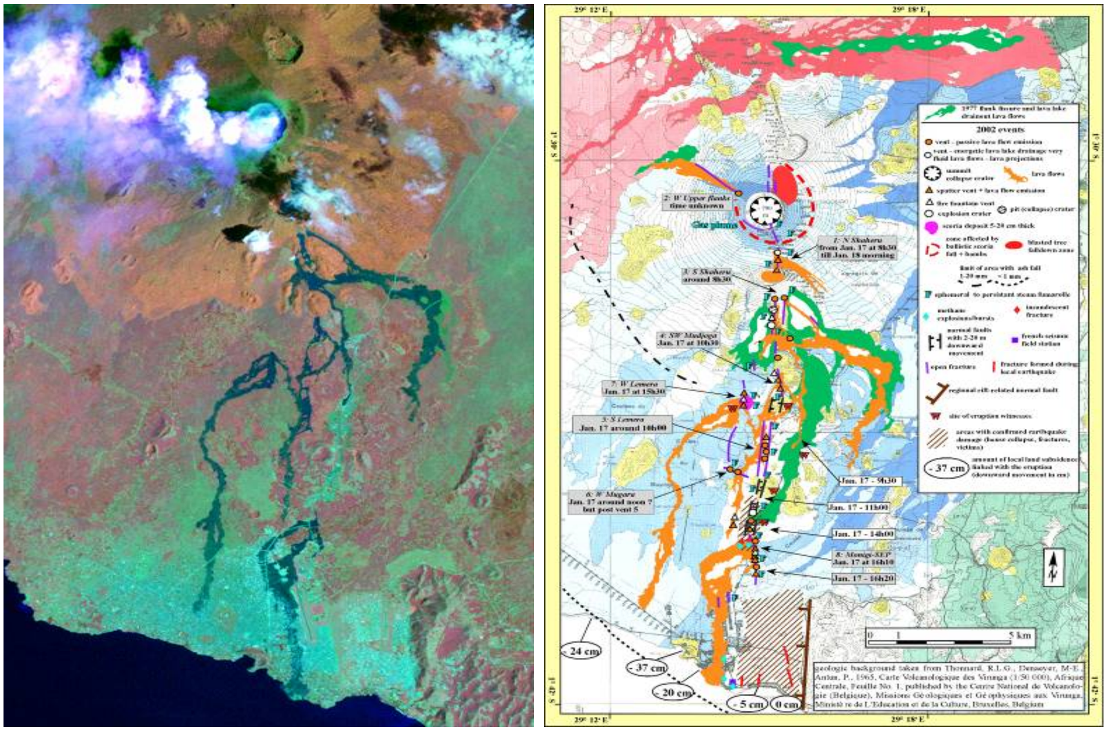


Figure 3.V.5: Hazard mapping for Nyiragongo (Democratic Republic of Congo) based on ground data and satellite image processing (Source: J.C. Komorowski).

Optical remote sensing

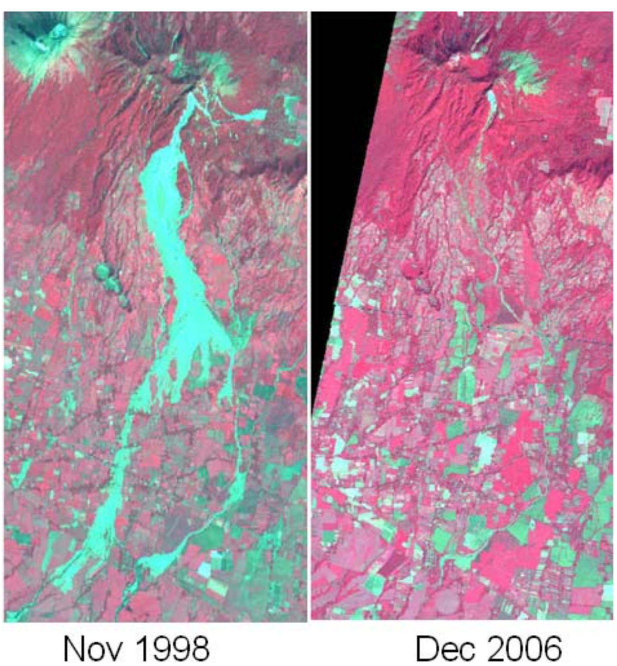


Figure 3.V.6: Traces of a lahar (mudflow) at Casita volcano (Nicaragua) disappearing quickly (note that the flow was some 20 km long!)

Many volcanic hazard types can be detected with optical instruments. For example, present crater lakes or glaciers can be seen in satellite pictures. If detailed data are available it is frequently also possible to see previous lava flows, tephra deposits or the remains of pyroclastic flows and lahars. (See Figure 3.V.5). We need to realise, though, that such traces can disappear very quickly (see Figure 3.V.6), and that we cannot date the observed phenomena. Image resolution is also critical to see hazardous features. Figure 3.V.7 gives examples of low and high resolution images of volcanoes that can be used to asses some of the present hazards.

Figure 3.V.7: Screen shots from Google Earth of Casita volcano (Nicaragua, left), and Mount St. Helens (US, right). Note the radically different level of detail those images provide.

Task 3.V.5: Internet exercise (duration 30 minutes)
Open Google Earth and try to find the 2 volcanoes shown in Figure 3.3.V.7. Explore the volcanoes by using different zoom levels, move around them, and switch the elevation data on and off (using the Terrain *button in the lower left layers menu). Explore which of the hazards shown in figure 3.3.V.1. are evidenced in the Google Earth data.*

Thermal remote sensing

Several volcanic hazards are associated with high temperatures, and in fact monitoring thermal anomalies is a good way to see signs of impending magmatic activity. A peculiar aspect of thermal remote sensing is that the hotter the heat source the lower the required image resolution can be still to see it. This means that to detect a temperature increase in a crater lake or on a volcano flank we need imagery on the order of 10-30 m resolution (e.g. SPOT, ASTER or Landsat TM), while to detect a lava lake much coarser data are sufficient. For example, for imagery with a resolution of 1km x 1km a magmatic feature (which has temperatures of 900-1200ºC) of less than $10m^2$ is sufficient to be detected! The advantage here is that we have geostationary meteorological satellites, such as Europe’s Meteosat Second Generation (MSG) that monitors all of Africa and much of Europe, and provides suitable data every 15 minutes. Asia and the America’s have similar satellites, thus detecting magmatic activity is routinely done. Figure 3.V.8 provides examples of thermal imagery of magmatic activity, from both a high resolution polar orbiter (ASTER [left]) and a geostationary satellite (MSG [right]). We have thus the ability to detect critical changes on the volcano to anticipate magmatic activity, but can also use those data to map lava flows without having to resort to dangerous field visits. There are already automatic systems that detect thermal activity at volcanoes and report it on a webpage (e.g. MODVOLC, http://modis.higp.hawaii.edu/, which is based on daily MODIS images and provides global coverage).

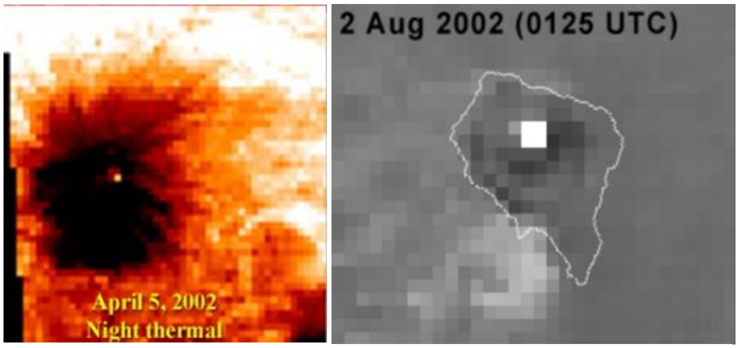


Figure 3.V.8: Sample thermal signals of magmatic activity – Aster night time (left) and Meteosat Second Generation (right).

Even though it has nothing to do with heat, the thermal part of the spectrum is also very useful to detect large gas emissions. For example, SO_2 has been mapped with the Moderate Imaging Spectroradiometer (MODIS, 1000m resolution), as well as with the Total Ozone Mapping Spectrometer (TOMS, ca. 50km resolution).

Task 3.V.6: Internet exercise (duration 30 minutes)
In Task 3.3.V.2 you identified some currently active volcanoes. Go to the MODVOLC page (http://modis.higp.hawaii.edu/)to see if you can find evidence of current magmatic (thermal) activity as well. Try to find 3 volcanoes where the USGS is listing activity and that also show a thermal signal on MODVOLC.

Radar remote sensing

Although there are far fewer operational radar satellites than optical instruments, they are very useful to monitor volcanoes as well, because they provide very different but complementary information. Radar is very sensitive to surface roughness and moisture, but also to subtle surface deformations. Therefore, radar is very well suited to detect a bulging in a volcano's edifice as a result of magma ascending (Figure 3.V.9), when imagery from 2 different dates is used (Differential Interferometry). Vertical changes as small as about 3 cm can be detected this way! However, if the volcano is densely vegetated it can be difficult to do such analysis, as the correlation needed between the images is then lost.

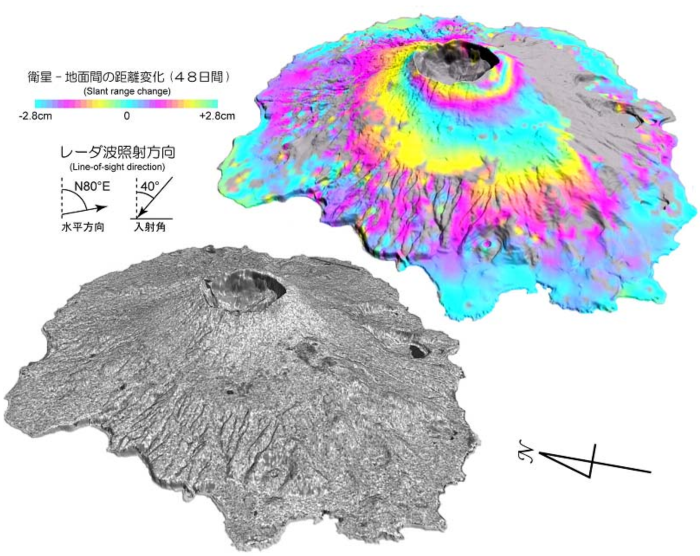


Figure 3.V.9: Crustal deformation after the 2000 eruption of Miyakejima volcano (Japan) detected by RADARSAT (Source: NIED, Japan).

Ground-based remote sensing

Recall that we term any method *remote sensing* where a non-contact measurement of a phenomenon is made. We typically think of satellites or airplanes here, but in fact it also includes measurement devises deployed on the ground that are not in direct contact with the object of investigation. For volcanic hazard assessment and monitoring a variety of instruments are used that are worth mentioning here. In principle, any of the remote sensing types described above can also be used on the ground. For example, a thermal scanner can be hand-carried or mounted on a tripod, and used to map any volcanic thermal features in detail.

Figure 3.V.10: Fourier Transform Infrared Spectrometer (FTIR) deployed at a volcano.

There are also sophisticated devices specifically designed to map volcanic gases, such as a correlation spectrometer (COSPEC) or a Fourier Transform Infrared Spectrometer (FTIR; Figure 3.V.10). Those instruments are usually placed on tripod and pointed directly at a source of the gas, or they "look" through the gas plume at a source of infrared light placed there. The phenomenon used here is that gas constituents such as SO_2 lead to a signal in the recorded infrared energy, allowing the precise calculation of the gas species and the quantity present in the beam.

Figure 3.V.11: Differential GPS deployed at a volcano.

While we can map deformation using radar, also here we can use ground based instruments. For example, measuring positions over time with a Global Positioning System (GPS) device reveals changes (provided a very detailed so-called Differential GPS is used; Figure 3.V.11). For remote measurements also an electronic distance meter (EDM) can be used that maps the distance between the EDM and reflectors mounted previously on the volcano's flank. This way, many readings can be made rapidly and safely. However, radar has the advantage that we get a continuous deformation picture, and not only spot measurements (compare with Figure 3.V.9).

Other devices that are frequently used to map volcanic hazards are microgravity meters (to look for gravity changes associated with magma movements), or ground penetrating radar (to look for buried fault lines or distinct deposition layers).

Three dimensional analysis

When talking about radar interferometry we also already talked about changes in the 3rd dimension. 3D analysis is a common tool in volcanic hazard assessment. For example, stereo aerial photographs can be used to perform stereoscopic investigations to find faults or steep flanks or cliffs (landslide potential). They can also be used quantitatively to create Digital Elevation Models (DEMs; see guidance notes on DEMs). Such DEMs can also be constructed to asses changes. Figure 3.V.12 shows DEMs depicting the situation East of Mount Pinatubo, before and after the 1991 eruption. The change we see corresponds to the material deposited by pyroclastic flows, leading to a smoothing of the terrain. From this difference we can calculate exactly how much material was deposited. This is important information, as each year following the eruption parts of the loose material were remobilised by rainfall, leading to fresh lahars. Figure 3.V.12 shows the change due to erosion in 1991, following the eruption in June of that year.

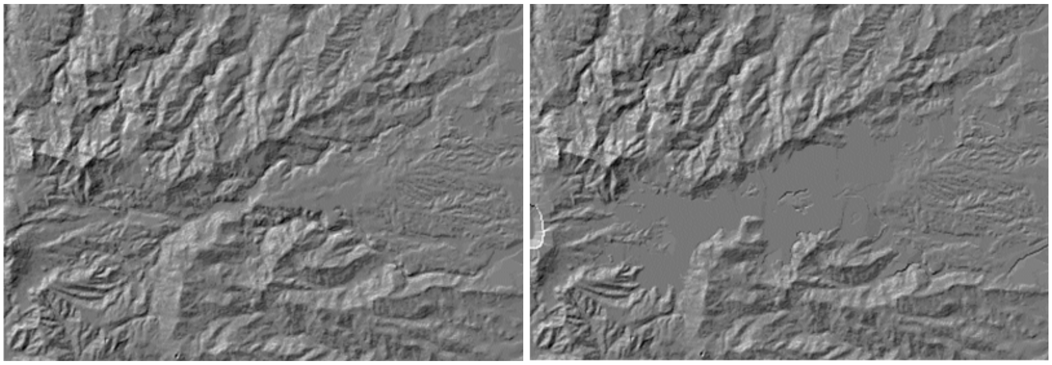


Figure 3.V.12: Digital Elevation Models before (left) and after (right) the 1991 eruption of Mount Pinatubo (Philippines).

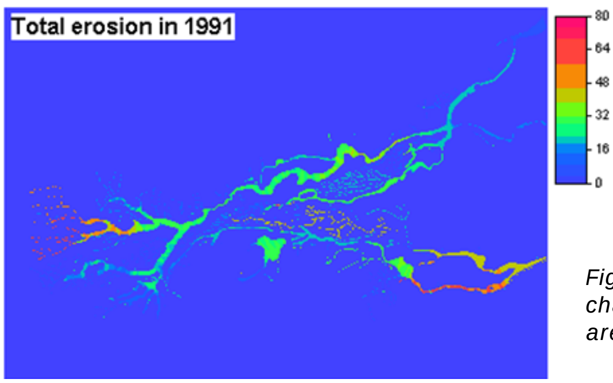


Figure 3.V.13: Digital Elevation Model of change, showing the material lost in the area shown in figure 11 in 1991.

Task 3.V.7: Exercise (duration 30 minutes)
We have reviewed in this session what volcanic hazards exist, and how those hazards can be assessed and monitored using remote sensing methods. Select a volcano of your choice that is located close to a populated area and that is currently active. Design a broad hazard monitoring strategy for that volcano that is based on remote sensing approaches. Consider specifically the following:

- *the hazard types present*
- *the temporal, spatial and spectral characteristics and thus monitoring requirements*
- *make a table listing the hazard, the monitoring type and needed sensor, and how often observations have to be done.*

Refer to the IGOS geohazards report (200&, see further reading list) for guidance on volcano monitoring.

3.V.5 Summary

Instead of a single hazard we see that we have to consider about 17 individual hazards at a single volcano, each with its own spatio-temporal characteristics. To understand the hazard situation comprehensively, we would have to study each of those hazards in terms of its magnitude, frequency and consequences on people, infrastructure and environment. Doing this in the field is time-consuming as well as frequently dangerous. Remote sensing provides many ways to study nearly all hazards not only in an easier manner, but frequently also in a more comprehensive way. For example, instead of spot measurement with a GPS or a thermal scanner we get a synoptic image (covering the whole area continuously). What is vital is that we understand every hazard in terms of its spatial, spectral and temporal aspects, so that we can design a suitable remote sensing based monitoring strategy. For several hazard types (e.g. to look for magmatic activity or large ash emissions that may pose a threat to aviation), automated systems have already been set up.

While we have largely talked about remote sensing in this chapter, it must be made clear that GIS also plays an important role. While remote sensing can provide the data (images, thermal readings, etc.), and image processing can be done to interpret those data, a GIS is the typical environment where all data are integrated and further processed. The DEM change detection shown in Figure 3.V.13, for example, was carried out in a GIS. You will see more examples of this in later chapters, and also learn how to do this yourself.

Self-test

Self test
In order to evaluate whether you have understood the concepts that were presented in this session. Please make the following test, and check the answers in Blackboard.

Question 1: Volcanic hazard
Which if the following can be considered volcanic hazards?
A) Pyroclastic flows
B) Ash columns
C) Collapsing buildings
D) Volcanic gases (e.g. SO_2 and CO_2)

Question 2: Remote sensing data type I
Which of the following remote sensing types is suitable to assess the increase in water temperature in a volcanic crater lake?
A) Geostationary weather satellite (e.g. Meteosat Second generation)
B) Radar remote sensing
C) Medium resolution instruments such as Landsat TM or ASTER
D) Aerial photos

Question 3: Remote sensing data type II
Which of the following remote sensing types is suitable to assess the surface deformation of a volcano, for example when magma is rising on the inside?
A) Stereo aerial photos
B) GPS
C) Laser scanning
D) Radar (Differential Interferometry)

Question 4: Volcanic hazard assessment

Why is volcanic hazard assessment so difficult?

A) Volcanoes are always in far away places

B) There are many types of hazard that need to be considered

C) Assessing the frequency of some hazard types can be difficult because they do not occur very often

D) Satellite data are too expensive

Question 5: Thermal remote sensing

Why is it sometimes difficult to map volcanic thermal anomalies?

A) The thermal features are too hot to sense them

B) Wildfires can be mistaken for a volcanic thermal anomaly

C) The thermal feature may be too small for a given/available thermal sensor

D) The temporal resolution of our satellites is too low to observe thermal anomalies

Further reading:

Douglas, J., 2007, Physical vulnerability modelling in natural hazard risk assessment: Natural Hazards and Earth System Sciences, v. 7, p. 283-288.

Francis, P. and Oppenheimer, C., 2003, Volcanoes, Oxford University Press.

Integrated Global Observing Strategy (IGOS), 2007, Geohazards Theme Report. www.igosgeohazards.org/pdf/theme_reports/igos_geohazards_report_2007.pdf

Tralli, D.M., Blom, R.G., Zlotnicki, V., Donnellan, A., and Evans, D.L., 2005, Satellite remote sensing of earthquake, volcano, flood, landslide and coastal inundation hazards: Isprs Journal of Photogrammetry and Remote Sensing, v. 59, p. 185-198.

Vallance, J.W., Schilling, S.P., Devoli, G., and Howell, M.M., 2001, Lahar hazards at Concepción volcano, Nicaragua: USGS Open-File Report, v. 01-457, vulcan.wr.usgs.gov/Volcanoes/Nicaragua/Publications/OFR01-457/OFR01-457_plate_1.pdf

Guide book
Choice session 3.E:
Earthquake hazard assessment

Objectives

After session 3.E you should be able to:

-

This session contains the following sections and tasks

Section	Topic	Task	Time required	
3.E.2	Definition and classification			
3.E.3	Locations and types of earthquakes			
3.E.4	Earthquake related hazards			
3.E.5	Application of remote sensing in earthquake hazard assessment			
3.E.6	Seismic hazard assessment approaches			
3.E.7	Inventory of spatial datasets required in earthquake hazard assessment			
3.E.8	Educational material			
		Total		

3.E.1 Introduction

Earthquakes are the greatest threat to mankind, killing and maiming thousands every year. According to the National Earthquake Information Center (NEIC) USA (2009), from 2000-2008 alone, an average of (almost) 28,000 people per year were killed throughout the world (see table 3.E.1 below). The death toll in most cases is in the least developed countries rather than the developed countries affected by similar magnitude earthquakes. The strongest and most destructive earthquake of 2008 occurred in Eastern Sichuan, China on May 12, claiming at least 69,185 lives. This 7.9 magnitude earthquake injured 374,171 people, while a further 18,467 remain missing and are presumed dead in the Chengdu-Lixian-Guangyuan area. More than 45.5 million people-a total greater than the combined populations of California, Arizona and Nevada-were affected by this earthquake, which struck in one of China's most densely-populated regions. The event also triggered many landslides, some of which buried large sections of some towns including Beichuan.

Table 1.E.1: Earthquake statistics for the period of 2000 to 2008 obtained from the USGS NEIC website (http://neic.usgs.gov/neis/eqlists/eqstats.html).

Magnitude	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009
8.0 to 9.9	1	1	0	1	2	1	2	4	0	0
7.0 to 7.9	14	15	13	14	14	10	9	14	12	4
6.0 to 6.9	146	121	127	140	141	140	142	178	166	21
5.0 to 5.9	1344	1224	1201	1203	1514	1693	1712	2074	1600	268
4.0 to 4.9	8008	7991	8541	8462	10888	13919	12838	12078	12463	999
3.0 to 3.9	4827	6266	7068	7624	7935	9193	9990	9889	11723	334
2.0 to 2.9	3765	4164	6419	7727	6317	4637	4027	3597	3858	290
1.0 to 1.9	1026	944	1137	2506	1344	26	18	42	22	4
0.1 to 0.9	5	1	10	134	103	0	2	2	0	0
No Magnitude	3120	2807	2938	3608	2942	864	828	1807	1930	4
Total	22256	23534	27454	31419	31200	30483	29568	29685	31774	1924
Estimated Deaths	231	21357	1685	33819	228802	82364	6605	712	88011	46

It is well known that an earthquake does not kill people, but that it is buildings which do. This is because most deaths from earthquakes are caused by building or other human infrastructure falling down during an earthquake. This warrant the need for carefully designed buildings and other infrastructure. The threat to human activities from earthquakes is sufficient to require their careful consideration in design of structures and facilities.

Why Study Earthquake?

There are two reasons as to why we should study and understand earthquakes:

- Most of the big cities of the world are situated along active major and minor plate boundaries where earthquake activities are predominant.

  The earth's surface does not exist in a static, unchanging "natural" condition interrupted only by the work of humans, but instead it is a dynamic system of which humans are a part. Knowledge about changes to the Earth's surface and the underlying processes that induce them has enormous impact on how society responds to these changes and, ultimately, the cost of responding to change.

- Most of the major towns and cities are situated in Quaternary sediments. In many geological maps Quaternary sediments are colored yellow with no details. The traditional view that Quaternary sediments do not exhibit major earthquakes or large crustal surface deformations; have obscured the fact that several observations have documented the contrary, albeit not on scales comparable with plate margin deformations. A detailed geologic mapping over the last two decades in selected Quaternary areas of the world has revealed several sites of recent or contemporary surface deformations, but still this type of information is poorly integrated and emphasized in the scientific community. Also more recent studies of earthquake occurrence in many parts of the world have revealed several regions of unexplained high seismic activity, but an undisputed correlation between earthquakes and surface deformation is still pending.

3.E.2 Definition and classification

Definition:
Earthquakes are vibrations of the Earth caused by the rupture and sudden movement of rocks that have been strained beyond their elastic limits.

Earthquakes are the expression of the continuing evolution of the Earth planet and of the deformation of its crust and occur worldwide. For millions of years, the force of plate tectonics have shaped the Earth, as the huge plates that form the Earth's surface collided, separated or slide past each other. At times, the movement is gradual while at other times, the plates are locked together, unable to release the accumulating energy. When the later energy is great enough, the plate breaks or shifts along a **fault** (Fig 3.E.1). Displacement happens in a matter of seconds to minutes. The strained rock snaps into a new position and, in the process of rebounding, generates vibrations called **seismic waves**, which we feel during an earthquake. Intensive vibration, or seismic waves, spread out from the initial point of rupture, the earthquake's **focus, or hypocenter** (Fig 3.E.2) in circles outward. The point on the Earth's surface directly above the focus is the **epicenter.** The line along which the fault plane intersects the Earth's surface is the fault **trace**. If there is a vertical movement along the fault, the cliff formed is called a fault **scarp.**

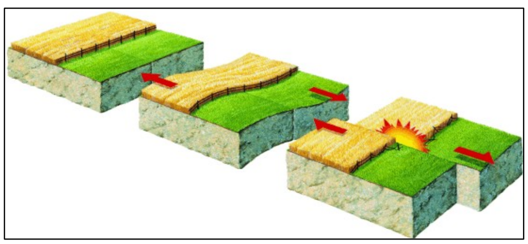


Figure 3.E.1

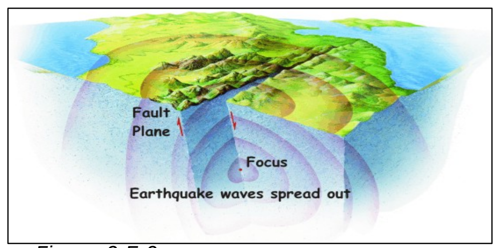


Figure 3.E.2

3.E.3 Locations and Types of Earthquakes:

The locations of major epicenters over nearly a decade show that most earthquakes (with some exceptions) are concentrated in linear belts corresponding to plate boundaries (Fig 3.E.3).

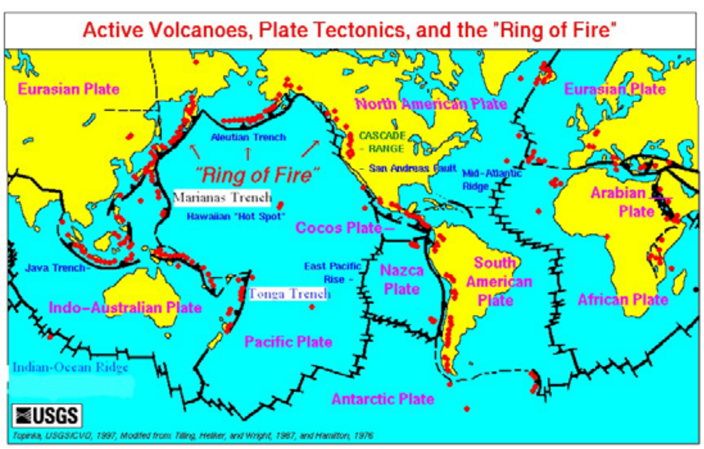


Figure 3.E.3 presents the Earth's outermost surface broken into 12 rigid plates which are 60-200 km thick and float on top of a more fluid zone (magma), much in the way that icebergs float on top of the ocean.

Earthquake Characteristics

The Earth is formed of several layers with different physical and chemical properties. Locations where earthquakes can occur include:

I. InterPlate Earthquake: Earthquakes that occur in the fault zones at plate boundaries (Example: Seismicity associated with the Himalayan seismic belt). Three types of plate boundaries are known (see Fig.5 and 6).

- ***Ocean spreading ridges:*** These are places in the deep ocean basins where the plates move apart. With separation, hot lava from the Earth's mantle rises between the plates, gradually cools, contracts, and cracks, subsequently creating faults. Most of these faults are normal faults. Near the spreading ridges, the plates are thin and weak. The rock has not cooled completely, so it is still somewhat flexible. For these reasons, large strains cannot build, and most earthquakes near spreading ridges are shallow and mild or moderate in severity.
- ***Subduction zones:*** Places where two plates collide and the edge of one plate pushes beneath the edge of the other in a process called <u>subduction</u>. Because of the compression in these zones, many of the faults there are *reverse faults*. About 80 per cent of major earthquakes occur in subduction zones encircling the Pacific Ocean. In these areas, the plates under the Pacific Ocean are plunging beneath the plates carrying the continents. The grinding of the colder, brittle ocean plates beneath the continental plates creates huge strains. The world's deepest earthquakes occur in subduction zones down to a depth of about 700 km. Below that depth, the rock is too warm and soft to break suddenly and cause earthquakes.
- ***Transform faults:*** are places where plates slide past each other horizontally. Earthquakes along transform faults may be large, but not as large or deep as those in subduction zones. One of the most famous transform faults is the San Andreas Fault. The slippage there is caused by the Pacific Plate moving past the North American Plate. The San Andreas Fault and its associated faults account for most of California's earthquakes.

II. Intraplate Earthquake:

Intraplate earthquakes are not as frequent or as large as those along plate boundaries. The largest intraplate earthquakes are about 100 times smaller than the largest interplate earthquakes. Intraplate earthquakes tend to occur in soft, weak areas of plate interiors. Scientists believe intraplate quakes may be caused by strains put on plate interiors by changes of temperature or pressure in the rock. Or the source of the strain may be a long distance away, at a plate boundary. These strains may produce quakes along normal, reverse or strike-slip faults.

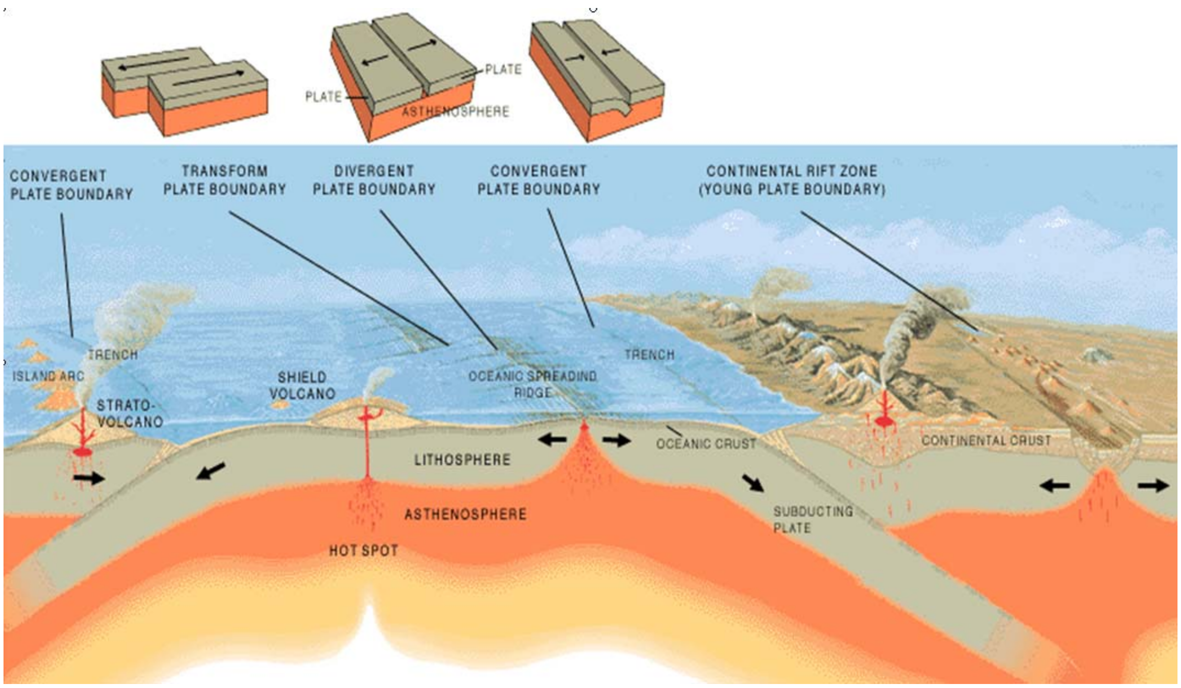


Figure 3.E.4. Earth Plate boundaries (USGS)

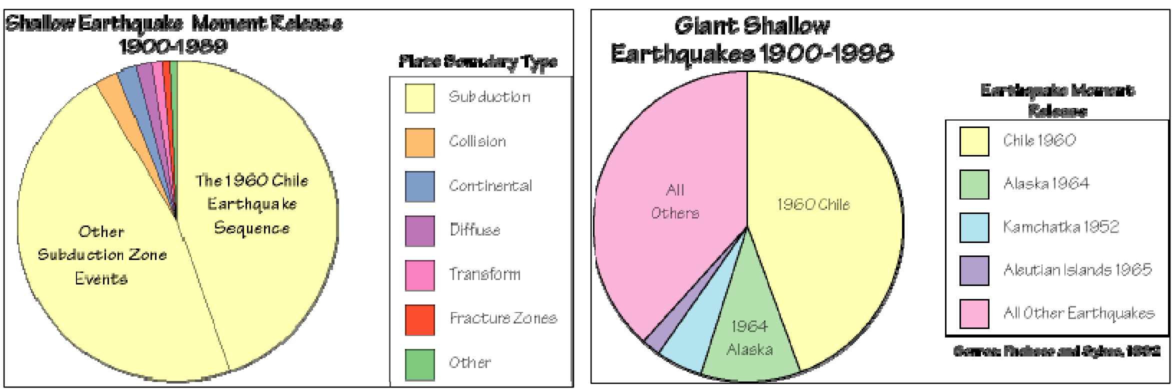


Figure 3.E.5 gives the amount of energy released in the different plate settings (modified after Ammons, 2001).

Types of Earthquakes:

There are three major types of earthquakes: **tectonic**, **volcanic,** and those formed by **human activities**. The region where these earthquakes occur and the geological make-up of that region define the earthquake.

Tectonic Earthquakes. These are caused by the sudden rupturing of rocks in response to various geological forces. Most tectonic earthquakes occur at the boundaries of major and minor plates: transform faults, spreading and subduction zones (see Fig 3.E.4). Perhaps the most famous **transform fault** known is the San Andreas Fault in California, where the North American Plate and the Pacific Plate both move in approximately north-westerly direction, with one moving faster than the other. The land to the east of the fault is moving south while the land to the west is moving north (Fig 3.E.5). Tectonic earthquakes are by far the most common and devastating. Such quakes pose particular difficulties for scientists trying to develop ways to predict them. They are scientifically important to understand the Earth's interior. On the other hand, earthquakes emanating from **subduction-zone** account for almost half of the world's destructive seismic events and 75% of the earth's seismic energy. They are concentrated in a 38,600 km long narrow band that coincides with the margins of the Pacific Ocean and, is known as the 'Ring of Fire' (see Fig. above). The points at which crustal rupture occurs in such quakes tend to be far below the earth's surface, at depths of up to 680 km. The **mid-ocean ridges** (the seafloor-spreading centers of plate tectonics), are also the sites of numerous quakes taking place at relatively shallow depths. Such quakes, account for only about 5% of the earth's seismic energy; are of moderate intensity, and daily recorded by the worldwide network of seismological stations. Other category of tectonic earthquakes includes the infrequent but large and destructive quakes that occur in areas far removed from other forms of tectonic activity but tear apart the earth's crust, forces such as those that created Africa's Rift Valley.

We can measure motion from large tectonic earthquakes using GPS because rocks on either side of a fault are offset during this type of quake.

Volcanic Earthquakes – These type originates as rhythmic earthquakes (or harmonic tremors), occurring as magma and volcanic gas (through conduits in the Earth's crust) which work their way upwards or accompany volcanic eruptions. Given that not all volcanoes are prone to violent eruption, and that most are quiet for the majority of the time, it is not surprising to note that they are by far less common than tectonic earthquakes The eruption of volcano Merapi (Java, Indonesia) in May 2006 for example, resulted in a 6.4 magnitude earthquake off the coast of Java with over 5000 people dead, approximately 40,000 injured and over 130,000 homeless. Similarly, on the island of Hawaii, seismographs may register as many as 1,000 small quakes a day before an eruption occurs.

Human Activity: Humans can induce earthquakes through a variety of activities; some of which include:

- Collapse earthquake**:** small earthquakes in underground caverns and mines that are caused by seismic waves produced from the explosion of rock on the surface.
- Landslides Collapse earthquakes: Earthquakes due to landslides are caused by the release of gravitational potential energy rather than elastic strain energy.
- Explosion earthquakes: produced by the detonation of chemicals or nuclear devices.

3.E.4 Earthquake Related Hazards

The principal ways in which earthquakes cause damage are by strong ground shaking and by the secondary effects of ground failures (surface rupture, ground cracking, landslides, liquefaction, subsidence, etc.). While 20% of death recorded account to crustal movement, the majority (around 80%) are secondary hazard; an indirect result of an earthquake. Very often, earthquakes with different magnitudes trigger different secondary hazardous events, frequently attributed to the epicenter area of a strong earthquake. (See Table 3.E.2).

A. Primary Hazard - Directly related to crustal movement (approx. 20%)-

Ground Motion – The shaking of the ground caused by the passage of seismic waves, especially surface waves near the epicenter of the earthquake are responsible for the most damage (to building and other structures). The strength of ground shaking (strong motion) depends upon:

- **Local geological conditions.** The soil and slope conditions through which the earthquake waves travel through in the area. In general, loose unconsolidated sediment is subject to more intense shaking than consolidated soil and bedrock.
- **T**he **magnitude of the earthquake**. The bigger the earthquake, the more intense is the shaking and the duration of the shaking.
- The **proximity to the epicenter**. Shaking is most severe closer to the epicenter due to amplification (an increase in strength of shaking for some range of frequencies) and drops off as it moves away from the earthquake source (attenuation). The distance factor is dependent on the type of the underlying material involved.

Amplification occurs where earthquake waves pass from bedrock into softer geologic materials such as sediments. Buildings on poorly consolidated and thick soils will typically suffer more damage than buildings on consolidated soils and bedrock.

B. Secondary Hazard - <u>Indirect result of earthquakes (approx. 80%)</u>-
Secondary earthquake hazards are those separate from, but induced by, the primary effects of strong ground shaking and fault rupture. Secondary geologic hazards include ground and slope failures and seiches, discussed below. (More broadly, secondary hazards also include non-geologic effects such as fires).

Fault and Ground Rupture resulting from earthquake happenings almost always follows preexisting faults, which are zones of weakness. During faulting, energy is released. Rocks continue to move until the energy is used up. Thus structures that are built across fault zones may collapse or split, roads disrupted, and many features that lie on or that cross the fault may break whereas structures built adjacent to, but not crossing the fault may survive.

Aftershocks – These usually comprise of smaller earthquakes of different magnitudes that occur after the major earthquake. They occur due to stress pattern changes surrounding the epicenter area and might continue until the crust adjusts to the changes. Aftershocks often cause structural damaged to building and other structures.

Earthquake-Induced Landslides – In mountain regions subjected to earthquakes, ground shaking can trigger all types of seismically induced landslides (e.g., soil slumps, rock falls, debris flows, rock avalanches) many kilometers from their epicenters. They can destroy roads, buildings, utilities, and other critical facilities necessary to respond and recover from an earthquake. Landslides triggered by earthquakes often cause more destruction than the quakes themselves. Since 1964 landslides resulting from large-magnitude earthquakes in Japan have accounted for more than half of all earthquake-related deaths.

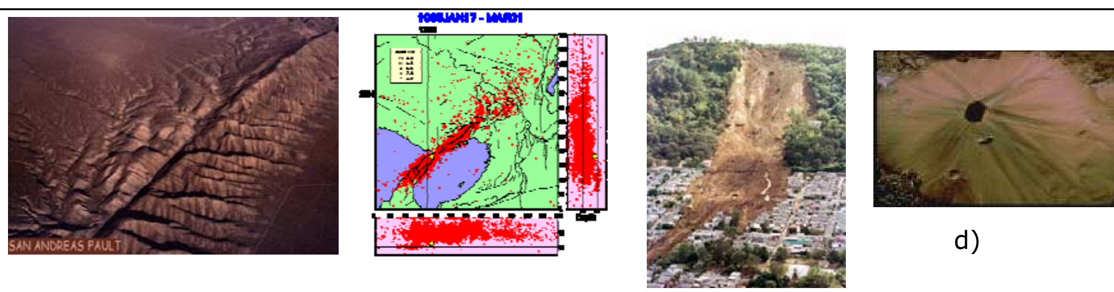


Figure 3.E.6: Indirect result of earthquakes. a) shows Earth manifestation of fault or ground rupture vivid in Landsat TM; b) shows aftershocks; c) the effect of earthquake induced landslide in Ecuador and the d) liquefaction.

Earth Cracks (earthquake dislocations): This is most dangerous secondary event occurring during the earthquakes. The movement is sudden and may result in considerable vertical (in case of normal or trust faulting) or horizontal (in case of strike slip faults) accelerations that might offset any building construction on its way. It should be absolutely forbidden to build dangerous facilities (like dams, nuclear instalations, factories, etc.), near or over the expressed earth cracks generated by old or recent earthquakes.

Liquefaction occurs when water-saturated materials (sands, silts, or (less commonly) gravels) are shaken so violently that the grains rearrange and the sediment looses strength or shearing resistance, begins to flow out as sand boils (also called sand blows), or causes lateral spreading of overlying layers. Liquefaction-induced horizontal ground movements can range from minor oscillations during ground shaking with no permanent displacement, to small permanent displacements, to lateral spreading and flow slides. Liquefaction can also induce vertical ground movements (settlement) by rearrangement of loose soils into a denser configuration. In the Mexico City earthquake of 1985, the wet sand beneath tall buildings liquefied and most of the 10,000 people who died were in buildings that collapsed as their foundations sank into liquefied sand.

Subsidence or Uplift. Tectonic subsidence or uplift is the sudden relative elevation change of a large area of the earth's surface due to an earthquake. Historically, the impact of subsidence has been more severe than uplift, especially where accompanied by flooding. In the 1964 Alaskan Earthquake for example, some areas were uplifted up to 11.5 meters, while other areas subsided up to 2.3 meters.

Tsunamis and Seiches: Tsunamis are giant ocean waves generated by shallow-focus earthquake, but can also be caused by underwater landslide and volcanic eruption. They can travel at a speed of 700-800 km per hour and can reach heights greater than 20 meters as they approach the coast. The most devastating tsunami to affect California in recent history was the 1964 magnitude 9.2 Alaskan earthquakes. The first wave struck Crescent City about 4 hours after the Alaska event, but the fourth and largest wave arrived 2 hours later. It flooded low-lying communities, destroyed homes and businesses, and killed 11 people. Seiches are waves that slosh in an enclosed body of water, such as a swimming pool, lake, or bay.

Floods from dam and levee failures. Flooding caused due to failure of man-made dams and levees, or due to tsunamis, and as a result of ground subsidence after an earthquake.

Fires. Fire is a secondary effect of earthquakes and it has a devastating effect. Because power lines may be knocked down and because natural gas lines may rupture due to an earthquake, fires are often started closely following an earthquake. The problem is compounded if water lines are also broken during the earthquake since there will not be a supply of water to extinguish the fires once they have started. In the 1906 earthquake in San Francisco more than 90% of the damage to buildings was caused by fire.

Table 3.E.2: table showing the earthquake magnitude versus the secondary effect of the earthquake. Never=0%, very rare= up to 5%; sometimes= 5-10%; rare=10-20%; Frequently=20-50%; very frequently=50-90%; always=100%

Earthquake magnitude/ Secondary effects	Fault Rupture	Aftershocks	Landslides	Rockfalls	Earth cracks	Subsidence/or uplift	Tsunamis or Seiches	Liquefaction	Floods	Fire
M =3.0-4.0	always	always	very rare	very rare	never	vary rare	never	never	never	never
M=4.0-5.0	always	always	sometimes	sometimes	never	sometimes	never	never	frequently	Very rare
M=5.0-6.0	always	always	frequently	very frequently	rare	frequently	very rare	frequently	sometimes	sometimes
M=6.0-7.0	always	always	very frequently	always	very frequently	always	frequently	always	Always	sometimes
M= > 7.0	always	always	always	always	always	always	always	always	always	always

3.E.5 Application of Remote Sensing in Earthquake Hazard Assessment

Over 50,000 earthquakes occur every year on Earth. About a thousand of these are over magnitude 5 on the Richter scale and often cause damage to human settlements. Satellite data provide a unique opportunity to measure fine changes in the earth surface which are often precursors of an earthquake.

A glance at the present activities of the major players in the Earth observation field from the technological perspective, NASA, ESA, etc. shows that long term missions comprise of complementary but far better sensor quality, higher spectral/spatial resolution and better calibration. Potential applications for one-meter and 60 cm satellite imagery, such as IKONOS, Quick Bird in a GIS environment for earthquake hazard are limitless. The modern operational space-borne sensors in the infra-red (IR) spectrum allows monitoring of the Earth's thermal field with a spatial resolution of 0.5–5 km and with a temperature resolution of 0.12–0.5 C. Surveys are repeated every 12 hours for the polar orbit satellites, and 30 minutes for geostationary satellites. The operational system of polar orbit satellites (2–4 satellites on orbit) provides whole globe survey at least every 6 hours or more frequently. Such sensors may closely monitor seismic prone regions and provide information about the changes in surface temperature associated with an impending earthquake. The optical data received by the various remotely sensed sensors can also serve as detailed base map upon which thematic map layers can be overlaid, or it can be used as an up-to-date data source from which various geological and structural features, neotectonics, slope instability features, land cover, soil degradation, hydrology and other activities related to elevation features are extracted to populate multiple GIS layers [25] in an earthquake hazard study.

With the operational use of sensors with higher spectral resolutions, such as ASTER *(Advanced Spaceborne Thermal Emission and Reflection Radiometer)*, the quantification of the composition of earth surface materials becomes feasible. ASTER data also serve to obtain maps of land surface temperature, emissivity, reflectance and elevation.

The European Space Agency (ESA) *Envisat mission* involves a laser altimeter, a SAR interferometry system (ASAR), an imaging spectrometer (MERIS) etc. An important issue within the context of ESA is the Global Monitoring for Environment and Security (GMES; part of a larger framework of three such monitoring systems, the G3OS) initiative. Data collected by *airborne spectrometers* have already demonstrated that it is possible to identify certain types of exposed mineralogy, to label the minerals present along seismic areas and to determine the fractions of the minerals occurring in small, sub-pixel units.

Since the launch of European Synthetic Aperture radar - ERS1/2 and Envisat ASAR, a technique called SAR Interferometry (inSAR) has become available. With the potential to simultaneously operate two platforms, the time between acquisitions can be reduced to ensure an adequate coherence between successive SAR scenes while maintaining each platform in an orbit configuration that ensures a maximum possible coverage of the Earth's surface. SAR Interferometry has greatly helped geophysical hazard analysis, and can provide with unprecedented precision:

- high-resolution images of earthquake-prone areas;
- topographic data (DTM's using stereopairs of radar images with differing viewing angles);
- Measurement of dislocation extent at the source of an earthquake;
- Measurement of small height variations due to the filling and drainage of magma chambers under volcanoes;
- Monitoring earthquake prone regions (with these instruments) to assist in the forecasting of earthquakes, as well as in the management and evaluation of earthquake-associated risks; and
- A map of coseismic deformation generated by an earthquake (Fig 3.E.7).
- The precise monitoring of surface deformation allowing accurate zoning, mapping and prediction of volcanic eruptions, landslides and ground subsidence.

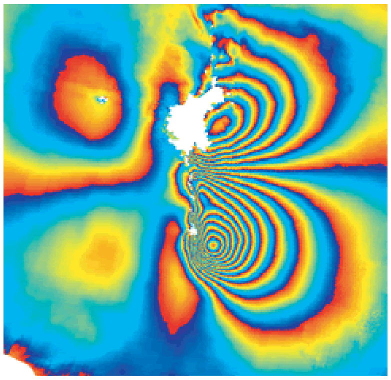


Figure 3.E.7: InSAR Data from the Bam Earthquake, Iran of 2003 showing surface deformation.

Differential interferrometry allows one to measure surface movements with sensitivity of the order of a few centimeters over large surfaces [26]. Similar InSAR data can also be obtained from RADARSAT and ALOS PALSAR.

The successful launch of the Envisat ASAR in March 2002 sparkled the interest for multipolarisation. The new technique, called POLinSAR (SAR Polarimetry and Polarimetric Interferometry) is giving promising results in many application fields, among which the study of Volcanoes and Earthquakes.

In most countries of the world, accurate topographic base map and digital terrain model (DTM) of the area under investigation for earthquake hazard is missing. In any GIS work therefore, this problem remains a handicap. An exciting development towards solving this acute problem is envisaged from the new *Shuttle Radar Topographic Mapping (SRTM*) acquired by Space Shuttle Endeavour in February 2001. The SRTM instrument captured allows one to create very detailed topographic maps of the Earth's surface using interferometry. This radar system gathered data that will result in the most accurate and complete topographic map of the Earth's surface that has ever been assembled. Already immense data covering the world, is processed open to all researchers and end users (either at 30 m or 90 m resolution) to accurately obtain knowledge regarding the shape and height of the land, and to assess: flood, soil degradation, slope instability features, erosion, geological structures especially in neotectonic studies, drainage analysis and landscape changes, all elements of high importance to earthquake hazard mapping (Woldai,2002a).

By combining those data with pre-existing data layers, it is possible to validate existing data to provide a better understanding of the phenomena occurring, and to elucidate previously undetected and unmonitored areas of motion, all at a fraction of the normal survey cost.

3.E.6 Seismic Hazard Assessment Approaches

Probabilistic and **deterministic** methods play an important role in seismic hazard and risk analyses. The two approaches can complement one another in providing additional insights into the seismic hazard or risk problem.

> ***Probabilistic**: This method incorporates both historical seismicity and geologic information within fault zones (Fig.9) that displays evidence of neotectonic activities (Late Pleistocene and Holocene times) and computes the probable ground shaking levels that may be experienced during, say, a 100-year, 500-year or 2,500-year recurrence period.*

The probabilistic assessment derives the long-term likelihood of shaking in each area and, therefore, tells how hazardous a given area is compared to others nearby. The three contour maps, developed by the U.S. Geological Survey (Fig 3.E.9), show the expected intensity of ground shaking (PGA) in the eastern U.S. for the three average return periods (100, 500, and 2,500 years). The three assessments correspond to probabilities of 40%, 10% and 2%, respectively, that in any 50 year-period the mapped ground motion values would be exceeded. These probabilistic estimates serve best for urban planning, particularly land-use zoning, and seismic building code regulations, but they also help to determine risk based earthquake insurance premiums.

Deterministic: This procedure bases the calculation of the seismic design of a facility on the largest earthquake or ground motion at the site of the facility. This method assumes the location and magnitude of specified scenario earthquakes and determines the effects from these particular events.

In contrast to the probabilistic method, deterministic scenarios provide the "what if", answers for particular assumed earthquakes. As we change their magnitudes and locations, we can see how various areas are differentially affected by different events. If you design for the worst thing possible, then you are likely to be safe. For deterministic scenarios, we do not ask how likely each scenarios is. The deterministic scenarios are good for testing a region's emergency preparedness and how it would cope with disaster losses of various magnitudes.

The stages in the deterministic seismic hazard mapping method involves: 1) Finding the nearest active fault; 2) Calculating the largest earthquake that could happen on this fault; 3) Assuming the largest earthquake happens at the closest point to your site and 4) Calculating what the ground motion will be.

The advantages of this method are that (a) it is relatively easily to do, and (b) it gives you a conservative answer (note for the uninitiated: "conservative" in this context means a value that maximizes safety). The disadvantages are that (a) often you don't know where the active faults are (several of the largest Californian earthquakes of recent years have occurred on faults that were previously unknown) and (b) it is easy to come up with grossly over-conservative hazard values.

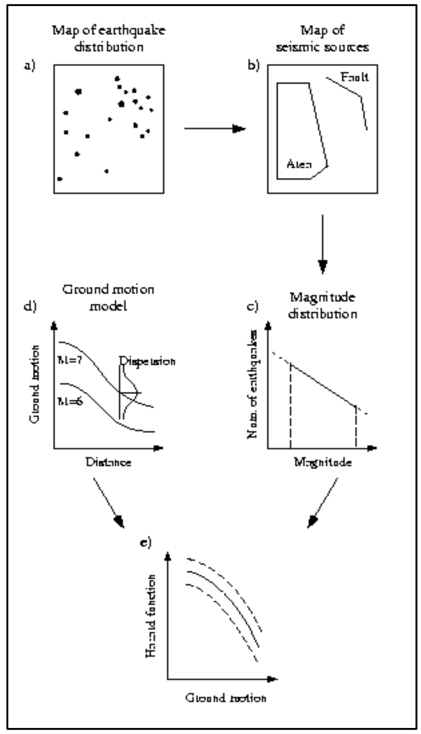


Figure 3.E.8. Characterization of seismic hazard in the probabilistic method achieved by the compilation of earthquake hazard (a), delineation of seismic sources (b), and magnitude-frequency distribution (c) For the evaluation of earthquake hazard, the characterization of attenuation of ground motion is described by attenuation functions (d) *and (e) shows the computation of the probability analysis. After Sellami (???)*

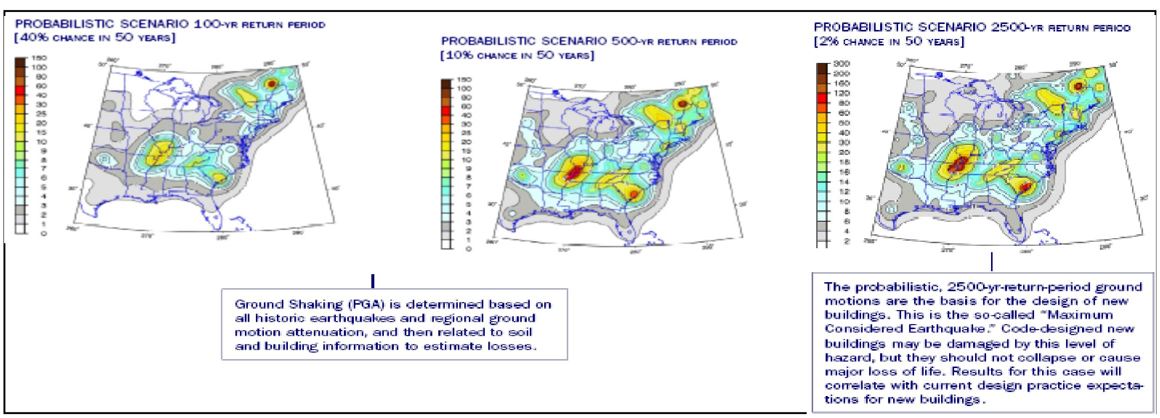


Figure 3.E.9. Maps showing the expected intensity of ground shaking (PGA) in the eastern part of the USA for the return periods of 100, 500 and 2500 years.

In many applications a recursive analysis, where deterministic interpretations are triggered by probabilistic results and vice versa, will give the greatest insight and allow the most informed decisions to be made. The most perspective will be gained if both deterministic and probabilistic analyses are conducted. Probabilistic methods can be viewed as inclusive of all deterministic events with a finite probability of occurrence. In this context, proper deterministic methods that focus on a single earthquake ensure that the event is realistic, i.e. that it has a finite probability of occurrence.

These points to the complementary nature of deterministic and probabilistic analyses: deterministic events can be checked with a probabilistic analysis to ensure that the event is realistic (and reasonably probable), and probabilistic analyses can be checked with deterministic events to see that rational, realistic hypotheses of concern have been included in the analyses.

The basic elements of modern seismic hazard assessment can be grouped into four main categories (*Giardin et al., 1999; Maquaire, Oliver,* 2005*).*

1. Earthquake catalogues and data bases: The compilation of a uniform data-base and catalogue of seismicity for the historical (pre-1900), early-instrumental (1900-1964) and instrumental periods (1964-today).
2. Seismotectonics and earthquake source zones: the creation of a master seismic source model to explain the spatial-temporal distribution of the seismicity, using evidences from seismotectonics, paleo-seismology, geomorphology, mapping of active faults, geodetic estimates of crucial deformation, remote sensing and geodynamic models to constrain the earthquake cyclicity in different tectonic provinces.
3. Strong seismic ground motion: the evaluation of ground shaking as function of earthquake size and distance, taking into account propagation effects in different tectonic and structural environments and using direct measures of the damage caused by the earthquake (the seismic intensity) and instrumental values of ground acceleration.
4. Computation of seismic hazard: the computation of the probability of occurrence of ground shaking in a given time period, to produce maps of seismic hazard and related uncertainties at appropriate scales.

Task: RiskCity exercise 03E: Earthquake hazard assessment (3 hours)

Go to the Riskcity exercise 03E and carry out the GIS exercise on seismic hazard assessment.

3.E.7 Inventory of spatial datasets required in earthquake hazard assessment.

Baseline & Other Thematic Data Needed:
- Topographic maps;
- Elevation, relief, drainage patterns and culture of an area;
- Remotely sensed data
    - Passive and active remote sensing data;
    - Interferometric data;
    - High-resolution seismic reflecting surveys;
    - Gravity maps;
    - Magnetic maps, and
    - Seismic refraction surveys
    - Spectroscopic data
- GPS network
- Earthquake catalogue
- Etc.

Geomorphologic inputs
- Terrain units
- Slope and aspect map
- Digital Elevation Model
- Erosion map
- Slope Instability map
- Slopes susceptible to landslides (30° or more)

Soil inputs:
- Soil types
- Engineering soil maps showing bearing capacity of soils.
- The thickness of the unconsolidated sediments dawn to real bedrock.
- The age and mineral composition of the soil.
- The depth of the ground-water table.
- Borehole data related to rock types, soil and subsurface groundwater flow

Geological input
A wider range of geological information is applicable to the determination of seismic hazard. These include:
- Inventory of reports and maps on the geology, structure and soil involved
- Surface and sub-surface geology (age and rock types)
- Stratigraphy
- Structural geological & tectonic mapping of the area/region with a detailed account of neotectonic activities
- Mapping of quaternary sedimentary

Structural Input:
Active faults mapping with type of disc placement involved in the Holocene-Pleistocene period
- Fault styles
    - Dip slip/fault slip/oblique
    - Normal/or reverse; sinistral or dextral
- Fault type
    - Normal/reverse/transform faulting
- Deformation style
    - Extension/compression/transformation
- Fault classification
    - Active or reactivated
- Fault geometry
    - Orientation of the fault
    - Dip and strike, slip
- Average displacement across the fault
- Depth of fault

Types of information derived from the seismogram
- Magnitude of the earthquake
- Seismic energy released by the earthquake
- Moment of the earthquake
- The spatial dimensions of the fault which ruptured
- The elastic constants of the medium in which the fault is located
- Orientation of the fault
- Average displacement across the fault
- Depth of fault
- Velocity with which rupture propagates on the fault
- Known faults and epicenters
- The stress drop across the fault
- The configuration of the fault plane at depth (i.e., whether planar or wrapped)

Seismological input
- Documentation of the earthquake history of the region (location, magnitude and maximum mercalli intensities illustrated by means of regional maps)
- Construction of recurrence curve maps
- Review of historical shaking, damage and other intensity information near the site
- Correlation of epicenter locations and tectonic structures
- Seismic attenuation data
- Seismic response data

Groundwater input:
- Groundwater level
- Drainage network
- Borehole data related to subsurface groundwater flow

Vulnerability data:
- data on damage from historical events;
- vulnerability curves for different structural types

Data for elements at risk:
Reports, publications, maps, etc. on elements at risk:
- Buildings (classification according to age, use, socio-economic class, building material, number of floors, contents)
- Network of roads and railways
- Network of major water conduits
- Distribution of sanitation facilities
- Network of gas and electric lines
- Distribution of hospitals, fire station and other public structureS
- Population (age distribution, average No. of people per house, gender distribution, socio-economic classification)
- Economic activities;
- Lowland areas subject to liquefaction;
- Area subject to salt-water invasion;
- Area subject to freshwater inundation;
- Map of isolated area
- Map of relative seismic safety.

3.E.8 Educational Materials

In this section, various illustrations and videos examples are assembled to facilitate one's understanding of earthquakes and its effects. The links to the videos and illustrations are provided below.

Animations and Films on:

a) Fault Motion:
These animations give very elementary examples of fault motion intended for simple demonstrations. For more about faults see the NOAA slide show and information page - a rich source of images and written information.

(http://www.iris.washington.edu/gifs/animations/faults.htm)

b) Shock Waves: One Hundred Years After the 1906 Earthquake
A 46-minute USGS film that includes dramatic historical footage, colorful animations, and interviews with earthquake experts. The catastrophe of the great 1906 quake spurred a century of progress in earthquake science and engineering. Current and future research includes drilling through the San Andreas Fault at depth in the SAFOD Experiment. Learn what you can do to reduce the risk to yourself and family.
Shock Waves received recognition as an outstanding documentary at the 2006 Telly Awards and has been nominated for an Emmy.

(**http://earthquake.usgs.gov/regional/nca/1906/shockwaves/**)

c) Earthquake – Natural Disaster:
Gives an overview of disasters from various events as a result of earthquake

(http://www.metacafe.com/watch/46548/earthquake/)

d) Animations for Earthquake Terms and Concepts
USGS Videos and Animations: earthquakes, plate tectonics, geology, tsunamis, and more.

(http://earthquake.usgs.gov/learning/animations/)

See also Earthquake facts on
(http://earthquake.usgs.gov/learning/facts.php)

e) World Historical Earthquake Locations – FGDC Metadata

(http://www.pdc.org/mde/full_metadata.jsp?docId=%7B659C82C4-E366-42A0-BEF7-743722067C2A%7D)

f) Earthquake images:
A comprehensive collection of earthquake related slides and photographs

http://www.johnmartin.com/earthquakes/eqshow/index.htm

g) Earthquake learning topics

http://earthquake.usgs.gov/learning/topics/

Selftest

In order to evaluate whether you have understood the concepts that were presented in this session. Please make the following test, and check the answers in Blackboard.

Question: Earthquake hazard assessment
Which of the following statements is true?
A) An earthquake has a particular magnitude, but can generate different intensities
B) An earthquake has a particular intensity, but can generate different magnitudes
C) An earthquake has a particular magnitude and a particular intensity
D) An earthquake can have several magnitudes and several intensities.

Question: Earthquakes

By means of a block diagram show the following:

- Fault plane
- Fault scarp
- Fault trace
- Hypocenter
- Epicenter
- Seismic waves

Question: Earthquake waves

Name at least 4 differences between a surface wave and a body wave.

Question: Probabilistic / deterministic

What are the main differences between a deterministic and a probabilistic method for earthquake hazard assessment.

Further Reading

The USGS website contains a wealth of scientific information on earthquakes and the associated hazard. To deepen your knowledge in this field, you are advised to look into:

- **Seismic Hazard Maps – on probabilistic hazard maps**

  http://earthquake.usgs.gov/research/hazmaps/products_data/index.php

- **Deterministic and Scenario Ground-Motion Maps - Learning on Shake Map Scientific Background**

  http://earthquake.usgs.gov/eqcenter/shakemap/background.php#scenario

- **Custom Mapping and Analysis Tools**
  Where you can:
  - Re-plot USGS maps for your region of interest.
  - Create a Custom Probability Map of your own
  - Java Ground Motion parameter calculator
  - Interactive hazard maps – Add/subtract GIS layers
  - Seismic design values for building
  - Etc.

http://earthquake.usgs.gov/research/hazmaps/interactive/

References:

- Ammons, Charles J. (2001). Introduction to Earthquakes and Earthquake Hazards, http://www.earthscape.org/t1/amc01/amc01j/amc01j.html (accessed May 2002)
- CDMG (1996). Probabilistic seismic hazard assessment for the state of California, Calif. Div. Of Mines and Geology, Sacramento, Open-file Rept. 96-08.
- Giardini, D., Grünthal G., Shedlock, K., and Zang. P. (1999). Global seismic hazard map produced by the Global Seismic Hazard Assessment Program (GSHAP), Map and legend
- Hays W. W. (ed.) (1981). Facing Geologic and Hydrologic Hazards: Earth Science Considerations. U.S. Geological Survey Professional Paper 1240-B (Reston, Virginia: U.S. Geological Survey, 1981).
- Kockelman W. W. (1983). Examples of Use of Geologic and Seismological Information for Earthquake Hazard Reduction in Southern California. U.S. Geological Survey Open File Report 83-82 (Reston, Virginia: U.S. Geological Survey, 1983).
- Maquaire, Oliver (2005). Geomorphic Hazards and Natural Risks in: The Physical Geography of Western Europe (Editor: Eduard A. Koster), Published by Oxford University Press, ISBN 0199277753, 9780199277759, 438 pages
- McGuire, R.K. (1995). Probabilistic seismic hazard and design earthquakes: closing the loop, *Bull. Seism. Soc. Am.*, 85, 5, 1275-1284.
- Somerville, P.G., N.F. Smith, R.W. Graves, and N.A. Abrahamson (1997). Modification of empirical strong ground motion attenuation relations to include the amplitude and duration effects of rupture directivity, *Seism. Res. Ltrs, 68, 1, 199-222.*
- Sellami, Souad (????). Evaluation of earthquake hazard;
- UNDRO. Disaster Prevention and Mitigation: Land Use Aspects (New York: United Nations, 1978).
- U.S. Geological Survey (1984). Proceedings of the Geologic and Hydrologic Hazards Training Program, March 5-30, 1984, Denver, Colorado, Open File Report 84-760 (Reston, Virginia: U.S. Geological Survey, 1984).
- http://www.nycem.org/techdocs/FinalReport/12Assess.pdf (assessed: March 10, 2009)
- http://www.seismo.ethz.ch/hazard/ndk/homepage.html.back
- http://www.earth-prints.org/handle/2122/769)
- http://earthquake.usgs.gov/eqcenter/recenteqsww/Maps/region/Africa.php

Guide book
Choice session 3.F:
Flood hazard assessment

Objectives

After session 3.F you should be able to:

- Distinguish different flood types and describe their main characteristics;
- Describe the hydrological cycle in general, and in specific those components relevant for floods
- Have a basic understanding of flood modeling approaches
- Describe how remote sensing data may be used for flood hazard and risk assessment

This section contains the following sections and tasks:

Section	Topic	Task	Time required		
3.F.1.	Types of floods	3.F.1: Internet exercise : recent floods 3.F.2: Classification of floods		0.5 h 0.1 h	
3.F.2.	River floods: Alluvial and flash floods	3.F.3: Visit the EFAS website		0.1 h	
3.F.3.	Flood modeling				
3.F.4.	Remote Sensing and floods	3.F.4: Visit the relief-web website		0.1h	
			Total		**0.8 h**

Floods are among the most damaging and most widespread hazards in the world. They occur every year on every continent. Figure 3.F.1. gives some examples from around the world.

Floods are part of the dynamics of rivers and streams and of coastal areas. Statistically, a river will exceed its mean annual peak discharge once every 2.33 years (Leopold et al., 1964). This will occur when heavy or continuous rainfall – or another source of water - exceeds the absorptive capacity of soil and the flow capacity of rivers, streams, and coastal areas. This causes a watercourse to overflow its banks onto adjacent lands. Also intrusion of sea-water into coastal areas due to storm surges – often in combination with hide tide conditions – are part of the natural dynamics of coastal areas. In general one can define a flood as the intrusion of water into normally non-inundated terrain, but this triggers the question of what is normally inundated terrain?

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Figure 3.F.1: Floods occur on all continents. Clockwise (starting top-left): Europe (Germany, 1997), India (Bihar, 2002), Africa (Mozambique, 2000) and USA (Mississippi, 1993).

Task 3.F.1: Internet exercise (duration 30 minutes)
Which areas are flood prone in your country / region? When was the last the big flood event? Try to locate three (internet) sources that provide information on these flood events.

3.F.1 Types of floods

There are many sources of water that may cause floods. Obviously the location, terrain characteristics and climate play a key role as to what degree an area is susceptible for floods and to what type of flooding. One can distinguish the following types:

Alluvial floods

Alluvial floods usually occur in larger river basins (> 1000 km^2) and are caused by sustained periods of rainfall or snow-melt over a large part of the basin area. The river transports the surplus of water to the sea, accumulating water from tributaries as the flood wave travels downstream. The accumulation of water combined with decreasing flow velocities in the lower parts of the basin due to lower river gradients (see fig xxx), results in an increase of the flood volume. At some point this may exceed the capacity of the river to contain the water within its banks. The excess water will overtop the natural or man-made levees (or breach through them) and flow into the low-lying parts adjacent to the river. These floods usually occur in relatively flat areas in the downstream part of the river basin, the alluvial and coastal plains, although the source of the water, rainfall in the upstream parts of the river basin, may be far away. This has two important consequences: 1) it is possible to monitor the flood wave as it travels downstream and local overbank flooding in the upstream parts should be warning signals for those downstream that a flood may be coming. This warning time may be several days for larger rivers; 2) the weather conditions in the flooded area may be relatively mild which is helpful for relief operations.

This type of flooding is often associated with relatively low flow-velocities in the overbank area, usually less than 1 m/s., although locally higher flow velocities may occur, e.g. due to funneling effects of infrastructure and buildings and behind dike breach locations. In the river itself flow velocities may also be higher. Although usually only a relatively small part of the river discharge enters the overbank area, the area affected is often quite large and the water may remain there for a long time (up to weeks).
The damage caused by these floods is related to the materials that became wet and dirty and to the socio-economic processes that have come to a halt. Most victims die to secondary hazards such as electrocution and hypothermia. If the flood waters remain for a long time the damage may be aggravated due to the deterioration of wooden and brick structures and to the breaking and clogging of underground infrastructure (e.g. sewer systems and water pipes). After the floodwaters have receded a layer of mud and dirt remains behind that needs to be cleaned up (costly!).

Summary characteristics: Slow, widespread, long duration, several day warning times, relatively flat terrain, larger rivers with large basins, and prolonged periods of precipitation, disruptive rather than disastrous.

Flash floods

These floods originate in mountainous catchments (basins) with steep gradients and they are the result of extreme precipitation, not only in quantity (mm of rain) but also in intensity (amount of rain per time unit – e.g. mm/hour). Such events are often associated with thunderstorms or typhoons/hurricanes. The water accumulates as it flows downstream to the river channel which results in an increase in the discharge in the channel. The discharge may rise even further when several river branches within a catchment merge to form a larger river. The shape and other characteristics of the catchment such as geology, vegetation cover and antecedent precipitation may increase or decrease the peak discharge. The high flow velocities of the water within the stream may give it the capacity to cause severe erosion and to transport debris such as boulders and trees. These floods give very little warning time, hence the name **flash floods.** Flash floods cause many casualties because people are swept away, even in shallow water and even in cars! The kinetic energy of the water plus the debris (projectiles) causes physical damage to buildings and infrastructure, up to the collapse of houses. Wooden structures may be swept away. The duration of the flood is usually very short – up to several hours - and the area affected is relatively small. After the flood waters have receded debris (rocks, bricks, trees, mud, etc.) and dirt remain behind which needs to be cleaned up. Sometimes this may require heavy equipment. Because flash floods are local events, the severe weather conditions that caused the floods may also hinder relief operations (heavy rain, strong winds).

Summary characteristics: Fast, small area affected, short duration, little warning time, associated with singular events (thunderstorms, typhoons), physical damage to buildings and infrastructure, casualties due to drowning.

Coastal and estuarine floods

In coastal areas the water may also come from the sea. When the wind is directed towards the land, it will push the water to higher levels due to its drag force. Low pressure systems (e.g. typhoons and hurricanes) may also cause a rise in sea-level due to the decrease in atmospheric pressure. Combined with the regular cycle of the tides and spring tide, this may result in sea water levels far above the regular average level. The shape of the coastline may increase the push-up effect of the wind. Especially in river estuaries the water levels may rise up to several meters. The rise of sea level will hinder the river discharge to the sea and a storm surge may therefore increase the chances of a riverine flood. When the sea breaks through the natural barriers (e.g. dunes) at the coastline or through the man-made protection measures (dikes), the storm winds will help to push the water through the breaches. This, in combination with the high gradient between the water level in the sea on one side and the low-lying areas on the other, will make that the salty seawater enters the low-lying areas with great force. Coastal floods are a deadly combination of storm winds, flood water and little warning times. Large areas may be affected and given the fact that coastal zones are among the most densely populated areas in the world with many of the largest cities located there, it is not hard to conclude that coastal floods are among the most catastrophic natural hazards. If there has been no precautionary evacuation, there will be no time to evacuate all the people from the affected areas. The storm winds will impede or severely hamper search and rescue operations. Once the storm has receded, large areas will remain flooded for a great length of time. This will not only disrupt society and cause severe socio-economic damage; it will also degrade buildings and infrastructure as well as the quality of the arable land due to the salt. See also section 3.C on coastal hazards.

Summary characteristics
Coastal areas, widespread, little warning time, salt water, usually associated with storm conditions.

Urban floods

Although this term may cause some confusion – isn't any flood occurring in an urban area an urban flood? – it describes a specific type of flood that is actually the result of the urban environment. Urban areas are characterized by a large percentage of sealed surface, that is, areas that do not allow water to infiltrate into the soil. For instance: paved roads, rooftops of houses and parking areas. The consequence is that all surface water will have to be drained through a storm drainage system or along the streets in open ditches. At some locations pumps may be needed for drainage (e.g. tunnels). If the capacity of the drainage system and of the pumps is insufficient to cope with the amount of precipitation or – to be more precise – with the precipitation intensity, the water will accumulate at the lowest areas and will flood tunnels, cellars and other unprotected underground structures. Also roads may be blocked when the water becomes deeper than approximately 50 cm because regular cars will start to float. If there is a current, cars may be swept away. Due to pressure build-up in underground drainage systems, manhole covers may start to float, which results in dangerous holes in the street. Pedestrians falling into these (by dirty water obscured) holes may drown. Even small, localized events may have a significant effect on traffic flow in the city when critical roads and tunnels are blocked. Frequently pumps are needed to drain tunnels, cellars and low-lying areas. Usually the duration of these floods is relatively short. When larger underground structures (parking lots, subway systems, etc.) are flooded, the consequences may be more severe and it will take longer to return to the pre-flood situation. Urban flooding is aggravated by unplanned city expansion (increase of unpaved area, without increase of drainage capacity) and poor maintenance of the drainage systems.

Summary characteristics
Urban environment, high intensity rainfall, inadequate or poorly maintained drainage systems

Other types:

The above four types of flooding are the most widespread and common. However there are numerous other sources that may cause floods. For example:

- **Tsunamis.** They are caused by an undersea earthquake or landslide. The displacement of the crust and/or ocean floor material triggers a series of low-frequency / long wavelength waves that, as they approach the coast, increase in height and may thus inundate the low-lying coastal areas. Tsunami waves can easily travel across the oceans. Tsunami warning systems are difficult to implement because of the little time between the moments that the tsunami is triggered and that it hits the coast. Tsunamis affect coastal communities and cause damage to boats and coastal property – see also section 3.E.4 and 3.C.2.

- **GLOFs: Glacial Lake Outbreak Floods.** In high mountainous areas, glaciers and (frozen) moraine ridges may block the flow of (melt)water and create large glacial lakes. Melting of the ice or permafrost, or another trigger like a landslide, may result in a collapse of the ice- or moraine dam. The water from the lake is (partially) released and water will rush down the steep mountainous streams. This may cause damage and casualties downstream.
- **Landslide Lake Outburst Floods.** Similar to GLOFs, but here a landslide body has blocked the river, resulting in a lake upstream of the landslide. The pressure of the water in the lake may result in a breaching of the landslide body, causing a sudden release of (part of the) lake's water volume.
- **Dambreaks.** Also man-made structures, such as reservoir dams may collapse to engineering failure, earthquakes, overtopping etc.
- **Dike breaches**. Along rivers, lakes and the coast, dikes offer protection to low-lying areas. Continuous processes such a groundwater flow, seepage, weathering, animal activity, tremors due to traffic, etc. but also earthquakes may weaken the strength of the dike resulting in its collapse when water pressure becomes too high. The chance of dike collapse depends on several factors such as:
    - Height difference between the water level on one side and the ground surface on the other
    - Structure of the dike (height and width)
    - Material of the dike (sand, clay, peat)
    - Sub-surface (lithological) conditions
    - Degree of consolidation
    - Maintenance
    - Surface cover (protection against wave action, erosion, etc.)
- **Accidents with water- and sewage pipes**

Figure 3.F.2. River run-off in China

Although the above mentioned types of floods have different characteristics, it is not always possible to classify a given flood event. Often a combination of types occurs. For instance during a typhoon a city may experience urban floods, flash floods, alluvial floods and coastal floods simultaneously.

Task 3.F.2: Flood classification (10 min.)
Have a closer look at the floods you found in Task 3.F.1. How would classify these events? Can you do that without problem, or could they be classified as different flood types (complex floods).

3.F.2 River Floods: Flash floods and alluvial floods

To understand floods and their origin, the hydrological cycle is a good starting point. See figure 3.F.3. The hydrological cycle describes the continuous movement of water on, above, and below the surface of the Earth. Since the water cycle is truly a "cycle," there is no beginning or end. Water can change states from liquid to vapor and to ice at various places in the water cycle but the total volume of water on Earth remains fairly constant over time. The largest reservoir of water is the collection of oceans and seas, accounting for 97.25% of the Earth's water; see table 3.F.1. The next largest reservoirs are ice caps and glaciers (2.05%) and groundwater (0.68%). Although surface water (lakes plus rivers and streams) and atmospheric water account for less than 0.012% of the total, it is this part of the hydrological cycle that requires our attention when we want to study floods.

Table 3.F.1: Water reservoirs (Source: Wikipedia)

Reservoir	**Volume of water (10^6 km³)**	**Percent of total**
Oceans	1370	97.25
Ice caps & glaciers	29	2.05
Groundwater	9.5	0.68
Lakes	0.125	0.01
Soil moisture	0.065	0.005
Atmosphere	0.013	0.001
Streams & rivers	0.0017	0.0001
Biosphere	0.0006	0.00004

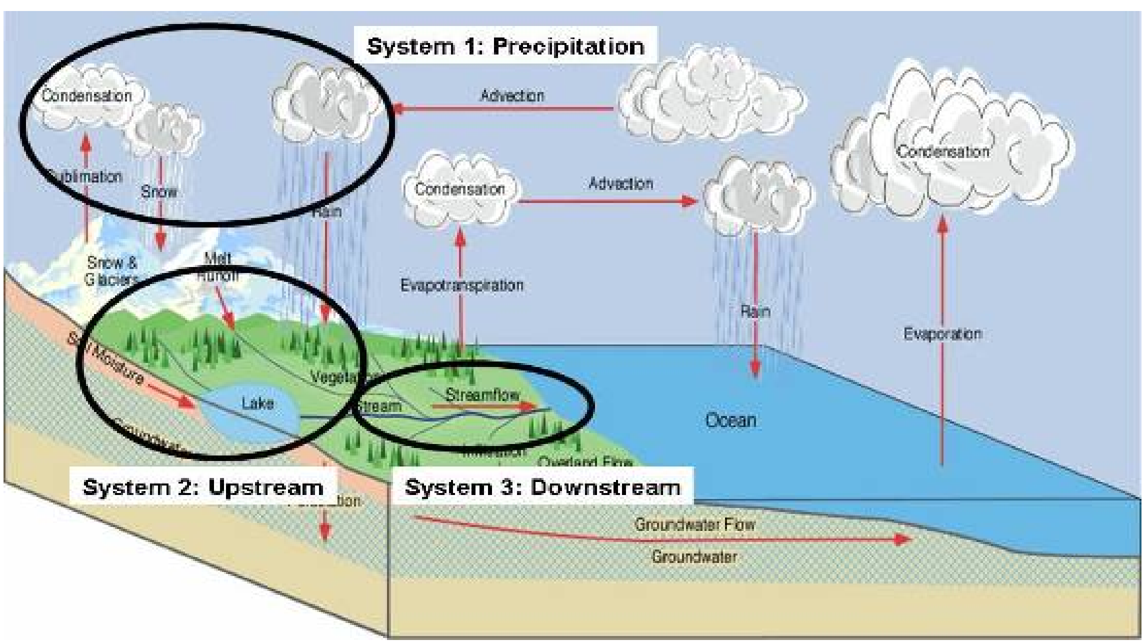


Figure 3.F.3. The hydrological cycle

In figure 3.F.3 three separate sub-systems are highlighted: Precipitation, upstream and downstream. These sub-systems describe that part of the cycle where atmospheric water becomes surface water that flows to the sea. For flood hazard assessment, a good understanding of these sub-systems and how they can be modeled is very important. Each sub-system has a list of questions that needs to be answered. These are described in the following sections:

Sub-system 1: Precipitation

Precipitation that reaches the surface of the earth can occur in many different forms, both in liquid form (rain, drizzle) and in frozen form (freezing rain, snow, ice pellets, and hail). Precipitation is responsible for depositing most of the fresh water on the Earth's surface. Approximately 505,000 km^3 of water falls as precipitation each year, 398,000 km^3 of it over the oceans. Given the Earth's surface area, that means the globally-averaged annual precipitation is about 1 m, and the average annual precipitation over oceans is about 1.1 m. (Source: Wikipedia). Frozen precipitation means that the water volume is not directly available for run-off; that requires a melting period. This is most relevant for high-latitude and high-elevation locations as a significant percentage of the precipitation will fall there in frozen form. A sudden warm period may release a large volume of liquid water which may lead to flood hazard downstream. This means that for flood studies in these regions one should not only forecast precipitation but also periods of higher temperatures and that one has to apply snow- and ice-melt models. In warmer parts of the world rain is the most important form of precipitation causing floods. Rain has two important aspects on flood generation:

Preparatory: Soils and local depressions (lakes, reservoirs) act as buffer that will store rain water. The buffered (or stored) rainwater is not directly available for run-off and will thus not contribute to the peak discharge (see also figure 3.F.5) in the stream. After a sustained period of rainfall, soils will become saturated and lakes and reservoirs will be filled. Once the buffer capacity is reduced to zero, all additional rain will quickly flow towards the streams and rivers as surface run-off.

Trigger: Rain that falls on the surface of the Earth may be stored in the soil or in depressions, or may flow over the surface as run-off towards the rivers. What percentage of water will actually reach the river system depends on many factors and these will be discussed in the following section. In situations where either the buffering capacity is reduced to zero (see section above on preparatory aspects) or where the intensity of the rain exceeds the speed in which the water can be buffered, a large percentage of water will reach the river system very quickly which may result in floods.

The forecasting of precipitation is not really the domain of Earth scientists, but rather of meteorologists. The key question that needs to be answered is how much precipitation will fall somewhere (in mm) and with what intensity (mm/hour). In the case of thunderstorms also the location of the storm is relevant. For other types of rain-depositing phenomena, such as typhoons and frontal systems, the "where-question" is less relevant because these events cover large territories, usually larger than the areas that are investigated in flood studies (with the exception of course of the largest river basins). The prediction of rainfall amounts and intensities, however, is extremely difficult and the same is true for the prediction of where thunderstorms will occur. Only recently have steps been taken to do real-time flood forecasting, that is flood prediction based on (long-term) weather forecasts (see e.g. http://efas.jrc.ec.europa.eu).

Task 3.F.3: Internet task (10 min.)
*Go to the website of EFAS (*http://efas.jrc.ec.europa.eu*) What floods were the "trigger" to initiate EFAS?*

Sub-system 2: The upstream

Sub-system 2 is where the spatially diffuse rain is being concentrated into run-off and stream flow. The water converges into the stream channels which transport it further downstream. This overland flow (surface runoff plus stream flow) comprises all gravity movement of water over the surface and through cannels which may vary from very small (rills) to very large (Amazon River). The standard way to express discharge is in volume per time unit, e.g. m3/sec (cumec) or liter per second, or cumec per square kilometer for a given catchment, or as depth equivalent over a whole catchment, e.g. in mm per day or per month. Figure 3.F.4 shows how sub-system 1, 2 and 3 are connected and it raises the main questions that need to be answered. Whereas in sub-system 1 the main question was how much rain will fall, the main question for sub-system 2 is how quickly will the water converge into the stream system and how fast will it move downstream. So apart from the "how much" question we now have added the temporal "when" question.

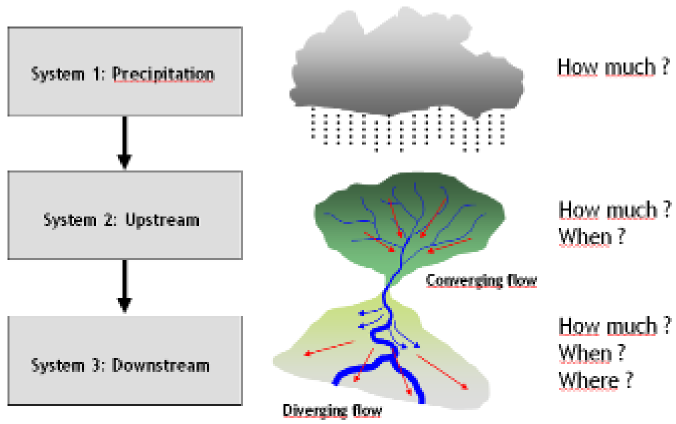


Figure 3.F.4 The three sub-systems connected

Quick flow and slow flow

Figure 3.F.5. gives a typical cross-section of a valley in the upstream sub-system. It shows that the rain (P) may reach the river by one or more of the following flow paths: a) direct precipitation into the waterbodies (CP); b) as overland flow (OF); c) as through flow (TF); and as ground water flow (GWF). The response of the stream flow to precipitation – that is the time between the start of the rain event and the start of the rising of the discharge (figure 3.F.6) - depends on many factors, such as shape of the terrain (morphometry), the hydrological characteristics of the soils, the landcover and the soil moisture content.

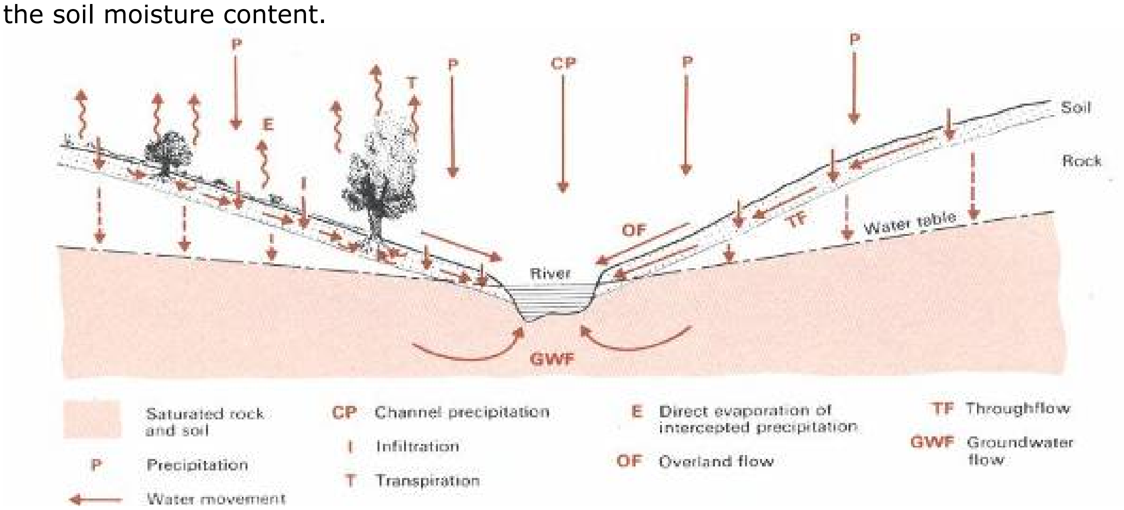


Figure 3.F.5 Water movement towards the stream system

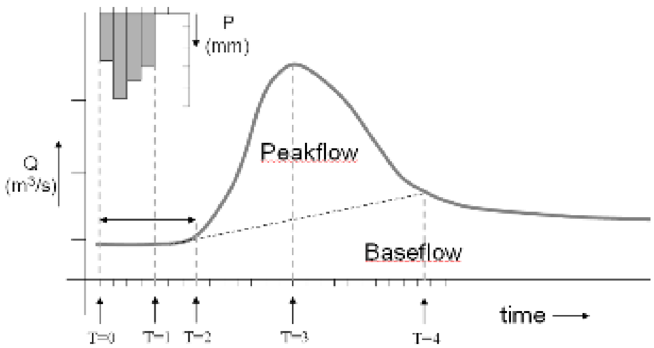


Figure 3.F.6 The stream's response to precipitation (t0 = start of the rain; t1 = rain stops; t2 = start of a noticeable response of the river; t3 = maximum of the peak flow; t4= end of the peak flow, return to base flow conditions)

However, when there is a clear rising of the stream discharge in the hydrograph that can be related to a rainfall event, then it is evident that some part of the precipitation has taken the rapid route to the stream channel, the so-called quick flow. Quick flow comprises precipitation that has fallen directly into the channel and overland flow. In some cases there may also be a rapid component to the through-flow, for instance in karst areas or when piping mechanisms exists. Quick flow is that part of the precipitation that causes the peakflow in the river (see figure 3.F.6).

The rain that infiltrates into the soil may first pass through an unsaturated zone before it reaches the ground water table. In both the unsaturated and saturated zones there is a downhill flow component directed towards the river, the so-called through flow and groundwater flow. Due to the higher resistance in the subsurface, it takes longer for the infiltrated water to reach the river channel. It is this part of the precipitation that contributes to the base flow of the river (see figure 3.F.6). The separation between peakflow and baseflow cannot be made unambiguously. For flood studies the prediction of the maximum peak flow, both in time and in quantity, is paramount, hence the key questions: "how much?", and "when?".

Sub system 3: The downstream

The transition of the "upstream" to the "downstream" part is not clearly defined. In many text books you'll find a third – intermediate – section the so-called "middle reach". In this text-book we'll define the downstream as follows:

In the downstream section of a river, the net long-term deposition of materials carried by the river waters exceeds the erosion capacity of that river.

This definition defines "downstream" as those areas where there is net accumulation of deposits and no clear incision of the river, such as alluvial fans and deltas. The rivers in these areas are characterized by avulsions, i.e. the change in position of the (main) river channel. On these relatively flat plains the flow direction of the water is not easily predicted because small obstacles may have a significant effect on the flow direction of the water. During floods, the water spreads out of wide areas. This raises the number of questions to three: how much, when and where?

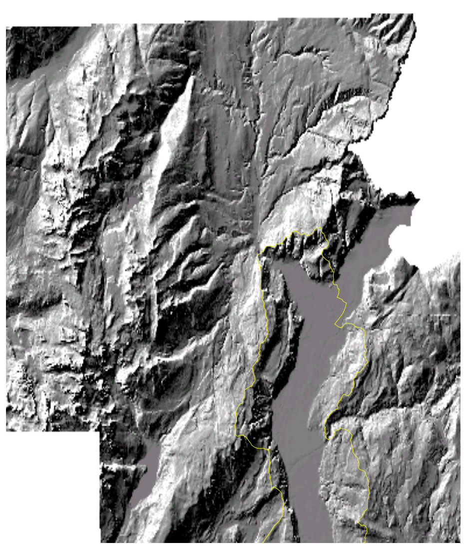


Figure 3.F.7. According to the above given definition, also the Adige valley near Trento can be considered as a "downstream" area. The river Adige, flowing through the flat terrain in the center, is filling in this large Alpine glacial valley with sediments.

The distinction between an upstream and downstream area is useful in the selection of the most appropriate flood hazard assessment techniques. In the upstream area a 1D flow modeling approach is most appropriate because it answers the two questions (how much and when) most efficiently. It uses the prior knowledge of where the water goes: The flow follows the hydrographic network that can easily be derived from the DTM or by digitizing stream networks. All water converges to these flow-paths. In the downstream area this prior knowledge is not available because flood water that has left the river channel may diverge and spread-out over large areas, see figure 3.F.7. In these situations where also the "where" question needs to be addressed, a 2D-waterflow approach is more appropriate.

3.F.3. Flood modeling

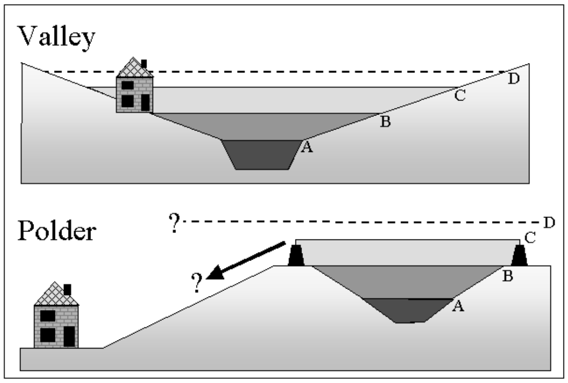


Figure 3.F.8 Morphological differences between upstream and downstream surface topography and its consequences for flood hazard zonation.

Figure 3.F.9: Floods in the lower Mekong area. The flood waters have affected over 200,000 square kilometers (2001). Source: Reuters / Alertnet.

In section 2.2 a flood hazard was defined as the probability that a certain area will be inundated within a given period of time. Thus, traditional flood hazard maps delineate the annual chance of inundation, as shown in the top part of Figure 3.F.8 In this situation there is an inverse relationship between water level and chance of occurrence: the higher the water level the smaller the chance that it happens. In Figure 3.F.8 location A is more hazardous than location D. This is typically an upstream situation.

In the lower part of Figure 3.F.8 the "Polder" situation is depicted, a situation that can be found in all major river delta areas, coastal plains and alluvial plains in the world where the river is flanked by widespread near-flat terrain; a typical downstream situation. In some cases the surrounding terrain lies below the level of the river as a result of different subsidence characteristics between the more sandy deposits in and along the riverbed and the clayey, peaty deposits in the back-swamp areas. Often this difference in height is enhanced by artificial drainage of the back-swamps that leads to further subsidence.

In the "polder" situation there is only a relation between the water level and return period of the flood as long as the river water does not overtop or breach the natural levees (B) or the dikes (C). A traditional hazard map equals the hazard in the whole polder area as the chance that the dikes are overtopped or breached. This approach does not allow the differentiation in degrees of hazard within the alluvial plain (or polder) because it does not consider the propagation of the inundation flow. Clearly, the water level D in the lower part of Figure 3.F.8 is not instantly achieved in the whole flooded alluvial plain or polder. It takes time to fill the bathtub. How much time depends on the flux of water into the area and the characteristics of the terrain, like resistance to overland flow and the presence of obstacles like buildings, embankments, etc. This temporal component is essential for decision-makers because people living in areas that are inundated within hours are more "at risk" than people living further-on that have still days to respond to the hazard. Authorities need to know in advance which people to evacuate first and which roads are still accessible. Traditional flood hazard maps do not provide the right information to develop such evacuation plans. Furthermore they offer no help to planners to analyze the impact of new developments within these areas on possible future inundations. Simulating scenario floods with a 2D flood propagation model can help in these cases. An example of a large alluvial flood is given in figure 3.F.9, a flood that occurred in the Lower Mekong region (Vietnam and Cambodia) in 2001.

Upstream – Downstream relationships

The upstream – downstream distinction makes it easy to connect the two systems. The result of an upstream analysis with a 1D flow model is a hydrograph at the outlet, say the apex of an alluvial fan or delta. This hydrograph can serve as upstream boundary for a 2D flow analysis in the downstream area. Figure 3.F.10 shows an example in Thailand where the downstream consequences of land cover changes in the upstream catchment were estimated. The upstream analysis was carried out with a 1D flow model (LISEM) and the downstream flood propagation modeling was done using a 2D hydraulic model SOBEK (developed by Delft Hydraulics, the Netherlands).

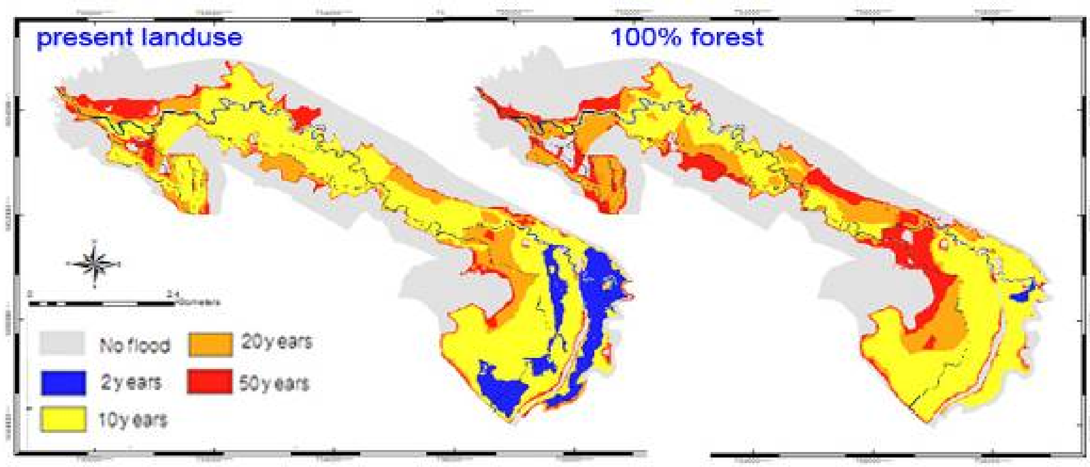


Figure 3.F.10. Two scenarios where the downstream flood consequences are estimated of land cover changes in the upstream area (not on the map). Source: Prachransri, 2007. Case study Thailand, in collaboration with the Land Development Department (LDD).

Flood intensifying factors

The catchment characteristics in the upstream area define for a large part, the peak discharge in the river downstream. Table 3.F.2 gives an overview of several key factors that influence the shape of the hydrograph.

Table 3.F.2

Flood intensifying factors:			
	Catchment Conditions		
		Stable	Area, slope, altitude, shape, geology, soils
		Variable	Vegetation, climate, human action, certain soil properties (infiltration), surface resistance
	Antecedent Conditions		
			Previous rain- and snow fall
	Network and channel conditions		
			Pattern, channel length, stream order, profile & gradient, bifurcation ratio, roughness, human action, (local) storage

The stable catchment conditions define for instance the amount of water that is added to the river network (the area), its velocity (the slope), the form in which the precipitation falls - snow or rain – (altitude), the shape of the hydrograph (shape – see below) and the amount of storage and loss to deeper groundwater (geology and soils). The variable conditions change through the seasons (vegetation, soil moisture conditions) or may change gradual (climate) or abruptly (human action). The surface resistance is strongly related to the vegetation cover that offers resistance to the surface flow of water, and thus affects the flow velocity. The antecedent conditions are strongly related to the previous weather conditions. Antecedent rain affects the soil moisture condition of the soils and the height of the ground water table. Network and channel conditions refer to the specific shape and patterns of the river channels, how they are connected, the river bed conditions in terms of roughness and for instance the presence of local depressions (lakes).

Figure 3.F.11 shows the relationship between the catchment shape (circular or elongated) and the hydrograph response. Rain falling on an elongated catchment (left-hand side) has a diverse range of travel times before it reaches the outlet. Rain falling close to the outlet leaves the area quickly, whereas rain falling in the far end has a much longer travel time. In a circular catchment (right-hand side) this variation in travel times is much smaller and rain falling in different parts of the catchment will reach the outlet nearly simultaneous. In an elongated catchment the diverse range of travel times results in a long, but relatively flat hydrograph, whereas in a circular catchment the hydrograph is much more concentrated with a much higher peak.

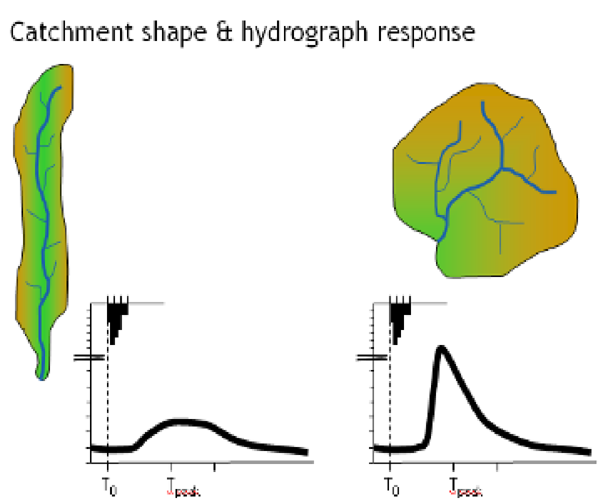


Figure 3.F.11. The effect of the catchment shape on the hydrograph.

3.F.4. Remote sensing and floods

For the analysis of flood events, remote sensing data is indispensible. There are several ways how data, obtained from space-based and airborne sensors, can be used for flood studies. Table 3.F.3 gives an overview; the four categories will be discussed below.

	Medium-Low Resolution	High Resolution	SAR	Other (e.g. LIDAR and SRTM)
Provision of spatial distributed data for modeling				
Validation of model results				
Elements at Risk mapping				
Post disaster rapid response data provision				

Table 3.F.3: Use of remote sensing data for flood hazard assessment (colour code: green = generally very useful, yellow = depends on the situation; white = generally not useful.

Data provision for distributed modeling

Model studies play an important role in gaining a better understanding of the dynamics and behavior of fluvial systems. However most hydrological and hydraulic models are data demanding and require spatial distributed information regarding topography, land cover and soils.

Remote sensing is a key source of data for topography parameterization: traditionally using stereo-photogrammetric methods to get contour maps, but more recently satellite data from e.g. the Space Shuttle Topographic Mission (SRTM), and stereo images from e.g. Aster have become cheap sources of surface elevation data with almost global coverage (see also section 2). Also LIDAR – explained in greater detail in section 2.B.3 – has become an important source of high-accuracy elevation information. Furthermore all kinds of parameters that are important for hydrological modeling are related to the land cover, e.g. interception, evapo-transpiration, surface roughness, etc. Remotely sensed images from satellites and aircrafts are often the only source that can provide this information for large areas at acceptable costs.

Validation of model results

Satellite imagery is not only a useful source of input data for hydrologic models, it also offers good possibilities to validate the output of the models when a flood has occurred. The observed extent of the flood can then be compared with the modeled prediction. Such validation is essential for flood modeling. Although optical remote sensing data could be used to derive the flood extent, it does require cloud-free images and these are not often available during flood events. Radar imagery is more convenient because it is not hindered by cloud cover that frequently accompanies flood events. The radar sensor is very good at distinguishing land and water boundaries because the water reflects almost all the incident microwave radiation away from the sensor, resulting in a black or dark tone for the water covered areas.

Elements at risk mapping

Perhaps the most promising application of RS is its use for elements at risk analysis. In session 4 for of this guide book we will look deeper into its use to identify individual structures. Recognition of the function of these structures is important for the assessment of their vulnerability and their importance and value. Especially for cities that experience fast and uncontrolled expansion into hazardous areas like floodplains, this offers an opportunity to monitor the increasing risks and impacts

Post disaster rapid response data provision

Another important application of remote sensed data is the rapid dissemination of spatial information immediately after a flood event has occurred. The best known system for rapid data availability is the so-called International Charter for Space and Major Disasters, which may be called upon after a major disaster has occurred. The data are provided by Charter partners, such as the German Space Agency (DLR), and UNOSAT who make map products that are made available via the Global Disaster Alert and Coordination System (GDACS, www.gdacs.org), ReliefWeb (www.reliefweb.int) or Reuters' AlertNet (www.alertnet.org).

Task 3.F.4: Internet task (10 min.)
Go to the website of Reliefweb www.reliefweb.int). *Where are currently / recently flood disasters?*

Task: RiskCity exercise 03F1: Flood hazard assessment using flood modeling (3 hours)

Go to the Riskcity exercise 03F1 and carry out the GIS exercise on flood hazard assessment using flood modeling.

Task: RiskCity exercise 03F2: Flood hazard assessment using satellite data (3 hours)

Go to the Riskcity exercise 03F2 and carry out the GIS exercise on flood hazard assessment using satellite images.

Selftest

Self test
In order to evaluate whether you have understood the concepts that were presented in this session. Please make the following test, and check the answers in Blackboard.

Question: River flood hazard assessment
What are the most important types of <u>output data</u> of a 2-D flood simulation model?
A) Ground water level, surface runoff
B) Water height, soil pollution
C) Water height, flow velocity
D) River discharge, evapotranspiration.

Question: Flood hazard assessment
What are the most important types of input data for a 2-D flood simulation model?
A) Waterheight, flow velocity, flow duration
B) Terrain altitude, surface roughness, river discharge
C) Rainfall, landuse, soils
D) Slope, infiltration capacity, evapotranspiration.

Define the flood risk in a polder area in the Netherlands.
Flood risk scenario's:
Below the level of 2m no dike breaches occur; no flooding.
You have the following data available:

Flood scenario I.: Flood level is **2.0 m** above NAP (Dutch Datum) in the polder. Return period = 100 years:
Flood Scenario II. Flood level is **2.5 m** above NAP in the polder. Return period = 250 years
Flood Scenario III. Flood level is **3.5 m** above NAP in the polder. Return period = 500 years

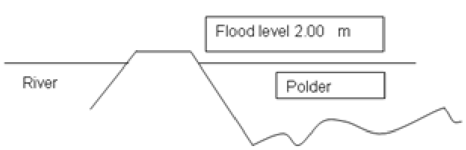
Land use

a	a	c	c
a	a	c	c
r	r	r	r
c	c	h	h

Legend:
a = agriculture
c = company
r = road
h = house

DEM (in meters above NAP)

1.5	1.5	3	3
1.5	1	3.5	3
1	1	2.5	3
1	1	2.5	3



Define the water depth in the polder for scenario's I, II and III, and indicate these in the map below.

Scenario I:

Scenario II :

Scenario III:

Guide book
Choice session 3.C :
Coastal Hazard Assessment

Objectives

After session 3.C you should be able to:

- List the different types of coastal hazards;
- Know about the Coastal Zone Management issues of your own country
- Find data of various coastal hazards to be used for coastal hazard zoning via the internet
- Perform basic GIS and RS modeling for coastal hazard zoning using the ILWIS software

This session contains the following sections and tasks

Section	Topic	Task	Time required		
3.C.1	Introduction to CZM issues	3.C.1 Visit the NOAA Website on Clean & Coastal Resource Management		0.5 h	0.5 h
3.C.2	Rapid Coastal Hazards	3.C.2 Find active cyclones		0.5 h	6.0 h
		3.C.3 Hazard Analysis Cyclones - *Part A*		1.5 h	
		3.C.3 Hazard Analysis Cyclones - *Part B*		2.5 h	
		3.C.4 Poster tsunami		0.3 h	
		3.C.5 News item tsunami Banda Aceh		0.2 h	
		3.C.6 Animations tsunami wave		0.5 h	
		3.C.7 NOAA Interactive tsunami database		0.5 h	
3.C.3	Slow Coastal Hazards	3.C.8 Analysis Enhanced Sea Level Rise		1.0 h	6.5 h
		3.C.9 Reading article subsidence Semarang		1.0 h	
		3.C.10 Modelling land subsidence Semarang		2.0 h	
		3.C.11 Looking at YouTube videos		1.0 h	
		3.C.12 Analysis change Solo River delta		1.5 h	
		Total			**12.5 h**

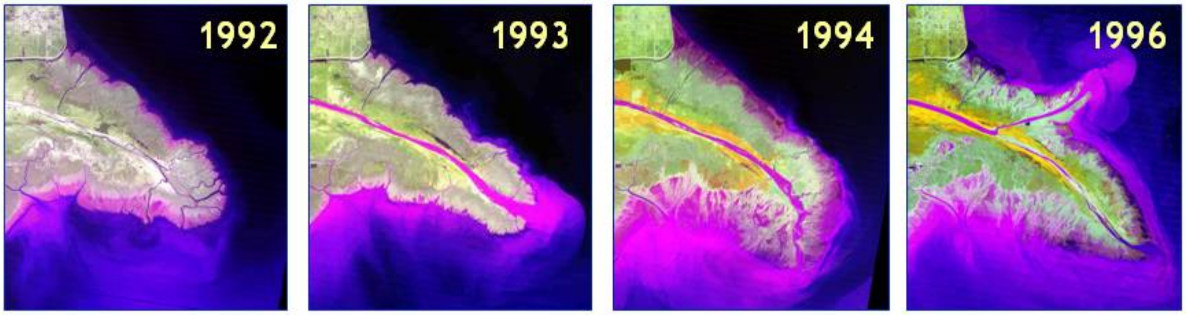
This session ends with a test, and the answers of this should be submitted through Blackboard

3.C.1 Introduction to coastal zone issues

About 70 percent of the world's population lives in the coastal zone. It is the most densely inhabited and industrialized part of almost every coastal country and contributes therefore significantly to the financial well-being of the people living in it.

The high concentration of the population along the coast creates also pressure on its resources. Most megacities in the world are situated in delta areas or at the coasts of estuaries, and suffer from air and water pollution, land subsidence due to groundwater extraction and flooding by the river and the sea. Some cities are very vulnerable to cyclone hazard and enhanced sea level rise due to global warming. Rural coastal areas are dependent on the surrounding lagoons, estuaries, mangrove ecosystems, creeks and inshore waters for their income, food security and well being.

The marine and coastal zones, including their upstream freshwater regions, are presently experiencing degradation in the form of surface and groundwater pollution, such as salt



water intrusion, but also coastal flooding, erosion & accretion, land subsidence as impact from land-based settlements activities; and mining activities of oil and gas.

Figure 3.C.1 Change of the yellow river delta, China in between 1992-2006, Landsat TM & ETM images (band comb. ; 4-5-3 : R –G – B). The suspended sediment in the sea water is shown with a pink colour. The delta is situated close to the Guadong oil field. The exploration area, surrounded by a sea dike is visible in the upper left corner. (Damen, 2006)

The challenge for coastal countries is to use the abundant but depleting coastal and marine environment resources wisely, so that economic development can be achieved without destroying the resource base on which it is founded. Consequently, coastal hazard and risk management has become an important programme for all people living in the coastal zone.

Integrated Coastal Zone Management (ICZM) is a proposed tool achieving sustainable coastal resource use, and one that has been adopted, in principle, by many coastal nations. The concept of integrated management emphasises the importance of coupling the economic, social and environmental dimensions for sustainable coastal resources utilization. Integration of these three pillars of sustainable coastal development starts from the adoption and application of advanced technological tools including geographic information systems (GIS) and change detection using multi-temporal remote sensing imagery (RS) that provide scientific knowledge and analysis and support decision-making for assessment practices and management methods (Figure 3.C.1)

In this Guidance Note examples are given of some of the most common coastal hazards, classified from rapid to relatively slow events. Also the processes are described with are leading to these hazards including examples on their analysis with geographic information systems and multi-temporal aerospace imagery.

Task 3.C.1 Coastal Zone Management (duration 30 minutes)

Visit the NOAA Website on Clean & Coastal Resource Management:

U.S. DEPARTMENT OF COMMERCE
National Oceanic and Atmospheric Administration

http://coastalmanagement.noaa.gov/issues/hazards_activities.html

- Select from the website: *Coastal Issues*.
- Find one or two coastal issues of your interest and compare this with possible plans in your own country.

Example of Integrated Coastal Zone Management in the Netherlands

The Netherlands is famous for its coastal protection with sea dikes at places where the natural defense against marine flooding by dunes is missing. As about half of the country is situated below sea level, it is essential that the national coastal zone management policy is based on a well established hazard analysis. All protection measures are therefore based on a flood hazard zoning of the whole country.

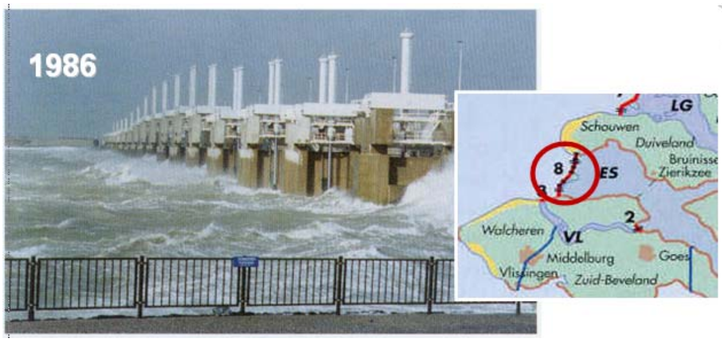


Figure 3.C.2 : Movable sea defense system along the Dutch coast. Delta works, Zeeland (RWS 2009)

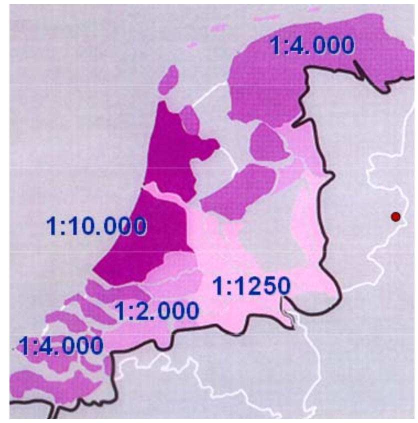


Figure 3.C.3 : Safety standards in respect to flooding in the Netherlands (RWS 1991)

The safety standard for the low lying western part of the coastal area is for instance based on a recurrence interval for sea flooding of once in 10.00 years; at other places this is once in 4.000 years. Inland, in areas of the rivers Rhine and Meuse the standard is 1:1250 or 1:2000 years for river flooding (Figure 3.C.3). The construction of storm surge barriers at the coast (Figure 3.C.2), or sea dikes is based on these safety standards.

In case of, for instance, coastal retreat due to enhanced erosion, mitigating action will be taken well before the "official" 1:10.000 coastline could be crossed. For this purpose, the position of the coastline is being accurately measured at a yearly basis.

In figure 3.C.4 an example if given of a coastal town North of Amsterdam, in which the coastlines for different recurrence intervals are indicated, based on the present erosion rate. This hazard information is used for future urban planning.

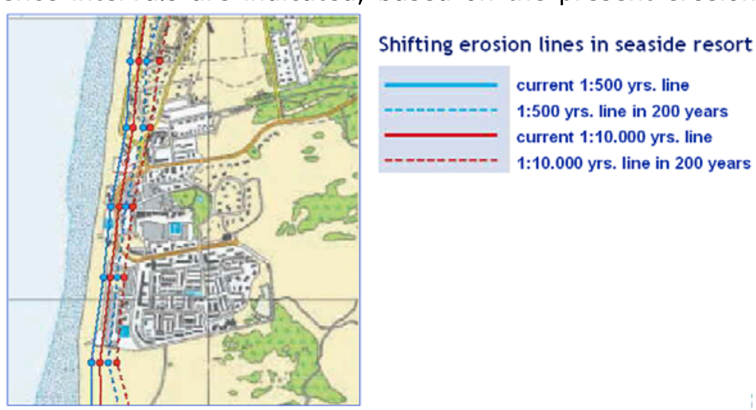


Figure 3.C.4 : Possible future coastlines due to coastal erosion in a coastal town North of Amsterdam, Holland. (RWS, 2002)

Regular suppletion of the sand ("beach nourishment") that has been eroded in front of the coast and along the beach can be a good option to mitigate the erosional process.(Figures 3.C.5&6). To calculate the volumes needed for this suppletion, elevation models are made at an annual base along the entire coast of the Netherlands; this is done by Lidar digital elevation modeling (see also GuideBook Session 2).

Figure 3.C.5 : Basal coastline (1: 4000 years) in red and Lidar DEM (hill-shade) of the same area. The Netherlands (RWS 1996)

Figure 3.C.6 : Beach nourishment along the Dutch coast. (RWS 1996)

3.C.2 Rapid Coastal Hazards

Cyclone hazards

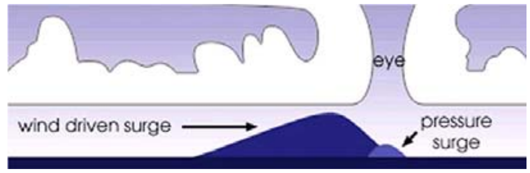


Figure 3.C 7 : Wind driven surge and pressure surge (NOAA-AOML)

The impact by *tropical cyclones* (also known as *hurricanes* or *typhoons*) is caused by tropical revolving storms. Cyclones are low pressure systems around which the air circulates. The storm grows as air spirals inwards, rises and is exhausted on the top by high level winds. Surface air converges at an increasing rate towards the low pressure at the storm center; this is called the "eye" of the cyclone (Figure 3.C.7). This pressure drop might cause the sea level to rise, which – accompanied by very strong winds (over 90 km/hr) gives *storm surges* of 5 m. or more, causing severe damage to agriculture and infrastructure and many casualties. Globally, about 80 cyclones are formed every year. They occur on the South-East coast of the United States, in the Caribbean, Madagascar and Mozambique, India and the Bay of Bengal (Bangladesh), from Thailand to Vietnam, Southern China and Southern Japan, and in Australia (Figure 3.C.8).

Figure 3.C.7 : Illustration of cyclone's eye and its circulation (UNDRO 1991)

Task 3.3.C.2 : Find active cyclones (duration 30 minutes)

On this website of you can follow cyclone tracks and also find historic data. Find data of the possible active cyclone of today:

http://www.solar.ifa.hawaii.edu/Tropical/tropical.

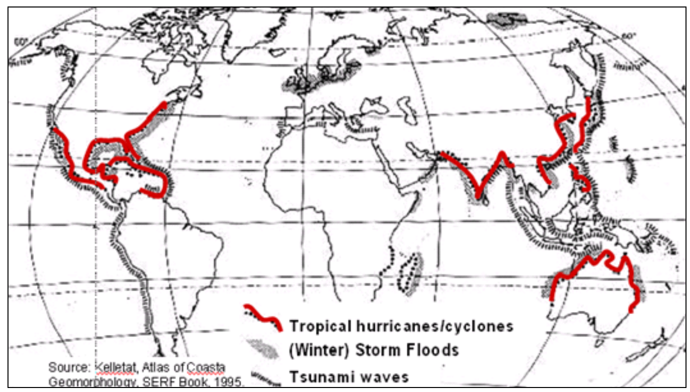


Figure 3.C.8 : Coasts with cyclone hazard (indicated with red lines) – Atlas of coasts (SERF, 1995)

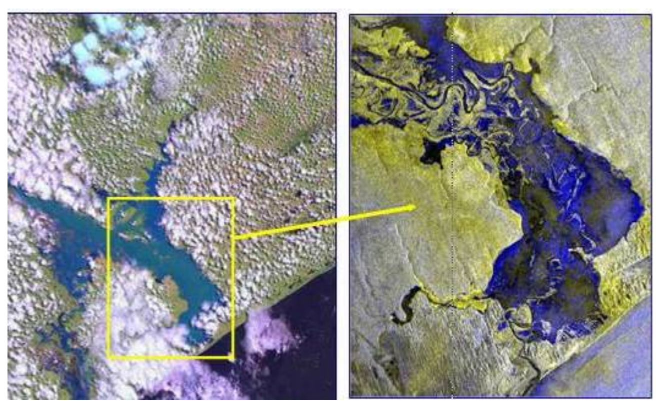


Figure 3.C.9 : Assessment of cyclone flooding using remote sensing. The left image shows the flooding of the March 2000 cyclone event in Mozambique on a Landsat image. The right image shows part of the same flood event on an ERS radar image, on which clouds are not visible. About 800 persons were killed by the event. (NASA Earth Observatory)

Cyclone hazard analysis of the coast can be based on the frequency of landfall (*Fig. 3.C.11*). For this, historic data can be used on wind speed and surge height (*Fig. 3.C.10*). Other methods of prediction and hazard modelling are based on peak gust wind speeds (*Figures 3.C.12 & 13*)

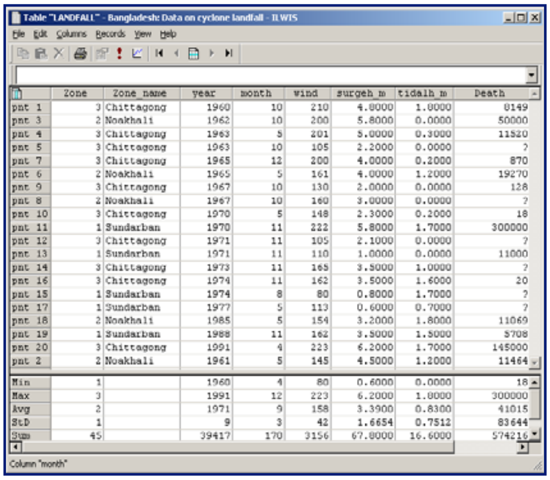


Table "LANDFALL" - Bangladesh: Data on cyclone landfall - ILWIS

	Zone	Zone_name	year	month	wind	surgeh_m	tidalh_m	Death
pnt 1	3	Chittagong	1960	10	210	4.0000	1.0000	8149
pnt 3	2	Noakhali	1962	10	200	5.8000	0.0000	50000
pnt 4	3	Chittagong	1963	5	201	5.0000	0.3000	11520
pnt 5	3	Chittagong	1963	10	105	2.2000	0.0000	?
pnt 7	3	Chittagong	1965	12	200	4.0000	0.2000	870
pnt 6	2	Noakhali	1965	5	161	4.0000	1.2000	19270
pnt 9	3	Chittagong	1967	10	130	2.0000	0.0000	128
pnt 8	2	Noakhali	1967	10	160	3.0000	0.0000	?
pnt 10	3	Chittagong	1970	5	148	2.3000	0.2000	18
pnt 11	1	Sundarban	1970	11	222	5.8000	1.7000	300000
pnt 12	3	Chittagong	1971	11	105	2.1000	0.0000	?
pnt 13	1	Sundarban	1971	11	110	1.0000	0.0000	11000
pnt 14	3	Chittagong	1973	11	165	3.5000	1.0000	?
pnt 16	3	Chittagong	1974	11	162	3.5000	1.6000	20
pnt 15	1	Sundarban	1974	8	80	0.8000	1.7000	?
pnt 17	1	Sundarban	1977	5	113	0.6000	0.7000	?
pnt 18	2	Noakhali	1985	5	154	3.2000	1.8000	11069
pnt 19	1	Sundarban	1988	11	162	3.5000	1.5000	5708
pnt 20	3	Chittagong	1991	4	223	6.2000	1.7000	145000
pnt 2	2	Noakhali	1961	5	145	4.5000	1.2000	11464
Min	1		1960	4	80	0.6000	0.0000	18
Max	3		1991	12	223	6.2000	1.8000	300000
Avg	2		1971	9	158	3.3900	0.8300	41015
StD	1		9	3	42	1.6654	0.7512	83644
Sum	45		39417	170	3156	67.8000	16.6000	574216

Column "month"

Figure 3.C.10: Table of historic cyclone events along the coast of Bangladesh. Columns: data of landfall, surge height in m., tidal height during landfall and number number of casualties (Damen, 2009)

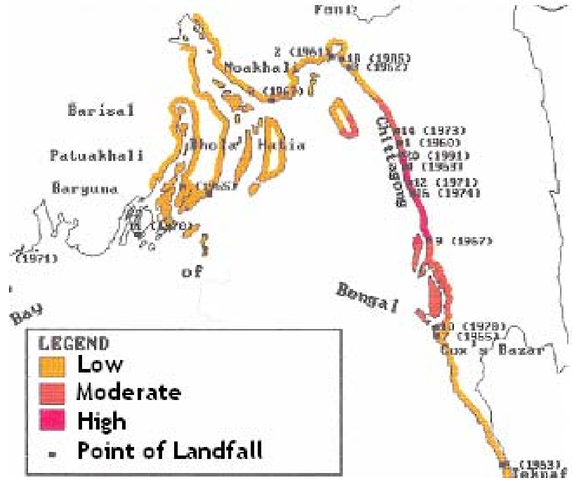


Figure 3.C.11 : Map of cyclone hazard zones along the coast of Bangladesh. Based on the table of historic events in figure 3.3.C.5 (Damen, 2009)

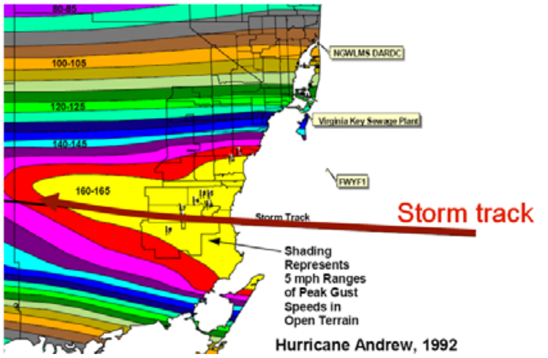


Figure 3.C.12 : Storm track modeling results based on peak gust wind speeds of Hurricane Andrew (1992), East coast US (HAZUS, 2004)

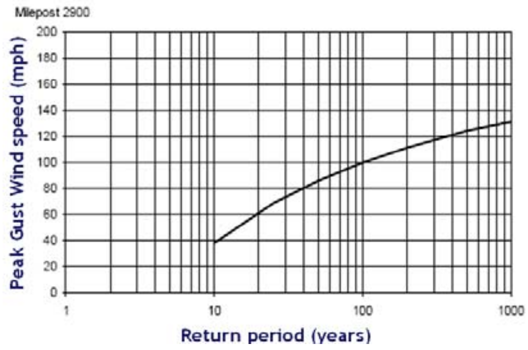


Figure 3.C.13 : Return periods peak gust wind speeds, US coasts (HAZUS, 2004)

Task 3.C.3 : Hazard analysis of cyclones in Bangladesh using ILWIS

Part A : **Analysis of historic cyclone events in Bangladesh (duration 1.5 hour)**

Analysis of cyclone data using Table Calculation on Surge Height, Wind Speed, Number of Casualties, etc. Display of the results in graphs

Part B : **Flood hazard analysis of the Baskhali area for different return periods of the cyclone events (duration 2.5 hour)**

Analysis of the satellite image together with ground photographs of the area; interpolation of elevation point data; cyclone flood modeling for different return period.

Tsunami hazard

Causes of a tsunami
- Displacement along fault line at ocean floor
- Landslides / slumps – submarine or along coastline
- Volcanic eruptions – submarine or along coastline

A *tsunami* is an exceptional disturbance of the sea level caused by an earthquake, landslide or volcanic eruption in and around the oceans. This can generate a sea wave of extreme length and period, travelling outwards in all directions from the source area with speeds up to 500 km/hr. Tsunami waves may attain heights of more than 30 meters by the time they hit the coast (Aceh tsunami December 2004). Several waves may follow each other at intervals of 15 – 45 minutes. (Fig. 3.C.14) In 1883 the explosive eruption of Krakatau volcano in Strait Sunda, Indonesia generated a

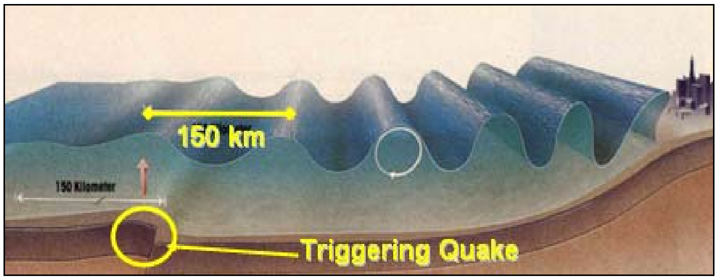


Figure 3.C.14 Tsunami wave triggered by displacement at sea floor

Task 3.C.4 : Poster Tsunami (duration: 15 minutes)

- Study the text and the pictures of the poster made by M. Damen, ITC

Task 3.C.5 : News item tsunami impact Banda Aceh (duration: 10 minutes)

- Look at the shocking news item of the tsunami flood disaster in Banda Aceh, December 2004.

Task 3.C.6 : Animations of tsunami wave propagation and impact in an urban area (duration 30 minutes)

- Observe the different computer animations.

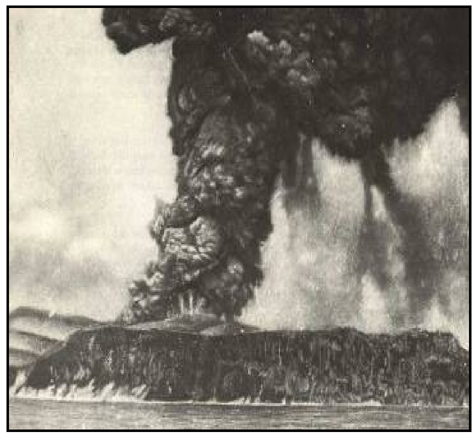


Figure 3.C.15 : Eruption Krakatau volcano, Indonesia in 1883 having caused large tsunami waves along the coasts of Java and Sumatra

Task 3.C.7 : NOAA Interactive tsunami database (duration: 20 – 30 minutes)

WARNING ! High Speed Internet connection needed !

- Visit the interactive web atlas (ARcIMS) of all global tsunami events
- Study the events close to your country

http://www.ngdc.noaa.gov/hazard/tsu_db.shtml

tsunami run-up of 35 meter

high on the nearby coasts of Java and Sumatra, sweeping away houses and large coral blocks (Fig. 3.C.15). The well known tsunami of December 26, 2004, was caused by an earthquake due to seafloor displacement west of Sumatra.

For detailed tsunami hazard analysis, the interpretation of multi-temporal images, in particular the delineation of the hazard zone with the help of elevation data such as Shuttle Radar Topography Mission data (SRTM) or damage assessment with high resolution air-borne and space-borne pre- and post disaster satellite imagery such as IKONOS and Quickbird can be very useful. (Figure 3.C.16)

Figure 3.C.16 : Quick Bird imagery of an island along the coast of Banda Aceh city. Left image: 23 June 2004; right image: 28 December 2004, therefore immediately after the tsunami disaster of 25 December of that year (Image processing: M.Damen)

As both the intensity and probability of the past tsunami events can not always be extracted in sufficient detail from existing databases , the term tsunami susceptibility zoning is preferred , defined as a qualitative rating for the terrain location, intensity and impact of the hazard. In Figure 3.C.17 an example is given of tsunami susceptibility classes in the Aceh area of North Sumatra, Indonesia, based on only a GlobeDEM digital elevation model of the coast (grid cell 1 x 1 km^2). Three classes have been made based on the elevation and width of the lower parts along the coast.

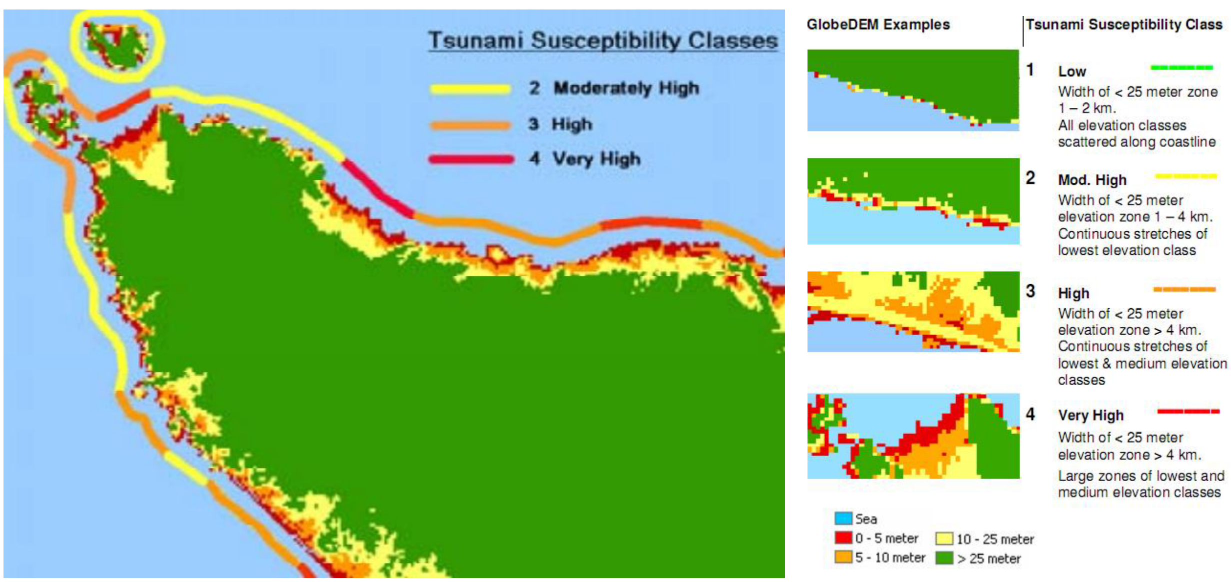


Figure 3.C.17 Semi quantitative Tsunami susceptibility classes of Aceh (North coast of Sumatra, Indonesia) based on a GLOBE DEM elevation model (Damen, 2005).

3.C.4 Slow Coastal Hazards

Enhanced Sea level rise.

Due to global warming and the Greenhouse Effect, the sea level will rise substantially in the near future. The International Panel of Climate Change (IPCC) has developed various scenarios for this (Fig. 3.C.18). In the "Business as Usual" scenario this rise will amount up to 40 cm or even more until the end of this century.

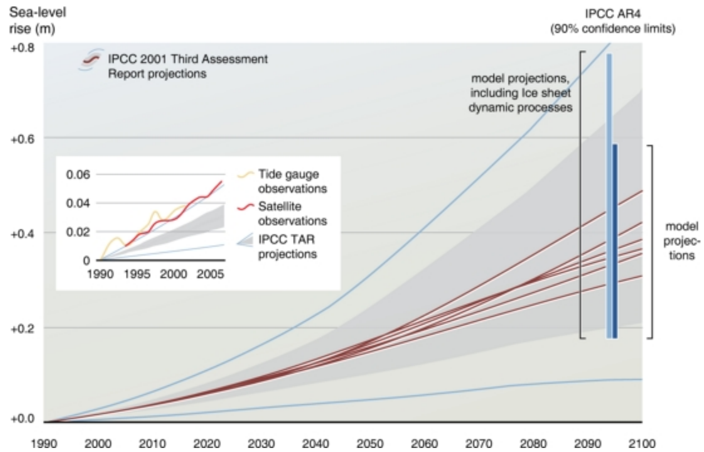


Figure 3.C.18 : Projected Sea Level Rise 21st Century (IPCC, 2009)

The enhanced Sea level rise has to be differentiated from *long term sea-level change.* These changes are so slow, that they are not considered as a hazard. World-wide changes in average sea level are described as *eustatic* to distinguish them from local influences, such as tectonic uplift or land subsidence. Eustatic sea-level changes result from two main causes: (1) changes in the volume of the ocean basins; and (2) changes in the volume of sea water. An example of the last course is sea level rise due to melting of glaciers after the last ice age.

In Holland the effect of eustatic sea level rise has been in particular hazardous due to the land subsidence in the last 1000 years in the peat areas caused by the lowering of the ground water and peat digging (Fig. 3.C.19)

At other places due to this transgression in the Holocene period (starting 10.300 years Before Present) coastlines has changed rapidly and moved "inland", creating delta's, lagoonal areas with tidal creeks, mudflats and peats as well as beach ridges.

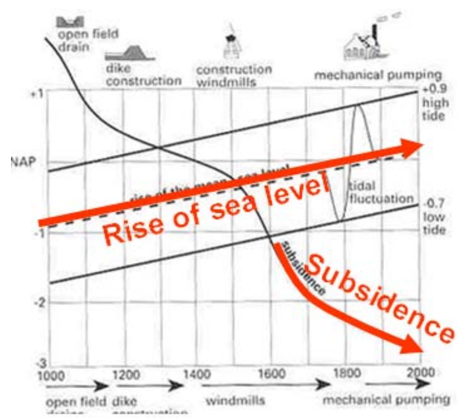


Figure 3.C.19: Land subsidence in Holland in the last 1000 years in the peat area in combination with eustatic rise of sea level (vd Ven 1993)

Enhanced Sea Level Rise scenarios for the Netherlands	
Low scenario	20 cm / century
Medium scenario	60 cm / century
High scenario	80 cm / century + 10% extra wind

Consequences:

1. Higher average water levels
2. More frequent storms
3. Larger tidal range

Task 3.C.8 : Hazard analysis of enhanced sea level rise

(duration : 1.0 hour)

- Use of the SRTM elevation model of Java and Bali, Indonesia for the analysis of enhanced sea level rise
- Display of the hazard zones in red, together with the drainage pattern.

Land subsidence

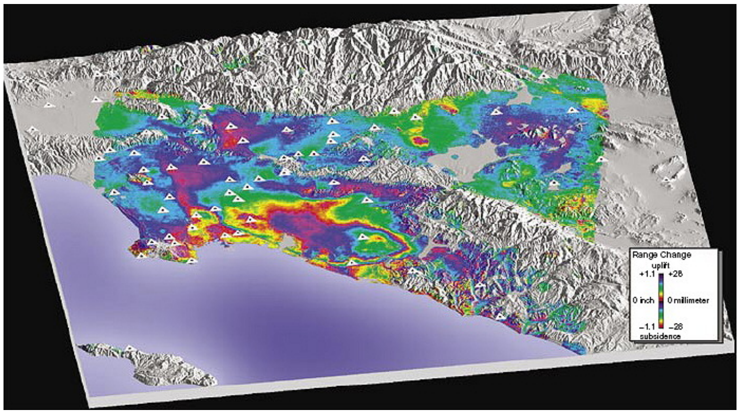


Figure 3.C.20 : Interferogram showing deformation in the Los Angeles Basin, April 1998 - May 1999 (USGS, 2005)

Subsiding coasts can be considered as a severe hazard, especially when they take place in urban areas situated in geologically young and "soft' sedimentary deposits. They can be caused by excessive ground-water extraction through industrial or private wells, as well as decreased discharge of the coastal aquifer.

Subsiding rates up to 15 cm a year or even more might take place. The subsided land is prone to flooding both from the sea and from rivers. A good example is Semarang city, Indonesia with subsidence rates up to 11.5 cm /year (See Figures 3.C.22-A & B).

The subsidence rate itself can only be determined by geo-technical investigations, such as point data. By using Satellite Interferometric Synthetic Aperture Radar (InSAR) technique, using images of different dates, changes in elevation can be measured too (Figure 3.C.20).

Subsiding cities (Rates since recording)	
Tokyo	4.6 m
Shanghai	2.7 m
Houston	2.7 m
Taipei	2.4 m
Bangkok	1.6 m
Semarang	11.5 cm/year

Figure 3.C.21: Rapid land subsidence causes flooding in the industrial area of Semarang, Indonesia (Photo: M. Damen

Task 3.C.9 : Reading article "Monitoring Land Subsidence in Semarang, Indonesia"
(duration: 1 hour)

- Read the article by Aris Marfai and Lorenz King on the "Monitoring Land Subsidence in Semarang, Indonesia"

This is a preparation to task 3.C.10

Task 3.C.10 : Modelling of Land Subsidence & Sea Level Rise in Semarang city, Indonesia
(duration : 2 hours)

- Analyse flooded areas in Semarang due to enhanced sea level rise and subsidence using ILWIS

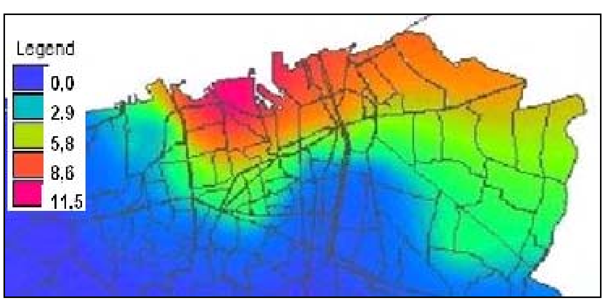


Figure 3.C.22-A : Subsidence rate Semarang city, Indonesia (cm/year). Interpolation from point data. Values in cm/year (M. Damen, 2009)

Figure 3.C.22-B : A Subsidence flooding in the industrial area of Semarang city, Indonesia. Asterbands RGB : 321 (M. Damen, 2009)

Coastal erosion and accretion

Coastal erosion & accretion is basically a natural process, which can becomes a risk to coastal infra-structure or other types of land uses, such as shrimp and fishponds or rice fields. The combined effect of wind-generated waves, tidal waves and currents from rivers, produce a highly variable and complex near-shore hydrodynamic system. Due to the movements of sediment on the sea floor and onshore, offshore and alongshore, the shaping of the coastline is taking place in a dynamic system in a continuous process.

Tides are movements of the ocean water caused by the gravitational effects of the moon and the sun in relation to the earth (Figure 3.C.23). They are very long waves that travel across the ocean and are transmitted into bays, inlets, estuaries and lagoons, causing tidal currents. The cycle produces two high and two low tides in approximately 25 hours. The tides are measured by tide gauges, located mainly at ports.

Spring tides occur when sun, earth and moon are in alignment; small tides or *neap tides* take place when the sun and the moon are at right angles to the earth.
Tidal currents, produced as tides rise and falls, alternate in direction in coastal waters. The tidal range in mid-ocean is small, about 50 cm. but its height is increased when it reaches the shallow waters of the continental shelf. Low tidal ranges occur most commonly on open coasts and in landlocked seas. The highest tides occur in estuaries or other coasts with convergent shores.

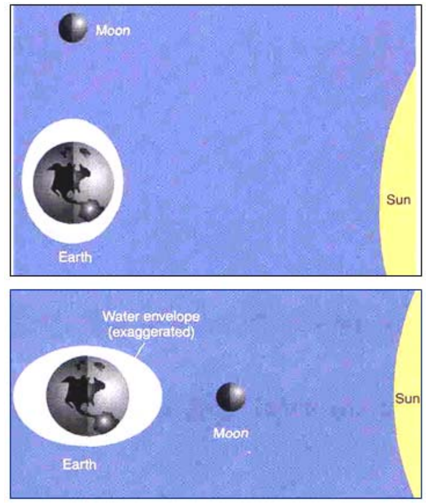


Figure 3.C.23 : Tides – position of moon and sun in relation to earth

Surface waves generated by wind are – besides tidal waves – the main source of energy along a coast. They form *ocean swells*, which are long, low waves with periods of 10 – 16 seconds. As the move towards the coast the wave crests gain in height steepness, and as they enter shallow water they break to produce a *surf* wave on the beach.

Wave refraction takes place when sea waves approach the coastline in a shallow water environment (see Figure 3.C.24). Ocean swell has a parallel wave crest in deep water, but as the waves move into shallow water they are modified by the frictional effects of the sea floor. The effect of this is that the angle between the swell and the bathymetrical contours diminishes, until they are approximately parallel to each other. The resulting curved patterns of wave crests can be observed from headlands or seen on aerial photographs.

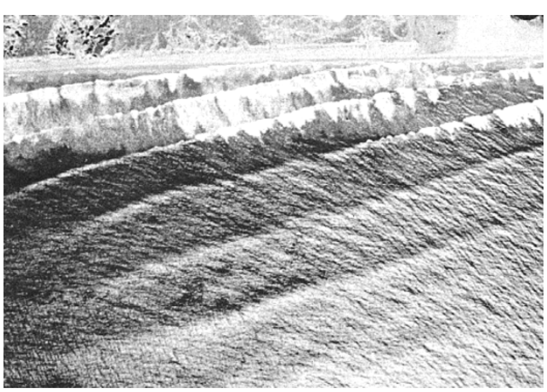


Figure 3.C.24 : Example of wave refraction at a coast. Panchromatic aerial photograph (ITC Photo database)

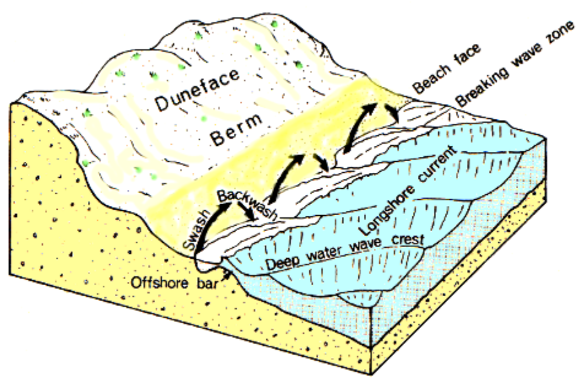


Figure 3.C.25 : Longshore drifting: Swash and backwash along a sandy beach

Even after refraction few waves are parallel to a beach, but approach it at an angle which causes the *swash* to move sediment diagonally up the beach in the direction of the wave approach. The *backwash* will run more directly down the beach so that the sediment undergoes net transport along the beach. The long shore movement of waves and the movement of sediment along the beach together create a *long-shore* or *littoral drift (*see also Figure 3.C.25*).*

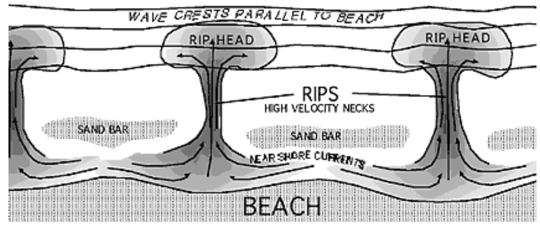


Figure 3.3.C.26 :Rip currents along a sandy beach (Berkely-EDU 2002)

On most coasts there are dominant waves from one direction and sediment is transported predominantly in that direction.

In the near-shore zone water carried onshore by waves is often carried away again by *rip currents*, which may be regularly or irregularly spaced (Figure 3.C.26). Currents are also produced by the discharge from river mouths. River outflow may carry sediments into the sea, maintain or enlarge river outlets or even form *deltas.*

Task 3.C.11 : Look at YouTube videos on Coastal Erosion (duration 1 hour):

- **Longshore drifting (Steve Vetesse):**
  http://oceanica.cofc.edu/an%20educator'sl%20guide%20to%20folly%20beach/guide/process2.htm
- **Longshore drifting :**
  http://www.youtube.com/watch?v=U9EhVa4MmEs&feature=PlayList&p=5F98D2A77B6A176F&playnext=1&playnext_from=PL&index=23

  http://www.youtube.com/watch?v=rCpZYlPqn6E&feature=related
- **The Quite Crisis** – Walney Dog productions:

  http://www.youtube.com/watch?v=5NMF1sqfR3Q
- **Deposition & Erosion** by Liam Sharpe– Cliff formation shown with 365 sequential photographs:

http://www.youtube.com/watch?v=ChEHQUMEkXw&feature=PlayList&p=96730DF14415DE67&playnext=1&playnext_from=PL&index=64

Inventory of spatial datasets required in coastal hazard & risk assessment

Baseline & other thematic data needed for coastal zone management purposes • Topographical maps • Bathymetrical maps • High res. Satellite images (IKONOS, QuickBird) • Elevation data with sufficient accuracy to show minor elevation differences in gentle / flat coastal terrain • Soil & Geomorphological maps • Hydrological maps • Geological maps, with detailed information on the Holocene coastal deposits • Population & infra-structural data of the coastal zone itself • Maps of nature conservation areas	**Data needed for enhanced sea level rise risk analysis** • Local (IPCC) scenarios of sea level rise • (Historic) meteorological data (wind speeds, rainfall, temperature) • Detailed elevation map of the coastal zone for impact modelling • High resolution aerospace data (aerial photographs & satellite imagery) to map (a.o) elements at risk • Database on population & infra structure, including amounts and vulnerabilities • Data on neo-tectonic land movements and other possible causes of land subsidence

Data needed for cyclone risk analysis
• Database of historic events, including gust wind speed, surge height, tidal situation during landfall, # casualties
• Meteorological and tidal data
• Historic cyclone storm tracks
• Detailed elevation model for impact flood assessment / modelling
• High resolution aerospace data (aerial photographs & satellite imagery) to map elements at risk
• Database on population & infra-structure, including numbers and vulnerabilities
• Data on available shelters & evacuation routes
	Data needed for land subsidence risk analysis
	• Multi-date elevation models:
	  o Regional: INSAR Interferogram
	  o Local: detailed DEM (from Lidar, photogrammetry, Diff. GPS surveys)
	  o Point data of subsidence rate
	• Data on surface drainage and subsurface hydrology
	• Lithological and structural data of sub-surface
	• Geological data on neo-tectonic land movements (up and down)
	• High resolution aerospace data (aerial photographs & satellite imagery) to map (a.o.) elements at risk
	• Databases on population & infra structure, including amounts and vulnerabilities

Data needed for tsunami risk analysis • Database of historic events • Detailed coastal terrain elevation for run-up modelling / hazard zone analysis • Bathymetrical maps for tsunami run-in modelling • Geological data on possible triggering locations • High resolution aerospace data (aerial photographs & satellite imagery) to map (a.o.) elements at risk • Database of population & infra-structure, including amounts and vulnerabilities • Data on available shelters / evacuation routes • Warning system	**Data needed for coastal erosion / accretion risk analysis** • Medium to high aerospace imagery of the coastline (aerial photographs, satellite imagery) • Tidal information • Marine data on wave directions, sediment transport, etc. • Discharge data of the river(s) and amounts of suspended sediment, etc. • Maps on coastal geology, geomorphology and soils • High resolution aerspace data to map (a.o.) elements at risk • Database on population & infra structure, including amounts and vulnerabilities

Depositional coastal landforms – the delta as an example

A *delta* is a low, nearly flat area of land at the mouth of a river where sediment accumulates. (Figure 3.C.27). Deltas may have many shapes with four common shapes widely recognized (Figures 28): (1) *elongated* or *digitate*, like the Mississippi, where alluvium is abundant and the river can built into the sea due to limited wave action, (2) *cuspate*, where wave erosion dominates the distribution of sediment away from the river mouth, (3) *lobate* like the Niger, where the river builds into the sea but wave action is effective in redistributing sediment along coastal barriers and *crenulate*, like the Mekong, where tidal currents produce numerous sandy islands separated by tidal channels along the delta front.

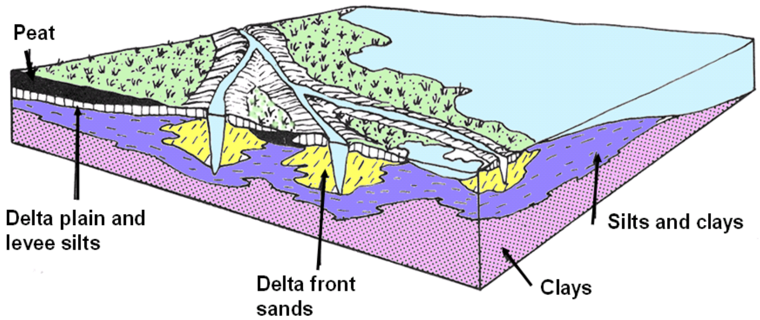
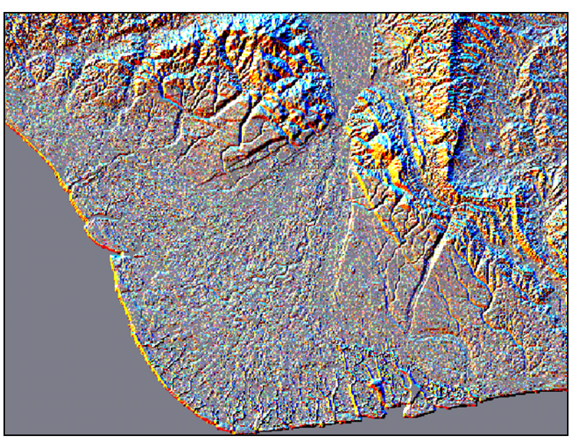


Figure 3.3.C.27 : The delta and its deposits



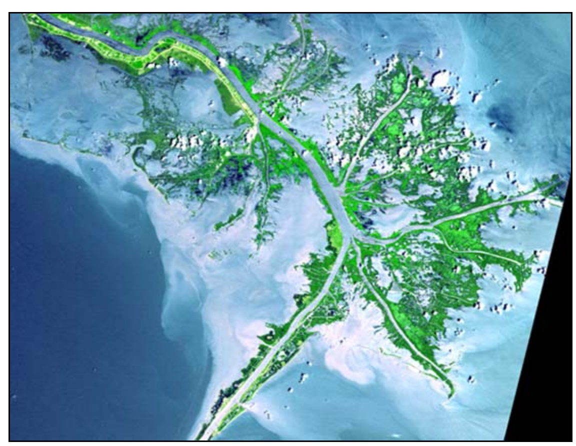


Figure 3.C.28- A : Upper left: Tiber delta -cuspate type Quickbird (Google Earth)

Figure 3.C.28- B : Upper right: Mekong delta – crenulate type Envisat - MERIS

Figure 3.C.28- C : Lower left: Niger delta – Lobate type S RTM elevation data – Color hillshade

Figure 3.C.28- D : Lower right: Mississippi delta – digitate Aster VNIR

Monitoring the Solo river delta, North coast of java, Indonesia

Most of the deltas change the position of the outlet over time. Examples of this are the Mississippi delta where the delta front changes its position several hundred kilometres over the last 5000 years and the Hunaghe or Yellow river delta in China. Below an example of the Solo delta at the North coast of Java, Indonesia (Figure 3.3.C.29).

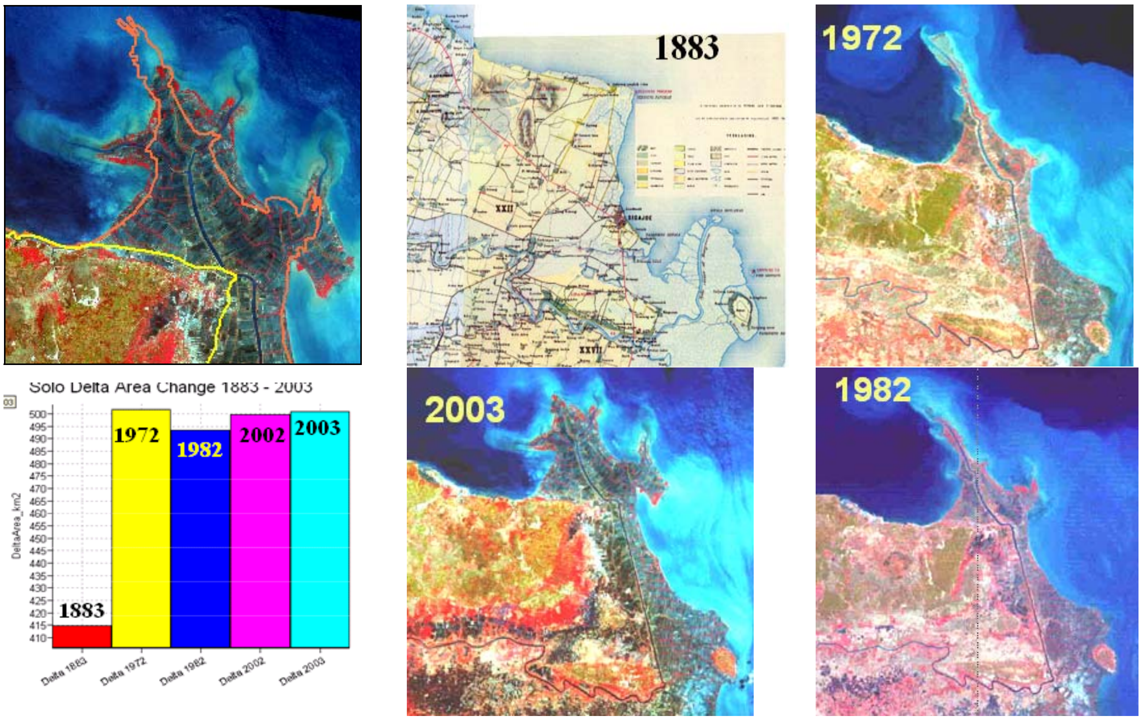


Figure 3.C.29 : Coastline and area change of Solo river delta, Indonesia – 1883: topographical map; 1972: Landsat MSS; 1982: Landsat TM; 2003: Aster VNIR. (M. Damen, 2009)

Task 3.C.12 : Monitoring of the change of the Solo River delta, Java, Indonesia (duration : 1.5 hour)

- Use the provided multi-temporal satellite images and digitized coastlines to analyze the change of the delta, using ILWIS software.

Summary coastal hazard assessment

Coastal hazard analysis and the mitigation of hazards and disasters should be integral part of coastal zone management. Examples are given from the Netherlands, such as the use of multi-temporal Lidar elevation data for the monitoring of the eroding or depositing amounts of sand along the beach.

A subdivision is made between geoinformation methods for the study of slow and rapid coastal hazards. An example of the first type is risk evaluation of cyclones based on statistical analysis of historic events together with GIS modeling of the flood surge impact and the people at risk. Multi-date high resolution remote sensing imagery is shown of Aceh, Indonesia for the analysis of elements at tsunami risk. By using medium resolution elevation data a crude tsunami susceptibility classification of then coastline can be made.

Examples of slow coastal hazards are the study of land subsidence in Semarang city, Indonesia using multi-date elevation models in combination with enhanced sea level rise. Finally some methods are shown on the analysis of of coastal erosion & accretion of delta environments with the use of multi-sensor and multi-date satellite imagery.

Selftest

In order to evaluate whether you have understood the concepts that were presented in this session. Please make the following test, and check the answers in Blackboard.

Question 1:
Mention the three important elements of Integrated Coastal Zone Management.

Question 2:
List some mitigation measures of coastal flooding.

Question 3:
Mention one Remote sensing technique to measure the volumes of sand that might erode or deposit along a sandy beach.

Question 4:
Mention the two most important causes of the sea level to rise due to a cyclone event along the coast.

Question 5:
List at least three causes of a tsunami.

Question 6:
At which places on the earth do the most tsunami events take place? Look for this at the NOAA tsunami database.

Question 7:
Mention at least two causes of the sea level to rise relative to the land area.

Question 8:
What kind of geoinformatics techniques can be applied to measure land subsidence over time?

Question 9:
Explain with a small drawing the process of swash and backwash along a sandy coast.

Question 10:
Mention the four main types of a delta.

Further reading:

- **RWS (2002)** – Towards an Integrated Coastal Zone Policy – Policy Agenda for the Coast - Min. of Transport, Public Works and Water Management, The Hague, The Netherlands
- **Damen & Khan (1985)** Cyclone Hazard in Bangladesh **-** Background information storm surge modeling, ITC
- **Cummins & Leonard (2005)** The boxing day tsunami In Indonesia, Geoscience Australia, Issue 77
- **Marfai, Muh. Aris & King, Lorenz (2007)** Monitoring Land Subsidence in Semarang, Indonesia – Env. Geology 53:651-659
- **Coastal erosion and Accretion –** Document 26 of Sustainable Development of European Coastal Zones. For more documents see: http://www.deduce.eu/results.html

References Coastal hazard Assessment

Berkely-EDU (2002) - Campus News http://berkeley.edu/news/media/releases/2002/05/23_tides.html

Damen, M. (2003) – Monitoring the change of the Yellow River delta using multi-temporal satellite images, PR China, ITC ILWIS Exercise

Damen, M. (2005) – Geo-information for Tsunami Susceptibility Zoning – Examples from the Coast of Indonesia – Map Asia Congress

Damen, M. (2009) – hazard Analysis of Cyclone Flooding in Bangladesh, ITC ILWIS Exercise

HAZUS (2004) : Multi-hazard Loss Estimation Methodology, FEMA, USA

IPCC (2009) – Projected Sea Level Rise for 21st Century

http://maps.grida.no/go/graphic/projected-sea-level-rise-for-the-21st-century#metainfo

NASA Earth Observatory: http://earthobservatory.nasa.gov/IOTD/view.php?id=524

NOAA-AOML – Atlantic-Oceanographic and Meteorological Laboratory, Hurricane Research division: http://www.aoml.noaa.gov/hrd/tcfaq/C1.html

RWS (1991) – Rising Waters, Impact of the greenhouse effect for the Netherlands (Doc. gwao 90.026). Min. of Transport, Public Works and Water Management, The Hague, The Netherlands

RWS (1996) – Coastline Management – From Coastal monitoring to sand nourishment, Min. of Transport, Public Works and Water Management, The Hague, The Netherlands

RWS (2002) – Towards an Integrated Coastal Zone Policy – Policy Agenda for the Coast - Min. of Transport, Public Works and Water Management, The Hague, The Netherlands

RWS (2009) Delta Works online**:** http://www.deltawerken.com/English/10.html?setlanguage=en

SERF (1995) - Kelletat, Atlas of Coastal Geomorphology, SERF Book

UNDRO (1991) – Mitigating Natural Disasters, Phenomena, Effects and Options. A manual for Policy makers and Planners. Publication within framework IDNDR

Ven, van de, Editor (1993) – Man-made lowlands – History of Water Management and Land Reclamation in the Netherlands – Int. Commission on Irrigation and Drainage. Uitg. Matrijs, Utrecht, Netherlands

Guide book
Session 4:
Elements at Risk

Cees van Westen, Nanette Kingma & Lorena Montoya

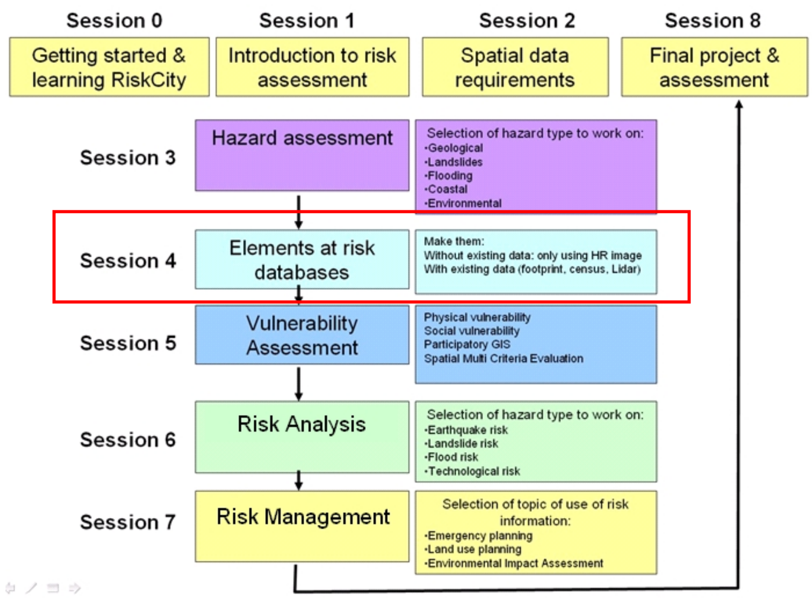
Objectives
After this session you should be able to:

- Understand the types of elements at risk;
- Characterize the elements at risk (buildings & population) in relation to different types of hazard;
- Know the sources for the mapping of elements at risk;
- Generate a basic elements at risk database for a situation where no information is available, except for a high resolution image;
- Generate an element at risk database for an urban area, using available data such as building footprint maps, census data and detailed elevation data.

In this session you will go through the guide book which deals with elements at risk mapping. We will look at urban land use first, and you will evaluate how you can identify different types of land use from high resolution imagery. You will also look at the relation between land use, building types and the population density.
We take two examples of elements at risk and look more in detail to those. First we analyze the characteristics of buildings that are relevant for estimating the vulnerability. We look at floorspace, construction type, and building costs. Three examples are given of the aspects related to building behavior for earthquakes, flooding and landslides. In the section on population we will look at the static and dynamic aspects of population and how you can estimate these. You can choose between 2 RiskCity exercises for making an elements at risk database: with or without existing data. The last part of the chapter deals with participatory mapping, and there you will also do a RiskCity exercise on how you can use information that was derived using Mobile GIS.

Section	Topic	Task	Time required		
4.1	Introduction		Day 1	0.7	1.5
		Task 4.1: HAZUS methodology		0.15	
		Task 4.2: Inventory of elements at risk		0.5	
		Task 4.3: Scales and types		0.15	
4.2	Urban land use			1.5	3
		Task 4.4: Make a land use legend for your area		0.5	
		Task 4.5: Recognizing land use types from Google Earth imagery		0.5	
		Task 4.6: List of identification criteria for landuse types		0.5	
4.3	Buildings		Day 2	1.5	6
		Task 4.7: Determine the important characteristics of buildings		0.5	
		Task 4.8: Generating an element at risk database from scratch		Choose one: 4	
		Task 4.9: Generating an element at risk database with available data	Day 3		
4.4	Population			0.75	0.75
4.5	Participatory mapping			1	4.75
		Task 4.10: Video on Community based approaches	Day 4	0.5	
		Task 4.11: RiskCity exercise on the use of Participatory mapping information		3	
		Task 4.12: Summary on the use of participatory mapping for disaster risk assessment		0.25	
		Total	**4 days**		**16 h**

4.1. Introduction.



The next step in a risk assessment, after analyzing the hazard, that we saw in the previous session, will be to evaluate the elements at risk. **Elements at risk** are the population, properties, economic activities, including public services, or any other defined values exposed to hazards in a given area. They are also referred to as "**assets**". Elements at risk also have spatial and non-spatial characteristics. First of all there are many different types of elements at risk (which will be treated in this session) and they can be classified in various ways. The way in which the amount of elements-at-risk are characterized (e.g. as number of buildings, number of people, economic value or the area of qualitative classes of importance) also defines the way in which the risk is presented to the end users (i.e. decision makers, emergency personnel and the general public). The interaction of elements at risk and hazard defines the exposure and the vulnerability of the elements-at-risk. Exposure indicates the degree to which the elements at risk are exposed to a particular hazard. The spatial interaction between the elements at risk and the hazard footprints are depicted in a GIS by simple map overlaying of the hazard map with the elements at risk map. The aim of the element at risk mapping is to build up a data base for the evaluation of the vulnerability of the elements at risk for certain hazards

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What are elements at risk?

- All objects, persons, animals, activities and processes that may be adversely affected by hazardous phenomena, in a particular area, either directly or indirectly. This includes: buildings, facilities, population, livestock, economic activities, public services, environment.

4.1.1 General classification of elements at risk

There are many different types of elements at risk, and also many different ways to classify them. Table 4.1 gives an example of such a classification.

Table 4.1: Classification of elements at risk

Physical elements Buildings: Urban land use, construction types, building height, building age, total floor space, replacement costs. Monuments and cultural heritage	**Population** Density of population, distribution in space, distribution in time, age distribution, gender distribution, handicapped, income distribution
Essential facilities Emergency shelters, Schools, Hospitals, Fire Brigades, Police,	**Socio-economic aspects** Organization of population, governance, community organization, government support, socio-economic levels. Cultural heritage and traditions.
Transportation facilities Roads, railway, metro, public transportation systems, harbor facilities, airport facilities.	**Economic activities** Spatial distribution of economic activities, input-output table, dependency, redundancy, unemployment, economic production in various sectors.
Life lines Water supply, electricity supply, gas supply, telecommunications, mobile telephone network, sewage system.	**Environmental elements** Ecosystems, protected areas, natural parks, environmentally sensitive areas, forests, wetlands, aquifers, flora, fauna, biodiversity.

In literature many different methods can be found to classify elements at risk, depening on the country, the setting (urban, rural, etc.) the objectives of the risk assessment, the scale, available resources etc.
For example the Asian Disaster Preparedness Center (ADPC) classifies the elements at risk into physical, economic, societal and environmental elements (see table 4.2) which can we linked later immediately to physical, economic, social and environmental vulnerability.

Table 4.2: Classification of elements at risk

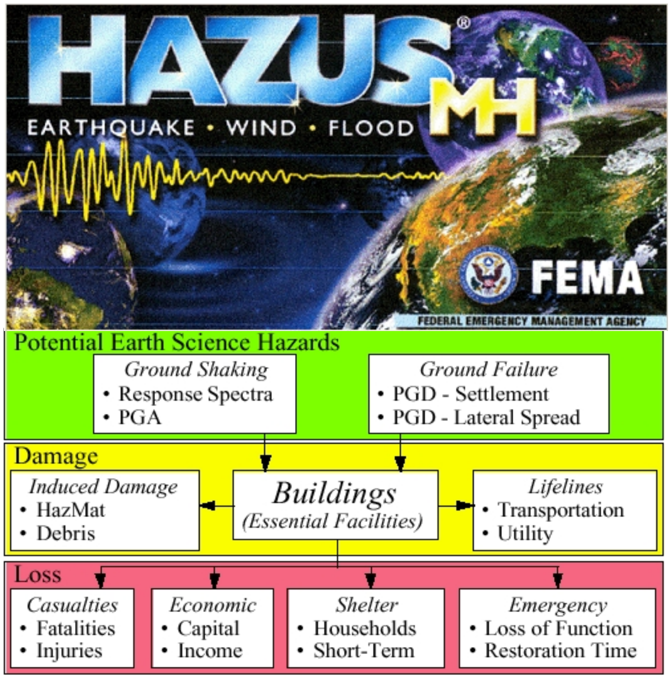
Physical elements **Infrastructure,** for example: roads, railway, bridges, harbors, airports etc. **Critical facilities**, for example: emergency shelters, schools, hospitals, nursing homes, fire brigades, police etc... **Utilities**: Power supply, Water supply Services: transport, communications etc... Government services: all levels - national, provincial, local Machinery and equipment Historical structures and artifacts	**Societal elements** Vulnerable age group categories Low-income groups Landless/Homeless Disabled Gender Single parent households Etc.
Economic elements Business and trade activities, Access to work, Agricultural land, Impact on work force, Productivity cost Opportunity cost	**Environmental elements** Environmental Resources: air, water, fauna, flora Biodiversity Landscape

Villagrán de Leon (2006), classifies the elements at risk according to different sectors: housing, basic lifelines, health, education, agriculture, energy, infrastructure, commerce, industry, finance and telecommunications. The sectoral approach is proposed from a policy point of view because it promotes assigning responsibilities to those private or public institutions in charge of each sector (Government ministries or others).

HAZUS MH methodology

HAZUS is by far the most advanced method for spatial multi-hazard risk assessment that is publicly available. HAZUS has been developed by the US Federal Emergency Management organization (FEMA) together with the National Institute of Building Sciences (NIBS). HAZUS is a software programme running under ARCGIS for estimating potential losses from earthquake, flood and hurricane hazards. HAZUS-MH software can be requested from the following website: www.fema.gov/plan/prevent/hazus
The HAZUS method also has a very extensive module dealing with the inventory and classification of elements at risk. In this chapter we will present parts of that. However, HAZUS is developed for the USA, and the elements at risk classification cannot be used directly in other countries, and particularly not in developing countries, where building types, population densities etc. will be completely different from those in the USA. Also the hazard characteristics may be quite different in the USA as compared to other countries. HAZUS requires a very extensive data input in terms of the elements at risk information and the hazard information, which is often not available in developing countries. Therefore the methodology often has to be simplified.

Figure 4.1: Opening screen and general structure of the HAZUS method for Multi hazard risk assessment



Task 4.1: HAZUS methodology (duration 10 minutes)

To get a first idea on the HAZUS methodology, please visit the Website
http://www.fema.gov/library/viewRecord.do?id=3299
Download and read the introduction.
You can also obtain it from the background materials directory for Session 4 on the course DVD.

A survey of elements at risk is always incomplete, and therefore a risk assessment study nearly always focuses on specific groups of elements at risk, such as buildings or population. In the exercises that we will do using the RiskCity case study we will in fact concentrate only on building and population as the two main types of elements at risk.

An important distinction to be made here is also the differentiation between **tangible** and **intangible elements at risk**. Tangible elements at risk are those things that can be identified, localized, mapped and quantified (For examples, most of the physical elements). Intangible elements are those things that are very difficult to quantify or map, as they do not have a particular spatial dimension (for instance, the cultural values, the wellbeing of communities, psychological conditions, and sociological behavior). When a disaster hits also these elements at risk may be severely impacted.

Task 4.2: Inventory of elements at risk (duration 30 minutes)

Imagine the neighborhood/city/country in which you live would be hit by a hazard event. Which elements at risk would be impacted?

- Make a selection of a particular hazard type (e.g. flood, landslide, earthquake, windstorm, explosion of an industry, major accident etc.)
- Select the scale: your neighborhood / city / region / country
- Think about the type of area where you live. What are the main characteristics in terms of buildings, population, economic activities, infrastructure etc.
- Create a table in which you list the elements at risk according to the different types indicated in the tables above.
- Define whether the elements at risk can be mapped, and quantified.

Hazard type: __________________

Element at risk	What is the effect?	Can it be mapped?	Can it be quantified?

Compare your results with that of the other course participants.

4.1.2 Elements at risk mapping versus scale and objective of the study.

Elements at risk inventories can be carried out at various scale levels, depending on the requirements of the risk study. In the previous chapter on hazard assessment, four different scales have been identified, ranging from small scale to detailed scale. In table 4.3 an overview is given of 4 scale levels versus the detail of the elements at risk that could be used. In the RiskCity case study we work at medium to large scale at the urban level, where information needs to be as detailed as possible, preferably at the individual building level, or at a slightly more aggregated level of mapping units or building blocks with homogenous land use type. In table 4.3 the areas with a red border indicate the elements at risk and the scale that is used for the RiskCity exercises. In these exercise we concetrate on the evaluation of risk for buildings and population. In fact many of the risk assessments concentrate on these two aspects.

Table 4.3: Elements at risk mapping versus mapping scale (red boxes indicate the combinations that will be used in the RiskCity GIS exercises)

Elements at risk type	**Scale of analysis**			
	Small < 1:100.000	**Medium 25-50.000**	**Large 10.000**	**Detailed >1:10.000**
Buildings	By Municipality • Nr. buildings	Mapping units • Predominant type (e.g residential, commercial, industrial) • Nr. buildings	Building footprints • Generalized use • Height • Building types	Building footprints • Detailed use • Height • Building types • Construction type • Quality / Age • Foundation
Transportation networks	General location of transportation networks	Road & railway networks, with general traffic density information	All transportation networks with detailed classification, including viaducts etc. & traffic data	All transportation networks with detailed engineering works & detailed dynamic traffic data
Lifelines	Main powerlines	Only main networks • Water supply • Electricity	Detailed networks: • Water supply • Waste water • Electricity • Communication • Gas	Detailed networks and related facilities: • Water supply • Waste water • Electricity • Communication • Gas
Essential facilities	By Municipality • Number of essential facilities	As points • General characterization • Buildings as groups	Individual building footprints • Normal characterization • Buildings as groups	Individual building footprints • Detailed characterization • Each building separately
Population data	By Municipality • Population density • Gender • Age	By ward • Population density • Gender • Age	By Mapping unit • Population density • Daytime/Nighttime • Gender • Age	People per building • Daytime/Nighttime • Gender • Age • Education
Agriculture data	By Municipality • Crop types • Yield information	By homogeneous unit, • Crop types • Yield information	By cadastral parcel • Crop types • Crop rotation • Yield information • Agricultural buildings	By cadastral parcel, for a given period of the year • Crop types • Crop rotation & time • Yield information
Economic data	By region • Economic production • Import / export • Type of economic activities	By Municipality • Economic production • Import / export • Type of economic activities	By Mapping unit • Employment rate • Socio-economic level • Main income types • + larger scale data	By building • Employment • Income • Type of business
Ecological data	Natural protected areas with international approval	Natural protected area with national relevance	General flora and fauna data per cadastral parcel.	Detailed flora and fauna data per cadastral parcel

Task 4.3: Scales and types (duration 10 minutes)
Compare your results of task 4.1 with the table 4.3. What can you conclude?

4.1.3 Basic units for risk assessment

Risk assessment should be done based on certain basic spatial units. These could be administrative units, such as countries, provinces, municipalities, wards or even individual buildings. Table 4.2 also gives suggestions for the best basic mapping unit to use. Even at large scales a risk assessment is normally not done at individual building level. This has several reasons:

- The attribute information required to do such a detailed risk assessment is generally not available, or very difficult to collect. For instance in the case of an earthquake, the behavior of each individual building is characterized by many factors which can vary from building to building. One would need to make a detailed structural engineering evaluation of each building in order to determine how this building would behave under particular earthquake acceleration. This study would be too time consuming, and therefore buildings are classified into groups. Individual study of buildings is only done for the critical facilities, such as hospitals.
- Displaying risk at individual building level is not realistic given the uncertainty in data and models. The vulnerability study is normally done using so-called vulnerability curves, which indicate the general behavior of buildings of a certain class (e.g. masonry two story buildings) and not for individual buildings.
- Displaying risk information at individual building level would lead to undesirable legal consequences, as it could have a large effect on real estate values, and possibly even on insurance premiums.

Therefore even at large scale, risk assessment is normally carried out for groups of buildings, located in so-called homogeneous units.

A **homogeneous unit** is a mapping unit that has more or less the same characteristics in terms of elements at risk. For instance the same landuse type or the same building types.

In the HAZUS methodology the loss estimation is done based on the census tracts. The census tract is considered as a homogeneous unit, and all estimations are given for that unit. Figure 4.2 gives an illustration of the various levels of elements at risk data that were available for RiskCity. The basic information was available in the form of individual building footprints, which lacked any attribute information. This level was considered too detailed as data collection for each individual building was too expensive. On the other hand, most of the attribute information related to population was linked to a polygon map of the wards of the city (see Figure 4.2.C). The detail of these units was considered too low, as the hazard varies significantly within one ward, and the integration of hazard data with general ward data would lead to non-reliable results. Therefore so-called mapping units were introduced as an intermediate level of elements at risk. They are considered to be more or less homogeneous units with respect to buildings types, socio-economic level and urban land use (See Figure 4.2.B). This mapping was done through image interpretation using the very high resolution imagery, and their boundaries are mostly formed by streets. The attributes from the higher and the lower levels were then converted to this intermediate level. For instance, the number of buildings per mapping unit was measured by overlaying the building footprint map with the mapping unit map. The average height of the elements at risk was estimated using the difference between the LiDAR DEM and the surface DEM generated from the contourlines with 2.5 meters contour interval, in the location of the building footprints (See Figure 4.2.D). Information of predominant urban land use was not available, and therefore had to be generated, based on detailed image interpretation (See Figure 4.2.E). Population information was only available at ward level (Figure 4.2.C), and the population values had to be distributed over the mapping units, based on the urban landuse, the height of the buildings and the footprint area, from which the total floor area per mapping unit and landuse class could be calculated. Population density was also calculated for different temporal scenarios (e.g daytime / nighttime / commuting time) using the urban landuse as the main criteria. Figure 4.2.D. illustrates the need for regular updating of the element at risk database, as around 560 of the building footprints displayed in the map (around 30000) were destroyed by floods and landslides during a recent disaster (see chapter 1 for more information).

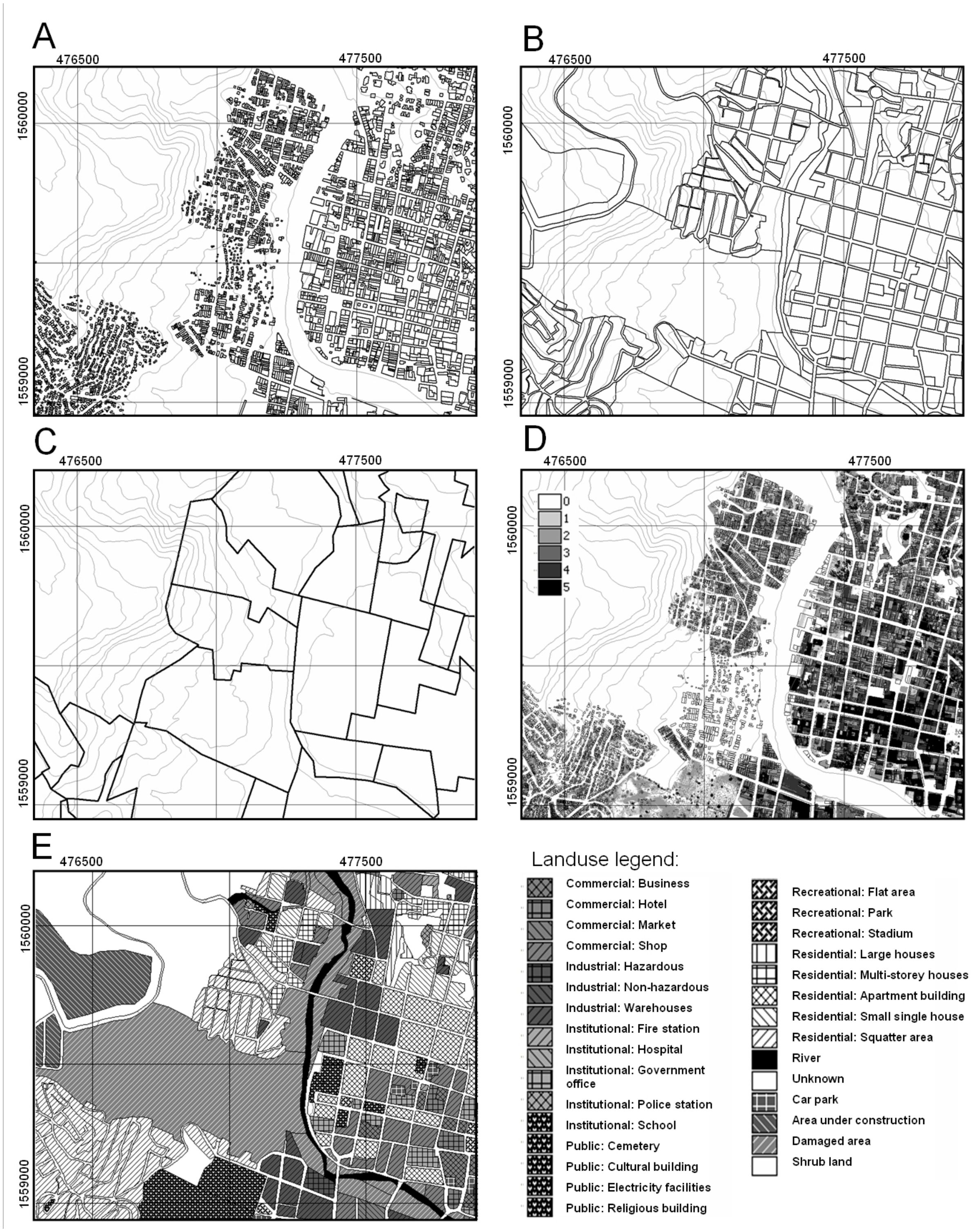


Figure 4.2: Different types of information that are important for the generation of an elements at risk database in RiskCity. A: Individual building footprints obtained by screen digitizing on airphotos and field verification , B: Mapping units, representing zones of more or less homogeneous urban landuse and building types, which are mostly coinciding with the street pattern C: Wards, for which aggregated population information is available D: Building height, in number of stories, generated using LIDAR data, and E: Land use classification of the mapping units, which forms the basis for assigning attributes to the buildings in the various classes, and for estimating the population density in different temporal scenarios (daytime, nighttime, commuting time).

4.2 Urban land use as main entry point

One of the most important spatial attributes of the mapping units for elements at risk inventory is the land use. The land use determines to a large extend the type of buildings that can be expected in the unit, the economic activities that are carried out, the density of the population in different periods of the day, etc.

4.2.1 Classification schemes

Table 4.4 gives the land use classification which is used in the Radius methodology, which is a simple method for estimating seismic losses in cities carried out in the International Decade for Disaster Reduction (1990-2000) (http://geohaz.org/contents/projects/radius.html).

Table 4.4: Urban land use classes used in the Radius methodology for earthquake loss estimation.

Code	Description
RES_1	Informal construction. Mainly slums, row housing etc. made from unfired bricks, mud mortar, loosely tied walls and roofs.
RES_2	Unreinforced masonry (URM) – Reinforced Concrete (RC) composite construction - sub-standard construction, not complying with the local code provisions. Height up to 3 stories.
RES_3	URM-RC composite construction - old, deteriorated construction, not complying with the latest code provisions. Height 4 - 6 stories
RES_4	Engineered RC construction - newly constructed multi-storied buildings.
EDU_1	School buildings, up to 2 stories.
EDU_2	School buildings, greater than 2 stories.
MED_1	Low to medium rise hospitals.
MED_2	High rise hospitals
COM	Shopping centers
IND	Industrial facilities

Table 4.5 gives the land use classification used in the HAZUS methodology for the US. In their methodology they refer to it as occupancy classes, as they are directly linked to buildings.

Table 4.5: Building occupancy classes as used in HAZUS.

Code	Occupancy Class	Example
Residential		
RES1	Single Family Dwelling	House
RES2	Mobile Home	Mobile Home
RES3	Multi Family Dwelling RES3A – RES3F (2 to ≥ 50 units)	Apartment/Condominium
RES4	Temporary Lodging	Hotel/Motel
RES5	Institutional Dormitory	Group Housing (military, college), Jails
RES6	Nursing Home	
Commercial		
COM1	Retail Trade	Store
COM2	Wholesale Trade	Warehouse
COM3	Personal and Repair Services	Service Station/Shop
COM4	Professional/Technical Services	Offices
COM5	Banks	
COM6	Hospital	
COM7	Medical Office/Clinic	
COM8	Entertainment & Recreation	Restaurants/Bars
COM9	Theaters	Theaters
COM10	Parking	Garages
Industrial		
IND1	Heavy	Factory
IND2	Light	Factory
IND3	Food/Drugs/Chemicals	Factory
IND4	Metals/Minerals Processing	Factory
IND5	High Technology	Factory
IND6	Construction	Office
Agriculture		
AGR1	Agriculture	
Religion/Non/Profit		
REL1	Church/Non-Profit	
Government		
GOV1	General Services	Office
GOV2	Emergency Response	Police/Fire Station/EOC
Education		
EDU1	Grade Schools	
EDU2	Colleges/Universities	Does not include group housing

In Table 4.6 the classification is given that is used in the RiskCity exercises.

Table 4.6: Urban land use classes used in the RiskCity exercise.

Code	Occupancy Class	Example
Residential		
Res_1	Res_squatter	Low income houses: squatter areas
Res_2	Res_small_single	Small single family houses, mostly in rows
Res_3	Res_multi	Multi-storey apartment buildings
Res_4	Res_mod_single	Moderately sized single family houses
Res_5	Res_large	Large free standing houses
Commercial		
Com_b	Com_business	Offices
Com_h	Com_hotel	Hotels
Com_m	Com_market	Market area
Com_s	Com_shop	Shops and shopping malls
Industrial		
Ind_h	Ind_hazardous	Hazadous material storage or manufacture
Ind_i	Ind_industries	Non hazardous industries
Ind_w	Ind_warehouse	Warehouses and workshops
Institutional		
Ins_f	Ins_fire	Fire brigade
Ins_h	Ins_hospital	Hospitals
Ins_o	Ins_office	Office buildings
Ins_p	Ins_police	Police station
Ins_s	Ins_school	Institutional : schools
Public buildings		
Pub_g	Pub_cemetery	Cemetary
Pub_c	Pub_cultural	Cultural buildings such as musea, theaters
Pub_e	Pub_electricity	Buildings related to electrical supply
Pub_r	Pub_religious	Religious buildings such as churches, mosques or temples
Recreational		
Rec_f	Rec_flat_area	Flat area or football field
Rec_p	Rec_park	Park area
Rec_s	Rec_stadium	Stadium
Vacant areas with no buildings		
Vac_c	Vac_car	Vacant : car parking and busstation
Vac_u	Vac_construction	Vacant area which is prepared for building construction
Vac_d	vac_damaged	Area recently damaged by hazard events
Vac_s	Vac_shrubs	Vacant land with shrubs, trees and gress
riv	River	River

Task 4.4: Make a land use legend for your area (duration 30 minutes)

Compare the result of your inventory of elements at risk that you made in Task 4.2 with the classification of land use types in tables 4.4 to 4.6

- Make a land use classification for your area, and for the hazard type that you selected.
- Indicate for each class the importance of this class for estimating losses of buildings and population. What makes each class different from the rest?

In the following pages we will illustrate the various land use types with examples from (mostly) RiskCity taken from high resolution imagery.

4.2.2 Residential areas

We start with residential classes. In total five residential classes have been identified. Most of them are rather straightforward to identify on imagery. Below three classes are shown in figure 4.3.

Figure 4.3: Example of residential building classes

Res_1: Slum / squatter areas

Res_2: Small single family houses

Res_3: **Multi-storey** houses

One of the most important urban land use classes for risk assessment are the slum areas, or squatter areas, as they will normally have the highest vulnerability to natural disasters. According to UN-Habitat 18% of all urban housing units (some 125 million units) worldwide are non-permanent structures and at least 25% of all housing (175 million houses) does not meet urban construction codes. This figure, in reality, is probably much higher. For every 10 non-permanent houses in the cities of developing countries, 3 or 4 are located in areas prone to floods, landslides, hurricanes and earthquakes (Source: http://www.unhabitat.org/)

The UN-Habitat uses five criteria to determine an area as a slum:

1. **Access to improved water** (access to sufficient amount of water for family use, at an affordable price, available to household members without being subject to extreme effort);
2. **Access to improved sanitation** (access to an excreta disposal system, either in the form of a private toilet or a public toilet shared with a reasonable number of people);
3. **Durability of housing** (permanent and adequate structure in non-hazardous location)
4. **Sufficient living area** (not more than two people sharing the same room).
5. **Security of tenure** (evidence of documentation to prove secure tenure status or de facto or perceived protection from evictions

Slums are characterized spatially by a number of aspects (R.Sliuzas, http://www.itc.nl/library/Papers_2004/phd/sliuzas.pdf).

- The buildings are poorly constructed, in an unplanned manner, which makes them more vulnerable to the impact of events like earthquakes and flooding.
- They are normally also constructed without building permits, and therefore do not follow construction standards.
- The density of buildings is very high, to such an extent that over 90 percent of an area is covered by roofs.
- This means that the density of population us also very high, leading to a large population vulnerability. Also the lower level of schooling, low income levels, as well as high percentage of infants, and unemployment contribute to the increased population vulnerability.
- The buildings generally have a general lack of spatial order, which makes such areas easier to interpret from high resolution imagery (See figure 4.3 and 4.4). However it is often not possible to map out the individual buildings within a slum. For mapping of slum areas a participatory mapping approach is most suitable (See section 4.5)

- Slums also have a lack of access and poor quantity and quality of infrastructure which makes rescue work and fire fighting activities very difficult. Slums have a lack of public facilities (schools, health, cemeteries, parks and sport fields). This causes that there are less locations that can be used for disaster preparedness activities.
- Many slums are located in hazardous, for instance on steep slopes or in areas with frequent flooding or water stagnation. These are the areas that were still free in the city and that are normally owned by the government.
- On the other hand slums also have often an advantageous location with respect to the short distance to the major places of informal employment (e.g. city centers) and the workers therefore have a lower travel costs.
- Many slums have been made illegally by invading terrain that belonged to others (either private owners or the government). Therefore land tenure is not secure, and there is always a risk of eviction. It also happens frequently that slums are made legal after a certain period of time. However, in such situations land ownership is still a major problem.

Slums have different stages of development. They can be in the starting phase with initial occupation of land and construction. They can also be in the consolidation phase where some basic services are provided and where the slum expands until the mature phase.

Figure 4.4: Example of slum areas on extremely steep slopes prone to landslides in Guatemala

Other residential building classes are easier to identify. In figure 4.3 and 4.5 four other classes are shown. The differentiation of the various residential classes is important because:

- The land use classes are often also linked to building types, and therefore can be used to link them to vulnerability curves. Class Res_5 generally has better quality buildings than the other ones.
- The land use classes define the number of people that will be present in the land use class at a given moment in time, which is required for population loss estimation (See also section 6). Multi-story apartment buildings for instance will have a much higher density of population as the same building is used by many individual households.

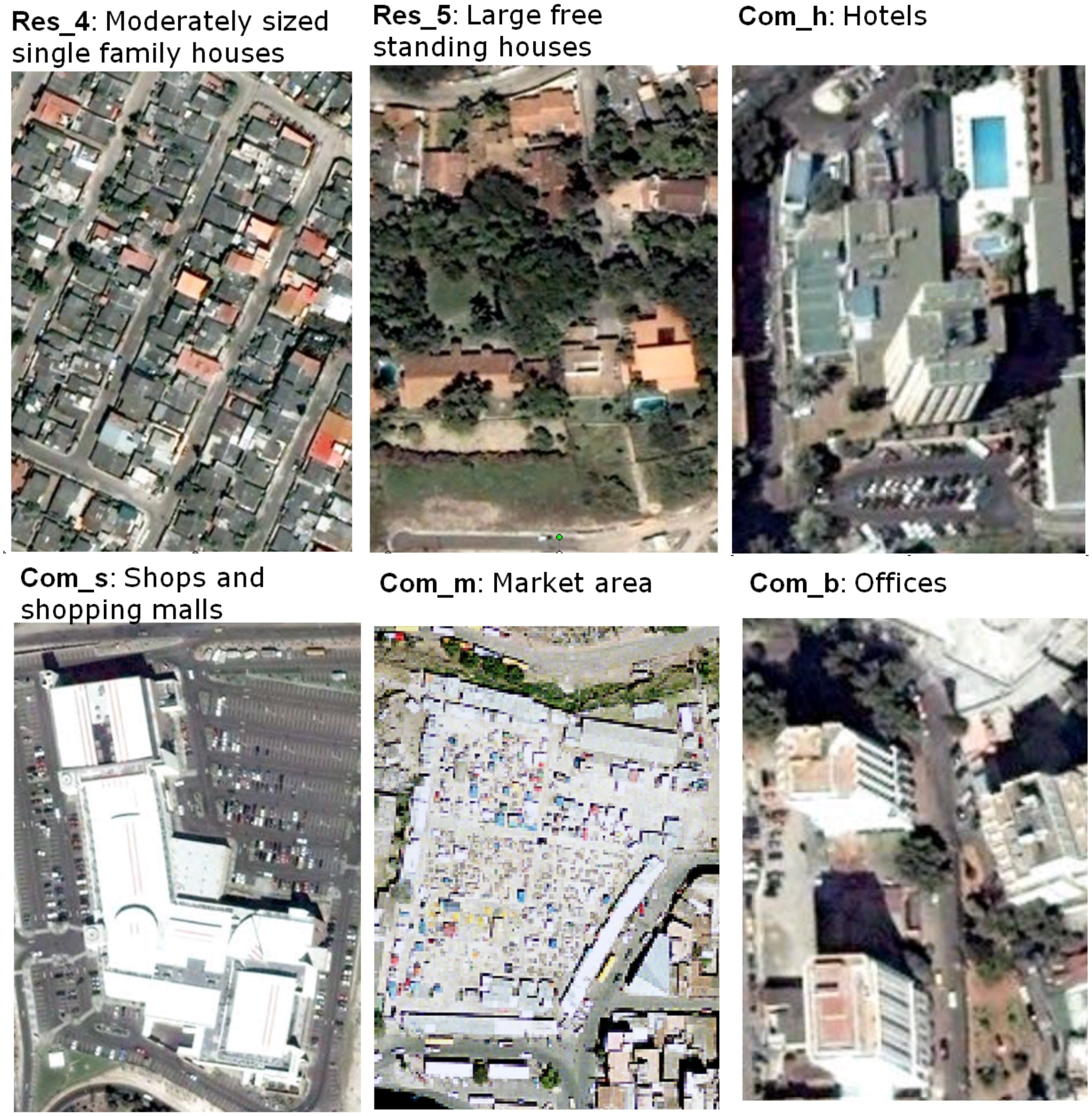
From a mapping point of view it will be often difficult to distinguish the different types of residential land uses on the basis of image interpretation alone.

Task 4.5: Recognizing land use types from Google Earth imagery (duration 30 minutes)

Identifying land use types from high resolution images

- Use Google Maps (http://maps.google.com/) and zoom in on the area that you have selected for the previous tasks (your own neighborhood or city). Select the option
- Try to identify the land use types that you have made in task 4.4.

Figure 4.5: Moderate and large residential buildings and hotels



4.2.3 Commercial land use types

Another important class of urban land use is that of commercial buildings and activities. In the figure above several examples are given. Most of the commercial activities are characterized by relatively high population densities during working hours, and low during evenings. For instance shops, offices, and markets are normally very crowded during working hours, and sometimes also during the evenings, but will be more or less empty during the night. For instance the shopping mall that is recognizable in figure 4.5 is characterized by very large parking lots surrounding the building, which indicates that there may be a very high population density in some periods. This is not the case for hotels, which tend to have a reverse situation, with a much higher population density in the evening and night, but also a certain level of occupancy during daytime.

For commercial land uses also the content of buildings should be taken into account as these are often of a high value. There a large difference can be observed between the shopping mall and the market example in figure 4.5. The economic value of both the building and the contents is much higher for the shopping mall than for the market, where as the population density might be much higher for the market area.

4.2.4 High Potential Loss facilities

High potential loss facilities are facilities that are likely to cause heavy losses if damaged by a hazardous event, such as an earthquake. These high potential loss (HPL) facilities include nuclear power plants, dams, military installations, and hazardous industries. For instance if a dam breaches due to the occurrence of an earthquake, it may cause excessive damage due to catastrophic flooding downstream. Also if a nuclear power plant, or hazardous industry get seriously damaged, the secondary effects will be very high due to emission of dangerous toxic or radioactive clouds. Table 4.7 Shows the classification used in HAZUS for high potential loss facilities.

Table 4.7: Classification of high potential loss facilities used in the HAZUS method for risk assessment

Label	Description
Dams	
HPDE	Earth
HPDR	Rock fill
HPDG	Gravity
HPDB	Buttress
HPDA	Arch
HPDU	Multi-Arch
HPDC	Concrete
HPDM	Masonry
HPDS	Stone
HPDT	Timber Crib
HPDZ	Miscellaneous
Nuclear Power Facilities	
HPNP	Nuclear Power Facilities
Military Installations	
HPMI	Military Installations

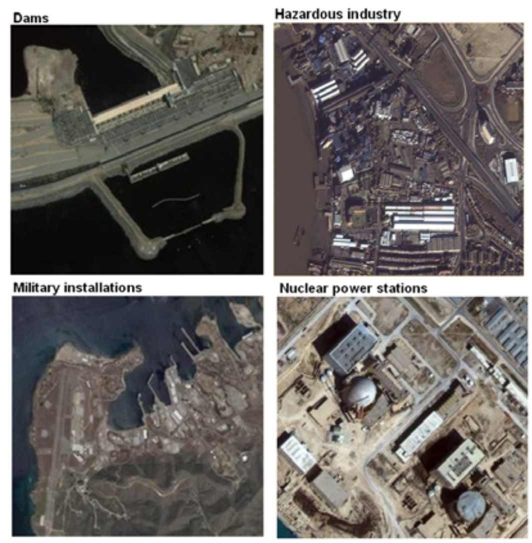


Figure 4.6 Shows examples of the classes of industry used in the RiskCity case study. We have differentiated industrial activities in three classes. Hazadous industry is a high potential loss facility, non hazardous industry might still have a substantial amount of workers in the industrial area, whereas for warehouses the density of workers will be much less.

Figure 4.6: Classification of industrial types in the RiskCity case study

4.2.5 Essential facilities

Essential facilities are those facilities that provide services to the community and should be functional after a disaster event. Essential facilities include hospitals, police stations, fire stations and schools. The damage state probabilities for essential facilities should be determined on a site specific basis, as is the case for high potential loss facilities (i.e., the ground motion parameters are computed at the location of the facility). The classification used in HAZUS is given in table 4.8.

Table 4.8: Classification of essential facilties used in HAZUS

Label	Occupancy Class	Description
Medical Care Facilities		
EFHS	Small Hospital	Hospital with less than 50 Beds
EFHM	Medium Hospital	Hospital with beds between 50 & 150
EFHL	Large Hospital	Hospital with greater than 150 Beds
EFMC	Medical Clinics	Clinics, Labs, Blood Banks
Emergency Response		
EFFS	Fire Station	
EFPS	Police Station	
EFEO	Emergency Operation Centers	
Schools		
EFS1	Grade Schools	Primary/ High Schools
EFS2	Colleges/Universities	

Figure 4.7 Several examples of essential facilities as used in RiskCity.

The essential facilities can be subdived into those that are essential for providing emergency response (fire brigade, police station, army barracks, civil defence buildings) and those that are crucial for medical care. After a disaster has happened it is of utmost importance that the available hospitals can provide aid to the people injured during the event within the first 3 days. This period determines whether relatively simply injuries can be attended, and if not these might become worse and even fatal due to the outbreak of epidemics. Therefore the evaluation of the behavior of hospitals during a hazard event like an earthquake is very important, as well as preparatory measures such as a emergency power supply.
Also schools, churches, office buildings, cultural buildings, and stadiums can be considered essential facilities, although to a lesser extend than the emergency response and medical facilities. Public buildings may serve as shelters after the occurrence of major disasters. On the other hand the behavior of such buildings during the hazard event is also important to study, as these buildings contain very vulnerable population. Figure 4.8 displays several examples of land use types that can also play a role in the evacuation. It also shows some examples of land use types that are considered "vacant" in terms of buildings but that still have a large importance in the risk assessment.

Figure 4.8: examples of several classes of recreational and vacant land use types of table 4.?

For instance the class **Vac_d** shows evidences of recently destroyed buildings (lower right corner where you only see the remains of the walls of buildings, and where the roofs have been destroyed) and a bridge that was washed out. The class **Vac_c** shows a situation where the amount of elements at risk (in this case cars and people) is very flexible over time. Depending on the time of the day and year, a disaster striking in such an area might cause no damage at all, or considerable damage. The class **Vac_u** shows an area that is under construction. In this particular example a new bridge is constructed. This illustrates the importance of updating the spatial information on the elements at risk, as there are constant changes in landuse that are taking place.

Task 4.6: List of identification criteria for landuse types

Based on the information in this section and task 4.5, now try to make a list of criteria for the various land use types, with emphasis on interpretation from high resolution imagery.
You might not want to describe all of them, but make a selection.
Are there also classes that you cannot identify from high resolution images?

Code	Occupancy Class	Identification criteria
Res_1	Res_squatter	High density of individual small houses in irregular pattern, unpaved streets or footpaths
Res_2	Res_small_single	
Res_3	Res_multi	
Res_4	Res_mod_single	
Res_5	Res_large	
Com_b	Com_business	
Com_h	Com_hotel	
Com_m	Com_market	
Com_s	Com_shop	
Ind_h	Ind_hazardous	
Ind_i	Ind_industries	
Ind_w	Ind_warehouse	
Ins_f	Ins_fire	
Ins_h	Ins_hospital	
Ins_o	Ins_office	
Ins_p	Ins_police	
Ins_s	Ins_school	
Pub_g	Pub_cemetery	
Pub_c	Pub_cultural	
Pub_e	Pub_electricity	
Pub_r	Pub_religious	
Rec_f	Rec_flat_area	
Rec_p	Rec_park	
Rec_s	Rec_stadium	
Vac_c	Vac_car	
Vac_u	Vac_construction	
Vac_d	vac_damaged	
Vac_s	Vac_shrubs	
riv	River	

It should be noted that image interpretation alone is often insufficient to classify buildings according to the land use. For instance it is not possible to identify hazardous industries, essential facilities and other land use types. Even buildings that can be identified clearly on images, such as churches, might have changed land use type. Also it is not possible to identify mixed land use types, for instance mixed residential and commercial. Therefore it is important to always carry out field studies to characterize buildings and to use as much existing information as possible.

4.3 Building characteristics and response

Buildings are one of the most important groups of elements at risk. They house the population and the behavior of a building under a hazard event, determines whether the people in the building might be injured or killed.

In order to be able to assess the potential losses and degree of damage of buildings that are exposed to a certain type of hazardous event, it is important to define two things:

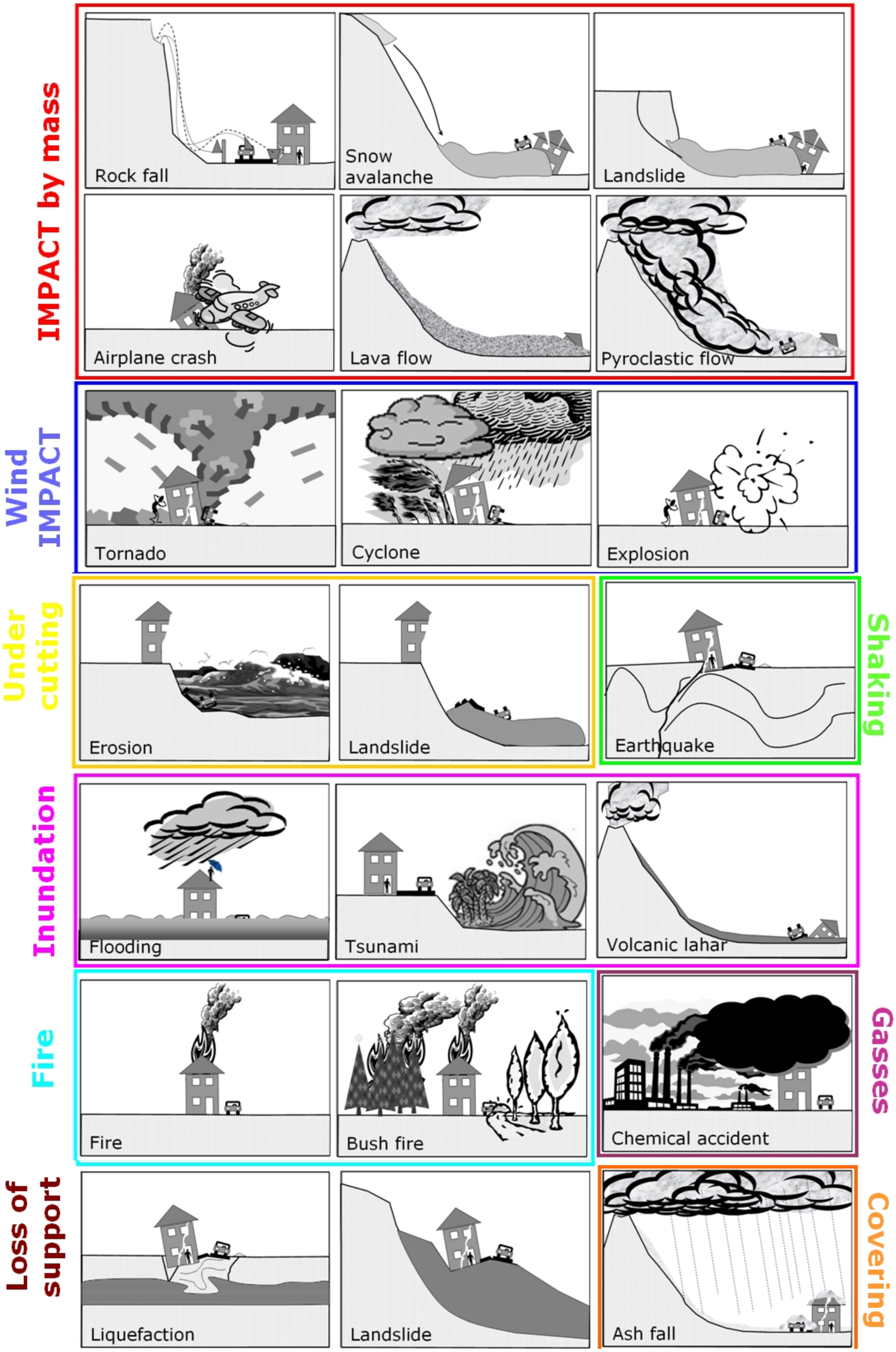
- The type of negative effect that the event might have on the building which is exposed to it.
- The characteristics of the building that define the degree of damage due to the hazard exposure.

The type of negative influence of the exposure can be in many different forms, which depend on the type of hazard that will occur. Figure 4.8 gives a schematic overview of the various hazard processes that may occur and that have a different effect on buildings. The following types can be differentiated:

- **Mass Impact**: the building is impacted by a phenomena that may have different characteristics:
  - Speed of impact. This could vary from a slow impact, for instance by a slow moving lava flow, to an extremely fast impact (e.g. snow avalanche, rockfall, or pyroclastic flow)
  - Medium of impact: impact can be by rock (rock fall), soil or debris (landslide), mud (volcanic lahar), snow, water (e.g. flashflood) or objects (e.g. airplane crash)
- **Wind impact**: the building is impacted by air, which may also create un underpressure or overpressure inside the building, which could lead to implosion/explosion of the building. Difference processes can be differentiated, such as tornadoes, cyclones or explosions.
- **Undercutting**: the building loses support because the soil below the foundation is eroded away by erosion (e.g. along coastlines, or along river channels) or landslides.
- **Shaking**: the building is subjective to ground shaking, as is the case in an earthquake.
- **Inundation**: the building is flooded, which can be suddenly and violently, in which case also the impact effect of water is important (e.g. flashfloods or tsunami). The flooding can also be slow and with a long duration, which will have a deriorating effect on the construction materials of the building.
- **Fires:** the building is subjected to fire, for instance in the case of a bushfire/forestfire, or in the case of an industrial accident.
- **Loss of support:** the building is subsiding as a result of underground cavities (e.g. due to mining), liquefaction or because the building is on a slow landslide.
- **Gasses:** the building is filled by toxic gasses, e.g. caused by industrial accidents nearby
- **Covering by materials:** the building is covered by materials which may weight on the roofs and would lead to roof collapse, as in the case of snow or volcanic ash.

Figure 4.9: Examples of buildings damaged by different processes (lahar, earthquake, cyclone, landslide, flood, debrisflow, tsunami).

Figure 4.10: Examples of the type of the hazardous processes to which buildings can be exposed. Each type of processes will have different effects.



Task 4.7: Determine the important characteristics of buildings (30 minutes)

Based on the information on the previous pages on the different hazard processes to which a building might be exposed, determine:

- What is the damaging effect of the particular hazard on the building?
- Which aspects of the building would make it most susceptible to be affected?
- Which characteristics of a building therefore should be taken into account for a vulnerability assessment?

Write the results in the table provided in the Excel file (task 47). If you can think of other processes that are not mentioned, please note them down below in the table.

Process	Hazard	Damage	Important Building characteristics
Impact by mass	Rockfall	Impact by rock blocks	
	Snow avalanche	Impact by snow mass	
	Landslide		
	Pyroclastic flow		
	Lava flow		
	Debris flow		
	Airplane crash		
Impact by wind	Tornado		
	Cyclone		
	Explosion		
Under-cutting	Erosion		
	Landslides		
Shaking	Earthquake		
Inunda-tion	Flooding		
	Tsunami		
	Debris flow		
Fire	Fire		
	Bush fire		
Gasses			
Loss of support	Liquefaction		
	Subsidence		
	Landslides		
Covering	Snow		
	Ash fall		

Buildings are consisting of different components. The main difference is :

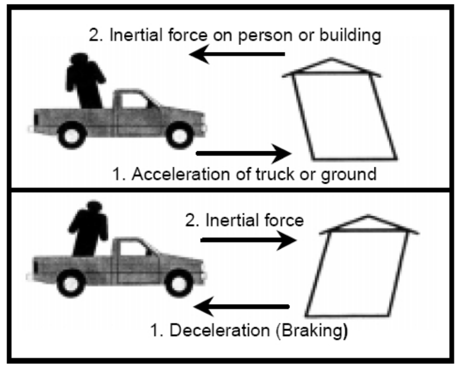
- **Structural elements**: those elements of buildings important for maintaining the structural integrity of the building: the building's structural support systems (i.e., vertical- and lateral-force-resisting systems), such as the building frames and walls. If these elements fail under a hazard impact, there is a large chance that the structure might fail.
- **Non-structural elements**: all those elements of a building not essential for its structural integrity. The failure of a non-structural element will not lead to the collapse of the building. Examples are: chimneys, infilled walls, water tanks, and of course all the contents of the buildings.

In the following section some examples are given of the effects that particular types of hazard have on buildings. We will do this for earthquakes, flooding and landslides.

4.3.1 Building behavior under an earthquake

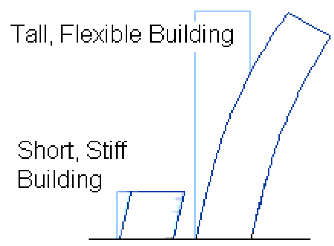
A summary of information on the behavior of buildings under an earthquake can be found at: http://www.conservationtech.com/FEMA-WEB/FEMA-subweb-EQ/index.htm and

Figure 4.11: Comparison between a person in a car and the behavior of a building in acceleration an deceleration movements.



During a strong earthquake a building may experience sudden movements in both horizontal as vertical direction. The building gets thrown back and forth by the earthquake movement, whereas the base part of the building, connected to the ground that is actually moving, has the first movement (See figure 4.11 with a resemblance of a person in a car). The rest of the building is "lagging behind" in this movement, which creates large frictions in the building. The force F that an upper floor level or roof level of the building should successfully resist is related to its mass m and its acceleration a, according to Newton's law, F= ma.
The heavier the building the more the force is exerted. Therefore, a tall, heavy, reinforced-concrete building will be subject to more force than a lightweight, one-story, wood-frame house, given the same acceleration. Damage can be due either to structural members (beams and columns) being overloaded or differential movements between different parts of the structure. If the structure is sufficiently strong to resist these forces or differential movements, little damage will result. If the structure cannot resist these forces or differential movements, structural members will be damaged, and collapse may occur.
Earthquakes are series of complicated interwoven series of waves, which a certain frequency (See also chapter 3 on the earthquake hazard part). All objects or structures have a natural tendency to vibrate. The rate at which the object wants to vibrate is its fundamental period (natural frequency). Which can be approximated by:

$$f_n = \frac{1}{2\pi}\sqrt{\frac{K}{M}}$$



Where K= Stiffness, which is the property of an object to resist displacement, and M=Mass.
Buildings tend to have lower natural frequencies when they are either heavier (more mass) or more flexible (that is less stiff).
One of the main things that affect the stiffness of a building is its height. Taller buildings tend to be more flexible, so they tend to have lower natural frequencies compared to shorter buildings.
There is a general rule of thumb that relates the number of stories to the natural frequency of buildings:

$$\mathbf{F_n = 10/n}$$

Where Fn = natural frequency of buildings, and n = number of floors. The relation between number of floors, natural frequency and fundamental period (1/frequency) is shown in table 4.9.

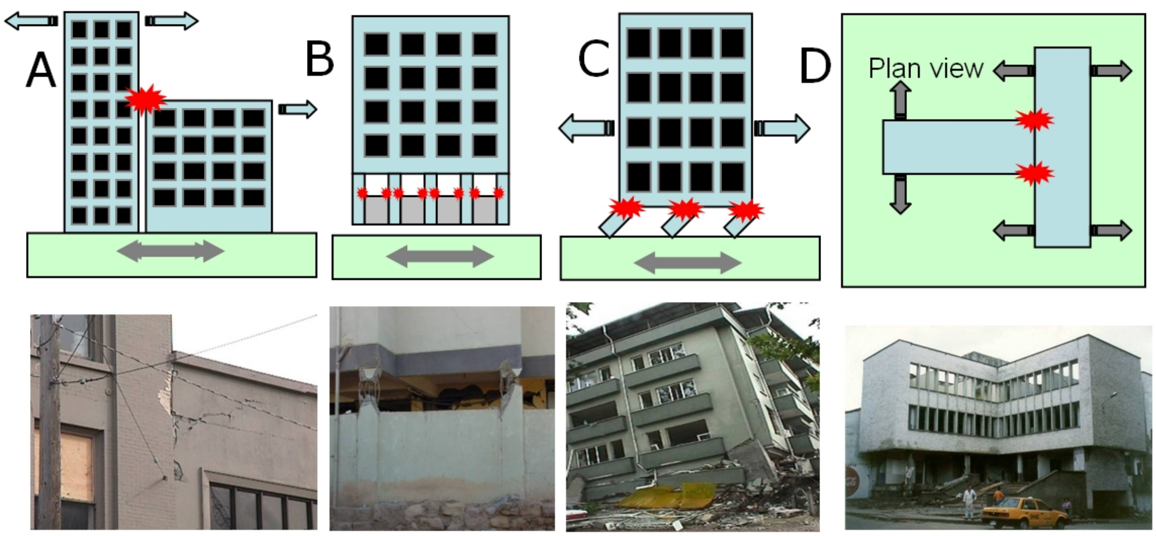
Table 4.9: General relation between number of floors, natural frequency and fundamental period of buildings according to the rule of thumb

Type of object	Natural frequency (Herz)	Fundamental period (Seconds)
One-floor buildings	10	1
2-5 floor buildings	5-2	0.5 – 0.2
5-10 floor building	2–1	0.2 - 1
10 – 20 floors building	1 – 0.5	1 - 2
20-40 floor buildings	0.5 – 0.25	2 - 4

Factors that influence the behavior of buildings under an earthquake are:

- **Duration and severity of ground shaking**. Large earthquakes tend to shake longer and harder and cause more damage. Earthquakes with Richter magnitudes less than 5 rarely cause significant damage to buildings, since acceleration levels (except when the site is on the fault) and duration of shaking for these earthquakes is relatively small. In addition to damage caused by ground shaking, damage can be caused by degradation of the building foundation, landslides, fires and tidal waves (tsunamis).
- **Soil types**. Soil also has a natural frequency which is determined by the soil type and the soil thickness. If the natural frequency of the soil is the same as the natural frequency of the building, the building will start to resonate. This can be compared with an opera singer that manages to break a glass by singing a pure tone with a frequency that is exactly the natural frequency of the glass. Soft, loose soils tend to amplify the ground motion and in many cases a resonance effect can make it last longer. In such circumstances, building damage can be accentuated.
- **Height of the building**. The height of a building determines its resonance frequency. Low buildings have a high resonance frequencies (large wavelengths), and tall buildings have a low resonance frequencies (short wavelengths). This means that low-rise buildings are susceptible to damage from high-frequency seismic waves from relatively near earthquakes and/or shallow depth. High-rise buildings are at risk due to low-frequency seismic waves, which may have originated at much greater distance and/or large depth

Figure 4.12: Examples of earthquake damage to buildings. A: Pounding of nearby buildings; B: Short column effect, causing break of columns; C: Soft storey effect, causing collapse of building over lower floor often used as parking lot; D: Torsion effect due to irregularly shaped building



- **Spacing of buildings**. Earthquake damage can be also caused by tall buildings that are close together and that are pounding against each other (see figure 4.12)
- **Building materials.** Under small earthquakes buildings behave elastically, deforming as force is applied and returning to its original shape when removed. However, if the shaking is very strong that limit of elasticity is reached, and ductility becomes important. Ductility is the property of certain elements that have inelastic deformation before failing. Ductile materials, such as wood, steel or reinforced concrete withstand earthquakes better than so called brittle materials such as unreinforced masonry.
- **Structural types.** The following structural systems can be differentiated:
  - **Bearing wall systems** consist of vertical load carrying walls located along exterior wall lines and at interior locations as necessary. Many of these bearing walls are also used to resist lateral forces and are then called shear walls. Bearing wall systems may use some columns to support floor and roof vertical loads. This type of system is very common and includes wood-frame buildings, concrete tilt-up buildings and masonry wall buildings.
  - **Building frame systems** use a complete three dimensional space frame to support vertical loads, but use either shear walls or braced frames to resist lateral forces. Examples of these include buildings with steel frames or concrete frames along the perimeter and at intervals

throughout the interior supporting vertical loads from floors and roof. Building frame systems typically use steel braced frames or concrete or masonry shear walls to resist lateral forces..

- o **Moment-resisting frame systems** can be steel, concrete, or masonry construction. They provide a complete space frame throughout the building to carry vertical loads, and they use some of those same frame elements to resist lateral forces. Shear walls (and braced frames) are not used in this system.

  Structural systems using concrete or masonry shear walls are stiff and result in buildings with short periods, whereas more flexible moment-frame systems have longer periods. In general, a large portion of the earthquake energy is contained in short-period waves. Therefore, short-period buildings with stiff structural systems are designed for larger forces than long-period, flexible, buildings. This concept is also applicable to the amount of force individual structural seismic elements and their components must resist. Stiff elements must be made stronger because they will attempt to resist larger earthquake forces than flexible elements in the same structural system.

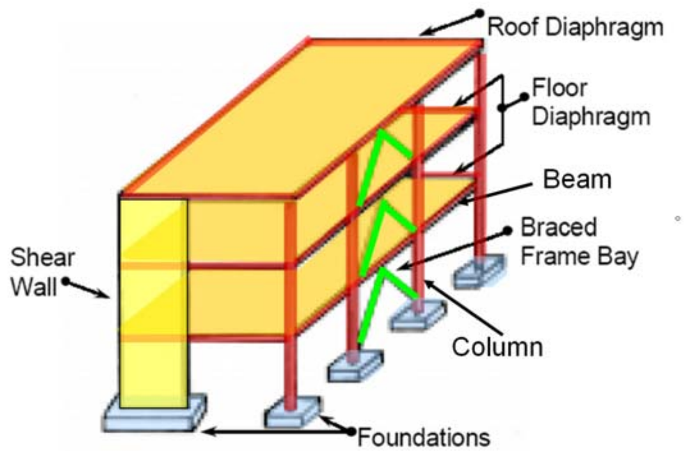


Figure 4.13: Building elements used to used to transmit and resist lateral forces. Diaphragms serve primarily as force-transmitting or force-distributing elements that take horizontal forces from the stories at and above their level and deliver them to walls or frames in the story immediately below

- **Connections**. Strong building connections allow forces and displacements to be transferred between vertical and horizontal building elements. In addition, strong connections increase the overall structural building strength and stiffness by allowing all of the building elements to act together as a unit. Inadequate connections represent a weak link in the load path of the building and are a common cause of earthquake building damage and collapse.
- **Damping**. Damping diminishes the resonance by pulling the energy out of the system as heat - in the way that a shock absorber in a car dampens a car's vibrations from bumps in the road. Damping is imparted to a building by the cracking and inelastic movement of its structural elements and it can also be deliberately added by installing shock absorber-like devices into the building's structure.
- **Weight Distribution**. Buildings that are wide at their base and have most of their weight distributed to their lowest floors generally fare better in earthquakes than tall, top- heavy buildings which act like an inverted pendulum. Inverted pendulum buildings usually experience greater displacements than those shorter and heavier near the base.
- **Building Configuration**. Square or rectangular buildings with floor plans with symmetrically place lateral force resisting elements tend to perform better in earthquakes than buildings composed of irregular shapes or 'those with large foyers or lobbies that create a soft story condition. Buildings with irregular shapes cannot distribute lateral forces evenly, resulting in torsional response that can increase damage at key points in the building. (see figure 4.12)
- **Maintenance of the building**. Especially in the case of steel and wooden buildings, poor maintenance leads to a decrease in the strength of the supporting frame. Decades of neglect in the form of lack of antirust paint for example, can lead to the weakening of steel frame systems.

4.3.2 Building behavior during a flood

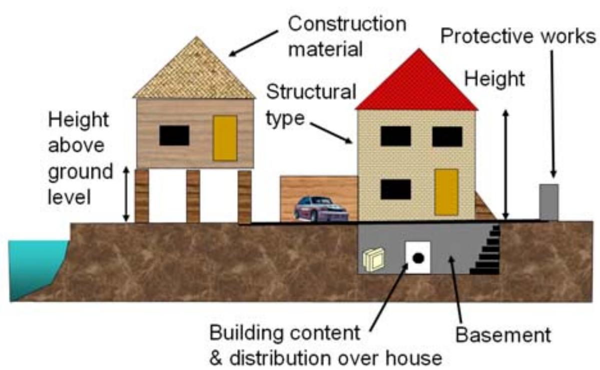
Damage to buildings from flooding is caused by a number of factors:

- **Type**: different flood types may cause different degrees of damage to buildings and their contents, e.g. coastal flooding, riverine flooding, flashflood. They will determine a number of the following factors.
- **Velocity**: fast flowing waters will have the capacity to impact the structure, and the lateral forces caused by the flood may produce collapse of buildings. High velocity floods may cause erosion/scouring of embankments, slopes, levees, and building foundations;
- **Height**: flood depth is an important factor as it will determine how much of the building will be submerged under water, and together with the velocity will determine the impulse of flooding. Impulse is velocity multiplied by height.
- **Duration**: flood duration is very important in relation to the construction materials of the building and the way they may deteriorate under the influence of water. For example masonry buildings will be heavily affected by salt water in the case of coastal flooding, which may have a long duration effect on the building.
- **Sediment**: the amount of sediments will determine the way in which a building and its contents is damaged and it will determine the clean-up costs.
- **Pollution:** polluted water will have a deteriorating effect on buildings and its contents.

The following building characteristics are important for determining the damage due to flooding:

- **Building use**: the use of the building will determine the number of people present in the building in different periods of time, and the contents and the value of the contents. This was already discussed in the previous section of this session.
- **Building materials**: the type of building materials will determine how they behave under water saturation, also with a long duration. Wood and masonry materials will have substantial large damage compared to steel or concrete.
- **Structural type**: the structural type, as mentioned in the previous section will determine whether the building can withstand the impact of fast floods
- **Height above the ground**: the height above the surface will determine the degree of flooding and which types of building contents are damaged.

Figure 4.14: illustration of building characteristics that are important for flood loss assessment.

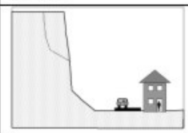
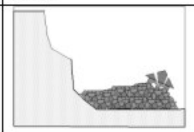
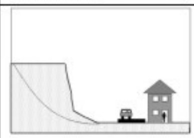
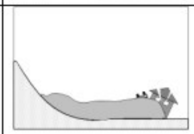
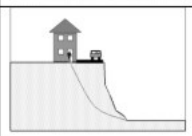
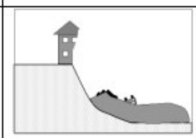
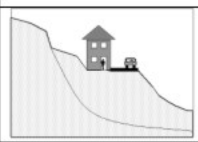
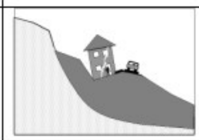
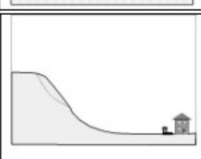
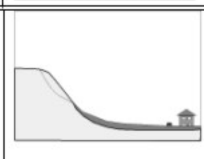
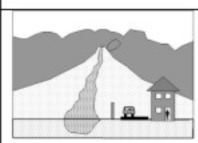
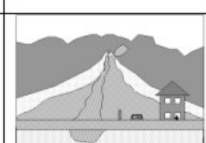
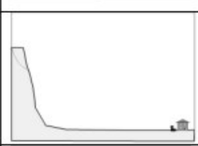
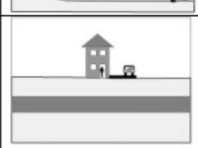
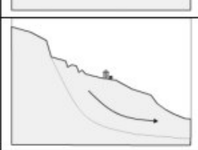


- **Maintenance level**. As discussed before poor maintenance weakens the building.
- **Location of doors and openings**: the location of openings will determine if and where flood waters can enter the building.
- **Presence of a basement**: the presence of a basement, and whether a basement has windows or not will determine the degree of damage even when the floodwaters are very low.
- **Height of the building**: the building height will determine how much of the building will be flooded. If the building consists of more storeys, the inhabitants will have distributed the content of the building over more floors, causing less damage when the lower floor is flooded. It also allows evacuation of people and valuable contents to higher floors.
- **Distance to the channel**: the proximity to a channel may determine whether the building will be undercut by a fast eroding stream, leading to the collapse of the building. Also the foundation of the building is relevant in this respect.
- **Presence of walls and other flood retaining structures**: the presence of walls around the building, or small levees will make that the building is flooded only at a later phase.

4.3.3 Building behavior under a landslide

Since there are so many different types of landslides, it is difficult to indicate what are the main building characteristics that determine the degree of loss to landslides, as indicated in figure 4.15. The type, velocity and volume of the movement will determine whether the building is only damaged or whether is will be completely destroyed. Also the distance of the building to the source of the movement will play a very important role, and the determination of the runout is therefore very relevant. The important building characteristics are more or less similar to those that are relevant for earthquakes, in particular the structural type, and the foundation type. The orientation of the building and proximity to other buildings are also very relevant, as a building may be in "the lee side or shadow" of other buildings which may take the main impact and reduce the damaging effect.

Figure 4.15: different ways in which a building might be affected by a landslide

Type	Before	After	Likely damage to elements at risk	Factors determining risk
Impact by large rockmass			**Buildings:** Total collapse likely **Persons in buildings:** Loss of life/ major injury likely **Infrastructure:** Coverage and obstruction / destruction of surface **Persons in traffic:** Loss of life/ major injury possible	• Volume of rockfall mass • Location of source zone • Distance to Elements at risk • Triggering factors • Local topography along track • Intermediate obstacles • Precursory events
Impact by single blocks			**Buildings:** Total collapse not likely. Localized damage **Persons in buildings:** Minor to major injury likely **Infrastructure:** Coverage and obstruction of traffic **Persons in traffic:** Loss of life/ major injury possible	• Volume of rockfall blocks • Number of rockfall blocks • Location of source zone • Distance to Elements at risk • Triggering factors • Local topography along track • Intermediate obstacles
Impact by landslide mass			**Buildings:** Collapse / major damage depending on volume **Persons in buildings:** None, persons are normally able to escape **Infrastructure:** Coverage and obstruction of traffic **Persons in traffic:** None, persons are normally able to escape	• Volume of landslide mass • Water content • Landslide material type • Triggering factors • Distance to Elements at risk • Local topography along track • Speed of landslide movement
Loss of support due to undercutting			**Buildings:** Collapse / major damage likely **Persons in buildings:** None, persons are normally able to escape **Infrastructure:** Complete destruction of road surface. **Persons in traffic:** None, persons are normally able to escape	• Volume of landslide mass • Water content • Landslide material type • Triggering factors • Retrogressive landslide • Cliff erosion • Speed of landslide movement
Differential settlement /tilting due to slow movement			**Buildings:** Tilted buildings with cracks. Normally no collapse **Persons in buildings:** None, slow movement. People not in danger **Infrastructure:** Tilting and cracks, traffic slowed down **Persons in traffic:** None, slow movement	• Volume of landslide mass • Water content • Landslide material type • Triggering factors • Speed of landslide movement • Amount of displacement
Impact by debris flow on slope			**Buildings:** Filled by mud, damage to contents **Persons in buildings:** Minor-major injuries. Depends on speed. **Infrastructure:** Coverage of road surface. Obstruction of traffic. **Persons in traffic:** Minor-major injuries. Depends on speed.	• Volume of landslide mass • Water content • Slope steepness • Local topography • Landslide material type • Triggering factors • Speed of movement • Size of blocks transported
Flooding by debris flow on alluvial fan			**Buildings:** Filled by mud, damage to contents **Persons in buildings:** None, persons are normally able to escape **Infrastructure:** Coverage **Persons in traffic:** None, persons are normally able to escape	• Volume of debris flow • Water & sediment content • Local topography of fan • Triggering factors • Distance from source • Distance from lahar channel • Speed
Impact by Sturzstrom			**Buildings:** Total collapse **Persons in buildings:** Loss of life **Infrastructure:** Total destruction **Persons in traffic:** Loss of life	• Volume of rockfall mass • Location of source zone • Distance to Elements at risk • Triggering factors • Local topography along track • Distance from source zone • Precursory events
Liquefaction			**Buildings:** Differential settlement, cracks **Persons in buildings:** Minor injuries or no-injuries **Infrastructure:** Differential settlement, cracks **Persons in traffic:** no-injuries	• Soil types • Soil strength • Grainsize distribution • Foundation types • Earthquake intensity • Water table
Deep seated creep movement			**Buildings:** Differential settlement, tilting, cracks **Persons in buildings:** Minor injuries or no-injuries **Infrastructure:** Differential settlement, cracks, broken pipes **Persons in traffic:** no-injuries	• Speed of movement • Local geological situation • Age of landslide • Seasonality of movement

4.3.3. Generating building attributes

Based on the three examples the following list of building characteristics is presented in Table 4.10. In this table the importance for a number of hazard types is indicated.

Table 4.10: Summary of importance of building characteristics for damage estimation for different hazard types. Red = very important, Yellow= less important, Green = not important.

Building characteristics	Earthquake	Flooding	Landslides	Techno-logical	Cyclone	Fire
Structural type	Red	Red	Red	Red	Red	Yellow
Construction materials	Red	Red	Red	Red	Red	Red
Building code applied	Red	Yellow	Green	Yellow	Red	Green
Age	Yellow	Yellow	Green	Yellow	Red	Green
Maintenance	Red	Red	Green	Yellow	Red	Green
Roof type	Yellow	Yellow	Green	Red	Red	Red
Building height	Red	Red	Red	Red	Red	Red
Floor space	Red	Red	Red	Red	Red	Red
Building volume	Red	Red	Red	Red	Red	Red
Shape	Red	Yellow	Yellow	Yellow	Yellow	Green
Proximity to other buildings	Red	Yellow	Red	Red	Red	Red
Proximity to hazard source	Yellow	Red	Red	Red	Red	Red
Proximity to vegetation	Green	Green	Green	Yellow	Red	Red
Openings	Yellow	Red	Red	Red	Red	Yellow

There are many items in the table that have to do with the quality of the construction. The structural type combined with the construction materials determine the strength of the building. But also the fact whether the building have been constructed according to a building code. The factor "age" can be used as a proxie to determine whether buildings are older or younger to the date when building codes where enforced in a given area. Age and maintenance also are indications for the current state of the building.
There are two factors that can be considered most important: **structural type** and building height. Table 4.11 gives a summary of the main structural types used in the HAZUS methodology for earthquake loss estimation. In the case of flooding and hurricanes, a more simplified classification of structural type and height of buildings is used. However, this classification of structural types can not simply be used in developing countries as they will often have far more buildings in the masonry class. Masonry buildings consisting of field stones, or adobe (mud blocks) are very common in developing countries. For instance figure 4.16 gives an example of a building classification used in the city of Lalitpur, Nepal.

Table 4.11: Building structure types used in the HAZUS methodology for earthquake loss estimation, combining structural types and height of buildings. Each combination has its own code, and is linked to vulnerability curves for that particular type. A description of each of the structural types can be found on http://www.conservationtech.com/FEMA-WEB/FEMA-subweb-EQ/02-02-EARTHQUAKE/1-BUILDINGS/D3-Bldg-types.htm

Main	Building structure type	Low rise 1-2 stories	Mid rise 4-7 stories	High rise ≥ 8 stories
Wood frame	Wood, Light Frame (≤ 5,000 sq. ft.)	1 (W1)	-	-
	Wood, Commercial and Industrial (> 5,000 sq. ft.)	2 (W2)		
Steel frame	Steel Moment Frame	3 (S1L)	4 (S1M)	5 (S1H)
	Steel Braced Frame	6 (S2L)	7 (S2M)	8 (S2H)
	Steel Light Frame	9 (S3)		
	Steel Frame with Cast-in-Place Concrete Shear Walls	10 (S3L)	11(S3M)	12 (S3H)
	Steel Frame with Unreinforced Masonry Infill Walls	13 (S3L)	14 (S3M)	15 (S3H)
Rein-forced concrete	Concrete Moment Frame	16 (C1L)	17(C1M)	18(C1H)
	Concrete Shear Walls	19 (C2L)	20 (C2M)	21 (C2H)
	Concrete Frame with Unreinforced Masonry Infill Walls	22 (C3L)	23 (C3M)	24 (C3H)
	Precast Concrete Tilt-Up Walls	25 (PC1)		
	Precast Concrete Frames with Concrete Shear Walls	26 (PC2L)	27 (PC2M)	28 (PC2H)
Masonry	Reinforced Masonry Bearing Walls with Wood or Metal Deck Diaphragms	29 (RM1L)	30 (RM1M)	-
	Reinforced Masonry Bearing Walls with Precast Concrete Diaphragms	31(RM2L)	32 (RM2M)	33 (RM2H)
	Unreinforced Masonry Bearing Walls	34 (URML)	35(URMM)	-
	Mobile Homes	36 (MH)		

Floorspace is another very important building factor required for loss estimation. It is used directly in combination with urban land use type to estimate the number of people in the buildings. Floor space should ideally be obtained from **building footprint maps**, or from cadastral maps. However, cadastral maps often show the various plots of land with different owners, which often do not coincide with building boundaries. Therefore, such maps are mostly made from high-resolution satellite images or airphotos, using on-screen digitizing. On-screen digitizing of building footprints can be a very labour intensive work. Literally thousand of individual polygons should be mapped. For instance, the RiskCity dataset that we are using is only for a part of the city, but it already contains around 30000 individual polygons. Sometimes it is possible to use already digitized building footprint maps. However, once should be careful with those, for several reasons. A common problem found is that there is no link between non-spatial data (e.g. housing data) and spatial data (e.g. building footprints).They might be in a data format like AutoCad DXF, which doesn't have topology, and which has a complete segment around each polygon. To edit this for so many polygons is very difficult. The other caution is that the map might not be up to date. This is illustrated in Figure 4.17 where an existing building footprint map from 1998 was updated with image interpretation from an Ikonos image. Also efforts have been made to automatically extract buildings from InSar, Lidar and IKONOS.

Attempts have been made to generate building footprint maps automatically from high resolution images using Object Oriented Analysis with image segmentation techniques (e.g. using the software Definiens). The results are promising, especially when also height information on buildings can be used in the analysis. However, still a lot of manual editing is needed, and currently the technique is not a substitute yet for manual interpretation.

Figure 4.16: Example of the number of buildings per homogenous unit for 4 different structural types of building in Lalitpur, Nepal: Adobe, Brick in Mud (BM), Brick in Cement (BC) and Reinforced Concrete Buildings (RCC). (Source: ITC MSc Jeewan Guragain, 2004.

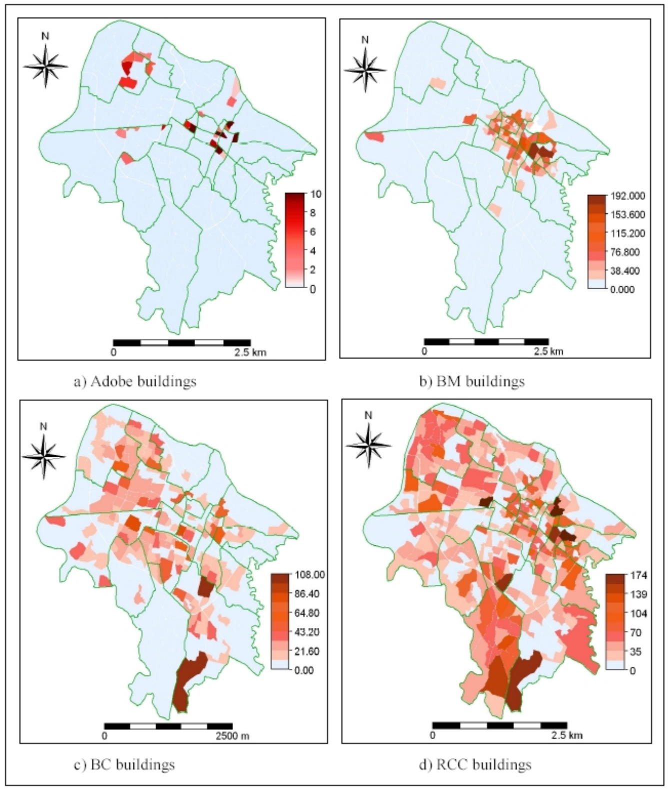
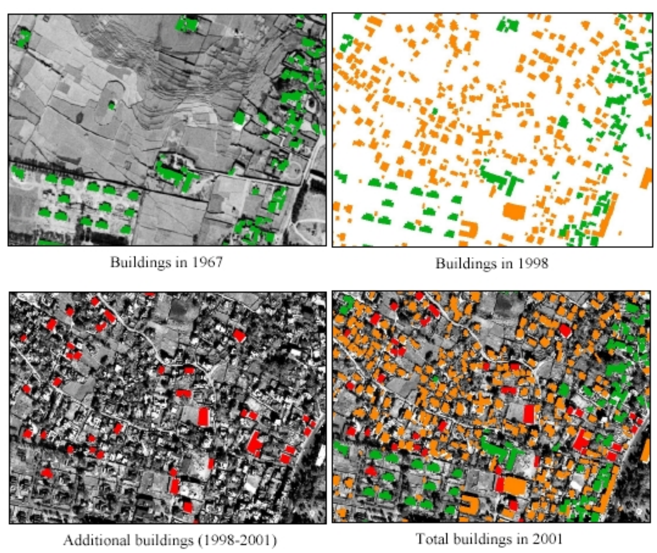
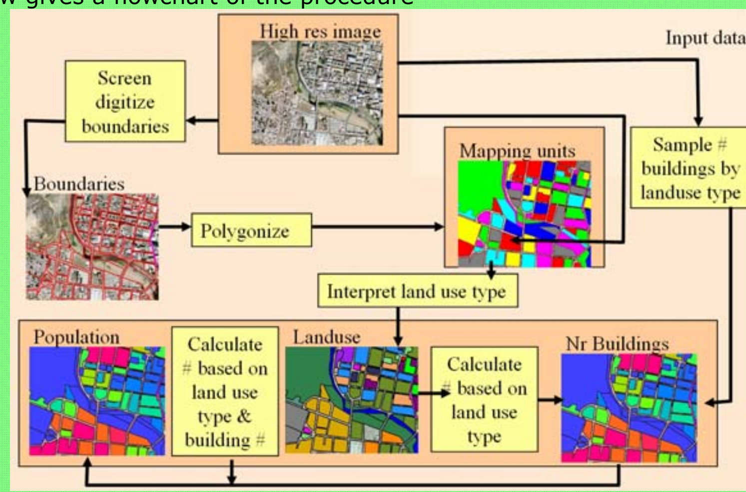


Figure 4.17: Illustration of the use of multi-temporal imagery for building mapping in Lalitpur, Nepal. A Corona image was used for 1967, and existing building footprint maps for 1998, and an Ikonos image for 2001.



Task 4.8: RiskCity exercise: Generating an element at risk database from scratch (duration 3 hours)

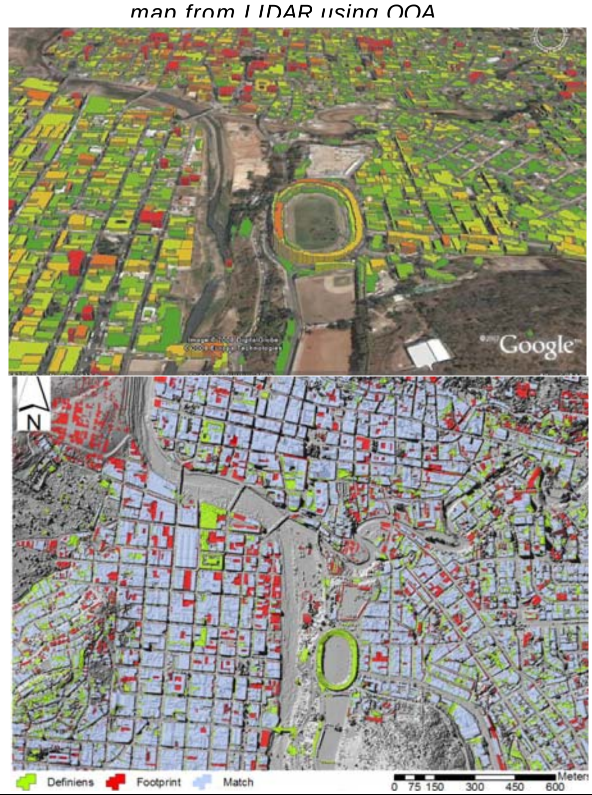
This is a good moment to pause the theory part and continue with the RiskCity GIS exercise number 4A: Generating an elements at risk database from scratch.
This exercise gives several methods for the generation of a database for the elements at risk within RiskCity, focusing on buildings and population. First it is assumed that no detailed building information is available, and the number of buildings has to be estimated based on the urban land use type and the average floorspace of buildings per land use type. Population estimates are made based on the building floorspace.
The basic unit for risk assessment we will use in this exercise is the so-called mapping unit. It consists of a number of buildings, and can be compared with a city block, or a census tract.
In this exercise you first generate mapping units by on-screen digitizing, and then you will collect attribute information on urban land use, number of buildings and population density.
The figure below gives a flowchart of the procedure



Building height

Another very important building attribute is height. It is needed to evaluate the vulnerability to earthquakes and flooding, and it is needed together with the area of the building footprints to calculate the total floorspace of the buildings within a mapping unit, or the building volume. Traditionally building height is very difficult to obtain over a large area. It is normally mapped in the field on the basis of house-by-house surveys. Another option is to use photogrammetry with airphotos or high resolution satellite imagery (e.g. Cartosat 1). However the best technique available is the use of Airborne Laser scanning (LiDAR). LiDAR data is used as point clouds with multiple returns, to determine the top of buildings, and the overall building altitude. This is converted to the number of floors based on the average height of one floor derived from a sample of the buildings. Object Oriented Analysis has proven to be quite successful for building footprint mapping from Lidar data (see comparison with original building footprints in figure 4.18).

Figure 4.18: Above: Visualization of building footprints in Google Earth in 3-D using Lidar height data. Below: Automatically derived building footprint map from LIDAR using OOA



Task 4.9: RiskCity exercise: Generating an element at risk database with available data (duration 3 hours)

We will now look at the RiskCity GIS exercise number 4B: Generating an elements at risk database with available data.
Now we assume that we have good data available for generating the elements at risk database:

- A LIDAR dataset which will allow us to calculate building heights
- A building footprint map which will allow us to calculate exact floorspace areas, and
- Census data which will improve the population information.

The aim of this exercise is to use this data to generate the required building attributes for the elements at risk mapping: number of floors, number of buildings per mapping unit, and day and nighttime population.

Building costs

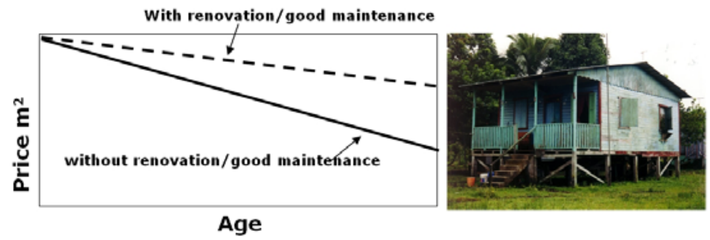
In order to estimate the cost of building one can differentiate the following source:

- Real-estate agencies, which represent the market price ("real"). Of course the market prices of buildings fluctuate depending on the economic situation.
- Cadastres in most developing countries, which indicate the ratable price ("fictitious") which is used as the basis for taxation.
- Engineering societies, which use the construction price ("replacement").
- Insurance companies, which use the insured amount for the building, if it is possible to have a building insurance against natural disasters,

In practice the costs of buildings are often based on the available data for either one of these sources. It is sometimes difficult to get hold of the building values as used by the cadastres, whereas it is easier to use the values from real estate agencies. Samples are taken from each type of building in the various land use classes. In some countries building societies produce a monthly index that allows to update property prices. Risk assessment can be carried out by using the replacement value or the market value. It is important to specify which one was used in the risk calculation.

An aspect that should be taken into account is the depreciation possibility. In some countries real estate is constantly growing in market value, provided that the maintenance to the building is adequate. The growth in value might be as high as 10 % a year, especially in economically positive periods, when there is considerable demand for real estate. In bad economic times and when the property is not maintained and the value of the building will go down rapidly as indicate in figure 4.19.

Figure 4.19: Depreciation: with age a building will loose its value due to deterioration.



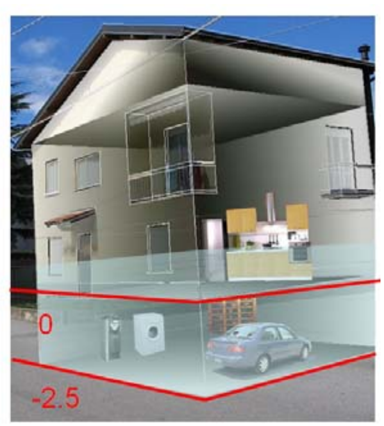
A common problem with obtaining values of buildings is related to inflation. For instance, the monthly rise in prices of building materials is not always proportional to monthly inflation. If cadastral prices are reliable but the valuation was carried out a few years back, it is difficult to update the property price.

Apart from building costs also the content costs are very relevant, especially for those hazards that have less structural damage such as flooding. Figure 4.20 gives an idea of the damage of the costs (building and content) increase with increasing flood level.

Figure 4.20: Percentage of losses of the total value of the property due to increasing flood level, starting at -2.5 when basement is flooded. (Source: Fabio Luino)

Real estate value:
€ 240.000

Height H (m)	Damage %	Loss
+1,0	24	€ 57.600
+0,8	20	€ 48.000
+0,6	16	€ 38.400
+0,4	12	€ 28.800
+0,2	7	€ 16.800
0	5	€ 12.000
-0,5	4,5	€ 10.800
-1	4	€ 9.600
-1,5	3	€ 7.200
-2,0	2	€ 4.800
-2,5	0	0



4.3.4 Collection information on buildings: example of Turrialba, Costa Rica

This part shows an example of an elements at risk database for the city of Turrialba, located in Costa Rica. A series of color aerial photographs with a scale of 1:40,000 were scanned with high resolution and combined with a Digital Elevation Model and a series of ground-control points for the generation of an orthophoto-map (See Figure 4.21). On the orthophoto all buildings within the city and its direct surroundings were digitized, as well as the land parcels, the roads and other infrastructures. This resulted in a digital parcel map, consisting of 7800 polygons. Each polygon was described in the field by a team of investigators, making use of checklists for the collection of data on hazard and vulnerability. For each parcel the following attributes were described:

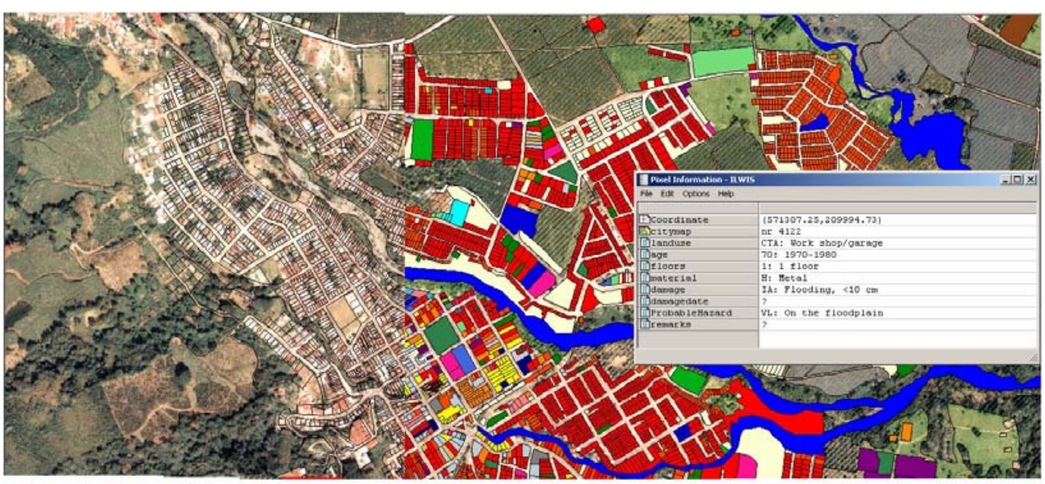
- **Use**: land use, with main division in residential, institutional, commercial, industrial, recreational, agricultural and others
- **Material**: material of the building, in order to estimate the vulnerability
- **Age**: age of the building, obtained through interviews
- **Value_building**: estimation of the replacement value of the building
- **Value_contents**: estimation of value of contents of building
- **Number of floors**
- **Hazard**: the hazard as observed or inferred by the experts in the field
- **Damage**: reported damage due to natural or human-induced hazardous events

Historical information on the occurrence of previous disastrous events was collected by interviewing elderly people, newspaper searches, and through the damage reports available in the INS (National Insurance Institute). Based on this information a database was generated, which is linked to the parcel database in GIS, and which allows for the generation of thematic maps on each of the above-mentioned parameters.

The database was used to generate vulnerability maps for the city. In the case of flooding, vulnerability functions were used to relate flooding depths with expected degrees of damage, using information for the construction of the buildings and for the contents of each building separately. On the basis of historical information, flood depth maps were generated for different return periods. These were combined with the vulnerability values and the cost information for the generation of cost maps. These were combined with the probability information in order to derive annual risk maps.

For the vulnerability reduction in the city by different hazards, the city map will be very helpful for the preparedness and disaster management. Besides this the map will be of great use for the municipality to find suitable areas for the further expansion of the settlement areas and also to relocate the people living in hazard prone areas. As the system is not only designed for disaster management, but serves as a multi-purpose tool, the municipality is using the orthophoto and the database for updating its land-ownership database in order to improve the tax collection system.

Figure 4.21: Different views of the large-scale database for the city of Turrialba. A: orthophoto, B: vector overlay of parcels, C: polygons displaying landuse type, D: reading information from the attribute database.



A B C D

4.4 Population

The population in urban areas has both static and dynamic characteristics.

- The **static** characteristics relate to number of inhabitants, the densities of the population and the age compositions;
- The **dynamic** characteristics relate to the activities patterns of the people, and the distribution of the population in space and time. One of the most important socio-cultural vulnerability indicators is the time-distribution of the population.

For population characteristics, data from the national censuses can be used. Data collected at household level e.g. age, gender, income, education and migration.

Census data is the only consistent source for demographic data with a wide geographic scope. It is the most reliable and detailed information for describing local areas: neighborhoods, cities, counties. They are also used as benchmark data for studying population changes (trend/direction), and are key input for making projections concerning population, household, labour force and employment. Census data is the basis for government development programmes at district levels, and policy development, management and evaluation of programmes in fields of: education, literacy, employment and manpower, family planning, housing, maternal child health, rural development, transportation and highway planning, urbanization and welfare.

Census data is costly to collect. In the US the 2000 census was calculated to cost around 56 US $ per house. Census data is also confidential data and as it contains private information it is normally only available at an aggregated level.

Cadastres and censuses are very important inputs for risk assessment. However the classification of building types tends to be unsuitable, and the census tracts or enumeration districts may change from one census to the next.

HAZUS uses census data to estimate direct social loss due to displaced households, and casualties. The Census Bureau collects and publishes statistics about the people of the United States based on the constitutionally required census every 10 years, which is taken in the years ending in "0" (e.g., 1990). The Bureau's population census data describes the characteristics of the population including age, income, housing and ethnic origin. See table 4.12 for a list of the fields obtained from the census data, and how they are used. The population information is aggregated to a census tract level. Census tracts are divisions of land that are designed to contain 2500-8000 inhabitants with relatively

Table 4.12: Census data available for the US which is used in HAZUS for shelter need calculation (S), casualty estimation (C) and occupancy class estimation (O).

Description of Field	S	C	O
Total Population in Census Tract	*		
Total Household in Census Tract	*		
Total Number of People in General Quarter	*		
Total Number of People < 16 years old	*		
Total Number of People 16-65 years old	*		
Total Number of People > 65 years old	*		
Total Number of People - White	*		
Total Number of People - Black	*		
Total Number of People - Native American	*		
Total Number of People - Asian	*		
Total Number of People - Hispanic	*		
Total # of Households with Income < $10,000	*		
Total # of Households with Income $10 - $20K	*		
Total # of Households with Income $20 - $30K	*		
Total # of Households with Income $30 - $40K	*		
Total # of Households with Income $40 - $50K	*		
Total # of Households with Income $50 - $60K	*		
Total # of Households with Income $60 - $75K	*		
Total # of Households with Income $75 - $100K	*		
Total # of Households with Income > $100k	*		
Total in Residential Property during Day		*	
Total in Residential Property at Night		*	
Hotel Occupants		*	
Vistor Population		*	
Total Working Population in Commercial Industry		*	
Total Working Population in Industrial Industry		*	
Total Commuting at 5 PM		*	
Total Number of Students in Grade School		*	
Total Number of Students in College/University		*	
Total Owner Occupied - Single Household Units	*		*
Total Owner Occupied - Multi-Household Units	*		*
Total Owner Occupied - Multi-Household Structure	*		*
Total Owner Occupied - Mobile Homes	*		*
Total Renter Occupied - Single Household Units	*		*
Total Renter Occupied - Multi-Household Units	*		*
Total Renter Occupied - Multi-Household Structure	*		*
Total Renter Occupied - Mobile Homes	*		*
Total Vacant - Single Household Units			*
Total Vacant - Multi-Household Units			*
Total Vacant - Multi-Household Structure			*
Total Vacant - Mobile Homes			*
Structure Age <40 years			*
Structure Age >40 years			*

homogeneous population characteristics, economic status and living conditions.

In the absence of census data static population information is generally derived through the building footprint map, where the land use type and the floorspace will determine the number of people present in a particular building. Standard values of population per area are used. Table 4.13 gives the general population values for RiskCity that will be used in the first exercise that deals with the generation of an element at risk map from scratch. In this method the population is estimated by mapping unit. For each mapping unit the number of buildings is estimated. Also the land use is given for each mapping unit. Table 4.13 then gives the general number of people present in a building of a particular land use type. These data are very general and do not incorporate the actual size of the building. For most of the residential areas this will be more or less adequate, as the 5 classes can also be fairly well linked with the average household size. For other land use types, such as schools, or hospitals this method might lead to wrong results, as it doesn't take into account the floorspace. In the second exercise that generates an elements at risk database using existing data such as building footprints, and LiDAR data, it is possible to estimate the floorspace for each building. In that case it is possible to calculate the number of persons per building by multiplying the average floorspace per person per land use type with the floorspace of the building. It is difficult to obtain general values for the average floorspace per person. Such type of information should be collected using participatory mapping, taking stratified samples for each land use class. For each sample the number of people in a building should be then related to the size of the building (See table 4.13). Table 4.14 shows the manner that HAZUS uses for estimating the dynamic population density in different land use types and different periods of the day. Note that all information on the required population estimates is coming from the census data (table 4.12). In the absence of census data the dynamic population can be estimated using day time and night-time factors as indicated in table 4.13

Table 4.13: Population distribution data used in RiskCity exercise. This is a major simplification of reality.

Land use class	People/ building	AVG floor space M2	Day time	Nightt ime
Com_business	20	20	1	0
Com_hotel	100	12	0.1	1
Com_market	1000	10	1	0
Com_shop	10	23	1	0
Ind_hazardous	10	1000	1	0
Ind_industries	25	400	1	0
Ind_warehouse	20	2000	1	0
Ins_fire	25	64	1	1
Ins_hospital	800	38	1	1
Ins_office	100	16	1	0
Ins_police	50	32	1	1
Ins_school	300	33	1	0
Pub_cemetery	0	0	0	0
Pub_cultural	200	13	0	1
Pub_electricity	0	0	0	0
Pub_religious	500	10	1	0
Rec_flat_area	0	0	0	0
Rec_park	0	0	0	0
Rec_stadium	20000	3	0	0
Res_large	5	90	0.2	1
Res_mod_single	6	17	0.2	1
Res_multi	20	13	0.2	1
Res_small_single	6	11	0.2	1
Res_squatter	7	5	0.3	1
River	0	0	0	0
unknown	0	0	0	0
Vac_car	0	0	0	0
Vac_construction	0	0	0	0
vac_damaged	0	0	0	0

	2:00 a.m.	2:00 p.m.	5:00 p.m.
Residential	0.99(NRES)	0.80(DRES)	0.95(DRES)
Commercial	0.02(COMW)	0.98(COMW)+0.15(DRES)+0.80(AGE_16)	0.50(COMW)
Industrial	0.10(INDW)	0.80(INDW)	0.50(INDW)
Commuting	0.01(POP)	0.05(POP)	0.05(DRES)+ 1.0(COMM)

where:
POP is the census tract population taken from census data
DRES is the daytime residential population inferred from census data
NRES is the nighttime residential population inferred from census data
COMM is the number of people commuting inferred from census data
COMW is the number of people employed in the commercial sector
INDW is the number of people employed in the industrial sector.
AGE_16 is the number of people 16 years of age and under inferred from census data (used as a proxy for the portion of population located in schools)

Table 4.14: Distribution of population for different periods of the day according the HAZUS methodology.

Participatory mapping for estimating population density and activity pattern

Participatory mapping can be a very useful tool for the generation of a population database, when detailed census data is lacking. Based on mapping of individual buildings together with interviews of local population it is possible to establish household activity patterns. An example of such a study is shown in Figure 4.22. Showing the daily distribution of household in their residence over the course of a day, for weekdays, sundays and holidays.

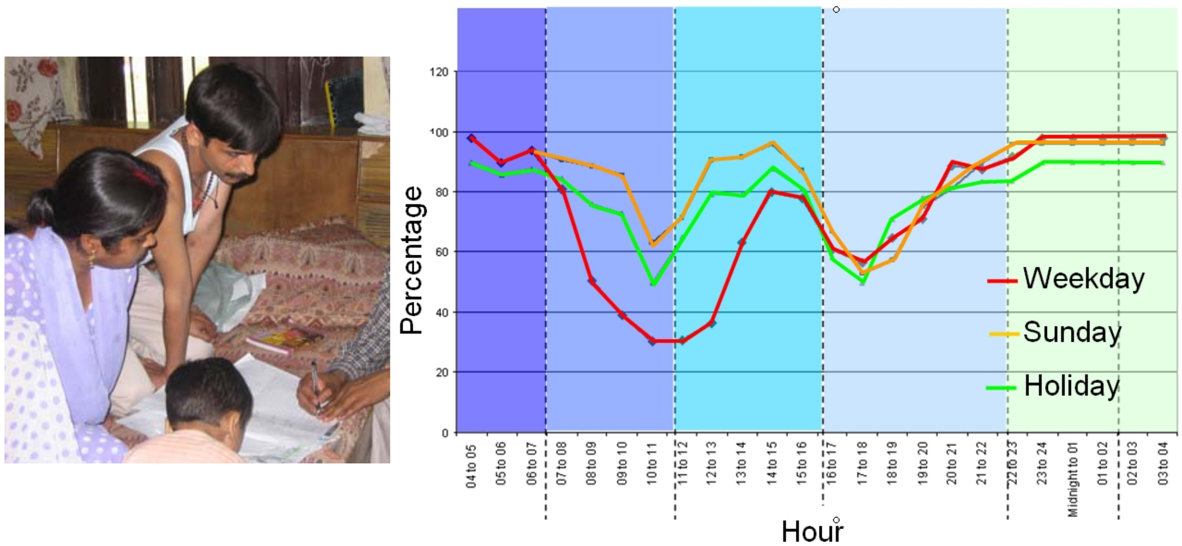


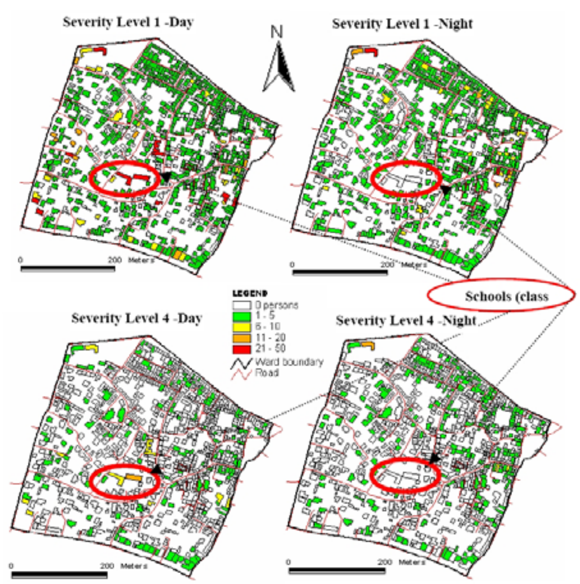
Figure 4.22 : Community based Household Activity Pattern Survey in Dehradun, India. Right: resulting activity pattern of households over a day.

Apart from people being present in buildings (by living/working/studying) there are also people who come from outside which stay for a while in the study area (e.g. for shopping, visiting, work or going to school). Based on similar activity studies for other urban land uses (school, shops, office etc.) it is possible to compute the population per building and per land use type for each period of the day, using a formula such as the one shown below. It should be noted that there is a considerable variation in commuting patterns and this type of formula should be calibrated.

$$\text{Hourly Presence of People} = \sum_{i}^{1} \begin{array}{l} [\text{No of Households per building}] \ *(\text{Average Hourly Number of Persons}) \\ [\text{No of Shops}] * (\text{Average Hourly Number of Persons}) + \\ [\text{No of Schools}] * (\text{Average Hourly Number of Persons}) + \\ [\text{No of Other Units}] * (\text{Average Hourly Number of Persons}) \end{array}$$

Figure 4.23: Example of population losses due to earthquakes for different perods of a day and different earthquake scenarios (Source: Jimee, Van Westen and Botero, 2008)

This community based information can then be used for population loss estimation, based on earthquake scenarios for different periods of the day. Figure 4.23 Shows an example for a ward in the city of Lalitpur, Nepal. The large differences between night and daytime scenarios can be observed especially in the school areas.



4.5 Participatory GIS for Disaster Risk Assessment

For the generation of information at the local level it is important to work together with local communities, and learn from their local knowledge. Local or indigenous knowledge is often critical in understanding the vulnerabilities and capacities of an area, but is rarely available on maps and even less so in a format that can be entered into a GIS. However, this information is crucial as the local population has the best knowledge on the hazard events that they have experienced; their local causes and effects, and the way their community had to cope with them. This information is essential for land use planning, conflict management, and for disaster risk management. After all, disaster risk reduction aims at reducing the risk of the people against disaster events, and for the implementation of sustainable disaster risk management policies the support and collaboration of local people is essential.

4.5.1 Local Knowledge

In a participatory approach the knowledge of local people is not simple "tapped" by the outside people involved in a risk assessment study. This can of course also be done, but then the local community is considered an information source, and not a partner in the risk management. Local people have a vast amount of knowledge on hazards, vulnerability, and risk. However not all of this knowledge is readily available. It is often "**tacit knowledge**", of which they were not directly aware as they normally do not communicate this to outsiders. Therefore there has to be a process of "**eliciting the knowledge**", making them formulate it, and interact with them. This cannot be done in a fast and unpersonal manner. There has to be an atmosphere of confidence between local people and the risk investigators, before people are willing to formulate this type of knowledge. Local knowledge can consist of many components:

- Knowledge of historical disaster events, and the damages they have caused.
- Knowledge on the elements at risk, and how they value them.
- Knowledge on the factors contributing to vulnerability.
- Knowledge of their coping strategies and capacities to confront disasters.
- Knowledge about commuting patterns

However, local knowledge is often not recognized as an important source of information by investigators working in disaster risk projects in developing countries, especially those that are controlled by higher authorities. The knowledge is often perceived as non-scientific and often discarded at the favor of probabilistic models for risk assessments. Local knowledge is also perceived as difficult to retrieve, difficult to be expressed in quantitative terms or to be converted into spatial formats. The goal of participation is to give at risk communities ownership, the ability to express themselves, to learn from them, and ultimately to empower them through the acknowledgement of their skills, abilities, and knowledge. Participation improves the self–confidence and capacities for risk management of local communities and municipal authorities. They become aware of local knowledge as an asset they have in their own territories and hands and therefore need less external human, technical and economical assistance.

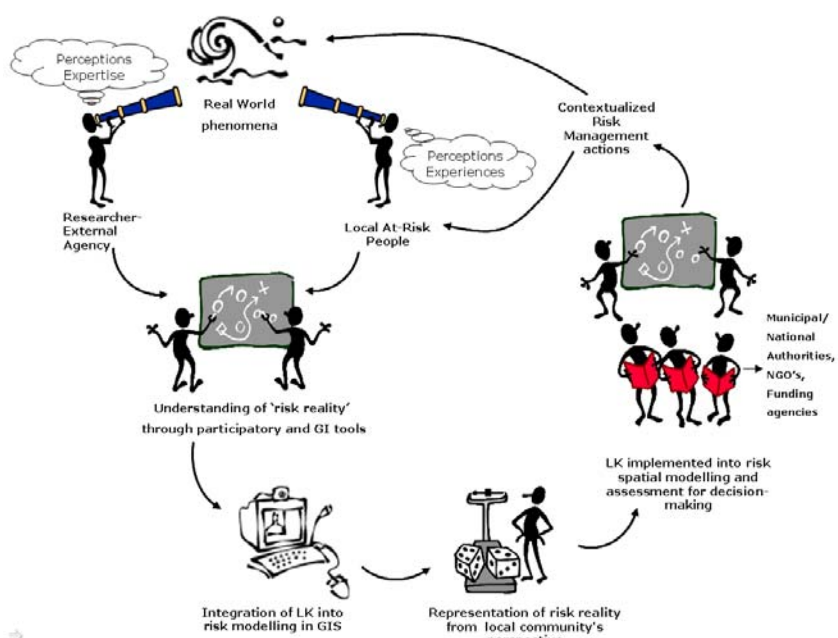


Figure 4.24: Local knowledge in participative risk assessment (source: Peters, 2008).

4.5.2 Tools for traditional community based Disaster Risk Management

Over the past decades many community-based methods have been developed as a diagnostic process leading to a common understanding of a community's disaster risks. The size of the hazard-related problems as well as the resources and opportunities to cope with these are identified and analyzed. Community risk assessment has four components: a) Hazard assessment; b) Vulnerability assessment; c) Capacity assessment and d) People's perception of the risks.

The tools commonly used employ methods such as workshops, (semi structured) interviews, transect walks in which the situation is discussed, focus group discussion, problem tree analysis, community mapping, ranking of problems and solutions, etc.

The information is assembled through tools such as Capacity and Vulnerability Assessment (CVA), Hazards, Vulnerability and Capacity Assessment (HVCA), and Damage, Needs and Capacity Assessment (DNCA). The typical information that can be gathered by these means is related to:

- Analysis of disaster management activities and practices at the community level.
- Community risk perception.
- Determination of the needs and expectations of the communities in relation to hazard mitigation and loss minimization.
- Assessment of their levels of preparedness.
- Methods to enhance their capacity and options for more effective responses to reduce vulnerability
- Community-based hazard management plans.

Figure 4.25: Examples of traditional CB methods for risk assessment using transets and sketchmaps (Source: Peters, 2008)

The Vulnerability and Capacity Assessment tool (VCA) is a practical and diagnostic method mostly used by NGOs for planning and evaluating projects. The VCA is aimed to help practitioners to understand the nature and level of risk that communities face, where the risk comes from; what and who will be worst affected; what assets are available at different levels to reduce the risk; and what capacities need to be further strengthened. Many toolkits have been developed, by organisatons such as IFRC, OXFAM, ADPC, ActionAID, Tearfund etc. For a good overview of the various methodologies please visit the webpage of the ProVention consortium: http://www.proventionconsortium.org/?pageid=43

Task 4.10: Video on Community based approaches (duration 30 minutes)
To understand better the community-based approach to disaster risk management at local level, it is good to watch one of the following videos on Youtube:
IFRC Preparing for Disaster: A community based approach
http://www.youtube.com/watch?v=AWS4s6E5ock
Building Community resilience to Disasters
http://www.youtube.com/watch?v=gmc3CoiCfKo

4.5.2 Focusing on spatial information in local risk assessment

The conventional methods for community based disaster risk assessment also collect and use spatial information, for example in the form of community mapping (See figure 4.25). However the product obtained through such processes, which are often also rather time consuming, remain where they are, or at best end up in a report, or are put on the wall of the community center. The spatial information is not maintained, and will be lost after a while. The spatial information is also not properly georeferenced so that it can be utilized in a GIS. Another problem is that such information is difficult to incorporate in the risk management planning of the local authorities. Where local authorities, who are responsible for the safety of the population living in the area of their jurisdiction, are not motivated or able to be involved in risk management, it is left up to the local communities to deal with the problem themselves. That is why there is such a large focus on these techniques by (international) NGO's working with low-income people in disaster prone areas. However, where the local authorities recognize their responsibility and are involved in risk assessment, it is crucial that the local information is incorporated into their plans.
Therefore it is surprising that there are not more applications of Participatory GIS or participatory mapping to hazard identification and risk mapping. Local people's direct experience or historical 'folk memories' of floods, water-logging, landslides, avalanches, storm damage, coastal inundation, etc., also of pest outbreaks, vulnerability to earth movements, etc., should be essential inputs to scientific assessments of the extent of hazards and the degree of risk. P-mapping and PGIS are excellently suited to the needs for incorporating local knowledge, participatory needs assessment & problem analysis, local prioritising, and understanding responses and coping strategies.

PGIS is a useful tool for extracting lay (indigenous) knowledge, perceptions of environmental problems and hazards, and presenting and communicating it to environmental scientists and local authorities.

Participatory GIS can be used for:

- Reconstructing historical hazardous events by obtaining eye-witness information from the local people in the affected communities.
- Obtaining information on the characterization of elements at risk at the local level. A considerable amount of information is not publicly available and can only be collected locally, with the help of the local communities.
- Understanding the coping mechanism that households in local neighborhoods employ with respect to the frequently occurring hazardous events like flooding.
- Understanding the factors that determine the level of vulnerability of the households in local communities, and their capacities.
- Evaluating the possible risk reduction measures that are suggested by local communities,
- Allowing interaction between local communities and Non-governmental organizations, as well as with local authorities.
- Post disaster damage mapping

It should be kept in mind that PGIS is not only about collecting information from the local communities, but rather about collecting information with them, and interact with them as they have local knowledge that is indispensable for reducing the risk.

Figure 4.26: Participatory mapping in action (Source: Peters, 2008)

4.5.3 Tools for Participatory mapping: Mobile GIS

In a participatory mapping approach basically the same tools can be used as in the traditional approaches mentioned before. More emphasis is given, however, to the representation of the spatial related information in a format that can be used in a GIS and can be updated and shared with other stakeholders. There is a wide range of non-digital techniques for participatory mapping, such as the generation of community maps on top of a large scale airphotos or satellite images. It is surprising how well local people are able to recognize their daily environment on such detailed images. Other techniques are the generation of simple scale models in 2-D or even in 3-D as people are much better at identifying features when they can refer to the terrain as they see it in three dimensions.
However the use of digital techniques for information collection are preferred, as this speeds up the process of data collection, and avoids the lengthy conversion of information into digital form. With the use of Mobile GIS it is possible to directly collect the spatial information, based on a high resolution image that can be uploaded into the palmtop computer, and link it with attribute information that is collected in the field. High resolution images can be compressed up to 25 times using software such as MrSid. Some of the most used tools for Mobile GIS are:

ArcPad
ArcPAd is one of the products of ESRI designed in combination with the ArcGIS suite, which allows users to make their own interface for data collection using a handheld device with a GPS connection. The data is collected in the format that can be directly applied in ArcGIS.

Cybertracker
CyberTracker software creates data entry templates to use on Windows PocketPC or PalmOS handheld computers to gather and map locally-generated, spatial knowledge. Connected to a GPS, CyberTracker instantly geo-references data. "CyberTracker's unique design allows users to display icons & text which makes data collection faster. It allows field data collection by non-literate users and school children". CyberTracker has been applied to local spatial knowledge in post-disaster relief operations. CyberTracker, Cape Town, South Africa. http://www.cybertracker.org/index.html

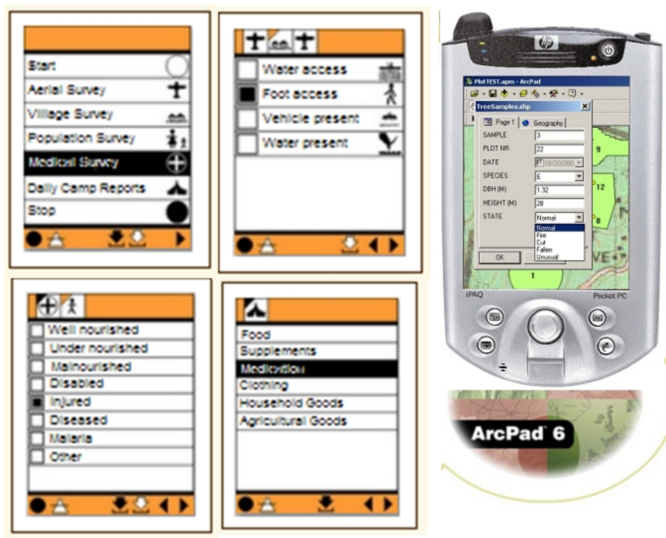


Figure 4.27: Left: Cybertracker input windows for a survey of disaster relief using simple icons. Right: View of ArcPad software installed on a hand held device.

Mobile GIS can be used for many of the steps involved in disaster risk management. Figure 4.28 shows an example for landslide mapping. Landslides are interpreted from stereoimages, and the interpretation is digitized and converted to the mobile GIS together with an orthoimage. In the field the boundaries are checked and the landslide attributes recorded. Figure 4.29 shows an example of mobile GIS developed for rapid mapping of building damage after a disaster (e.g. earthquake). In such cases there is a need for a rapid survey of many buildings, and a classification should be made in order to indicate if the building is still inhabitable.

Although mobile GIS has become a standard tool in many data collection projects, and is now also very affordable, it also has a number of limitations. There is always the danger that data might be lost if the device is stolen, damaged, or if data is accidentally deleted. Working with mobile device with small screens can also be rather problematic, especially in conditions of direct sunlight. Furthermore there is a danger that the operation of the device takes more time than the discussion with local people.

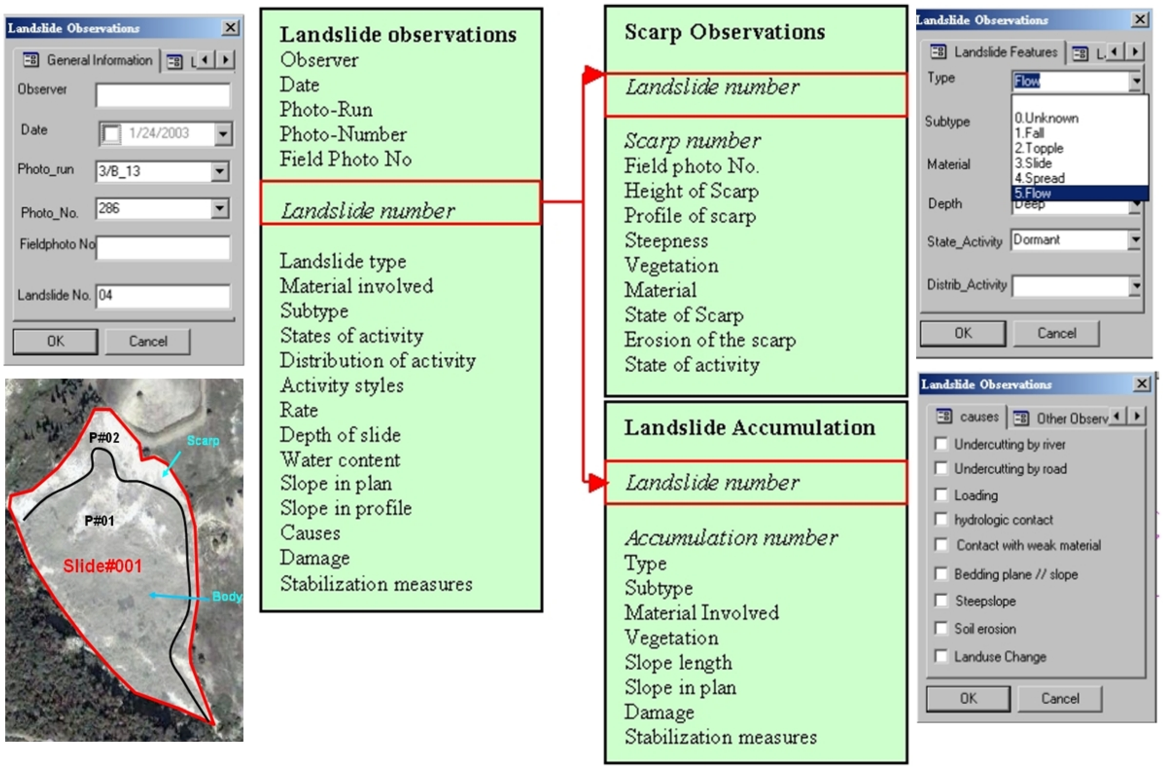


Figure 4.28: Mobile GIS for landslide inventory mapping. An example of the part of the database structure (center), input screens (left and right) and the interpreted landslide from a high resolution image, which is checked in the field.

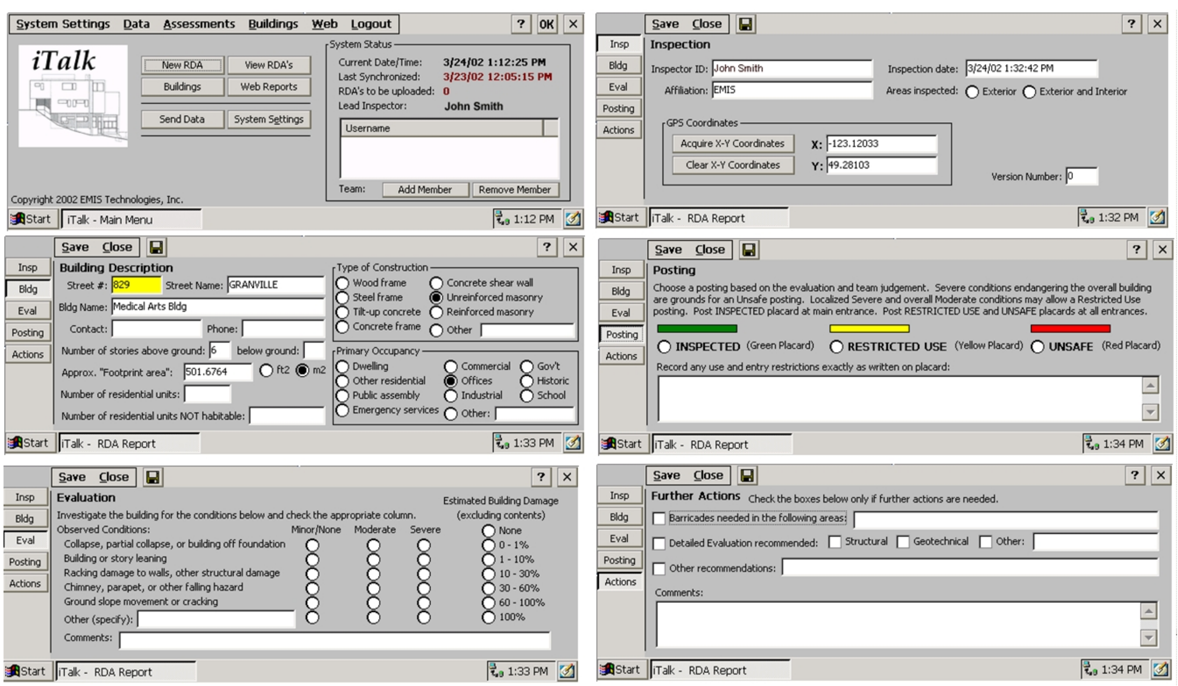


Figure 4.29: Example of a tool for the use of Mobile GIS for rapid damage assessment after a disaster (e.g. earthquake): iTalk. Source: http://www.emistech.com)

4.5.3 Participatory mapping in hazard assessment.

The use of participatory mapping is a very important tool in hazard assessment, for:

- The **reconstruction of historical disaster events** with respect to the extension, severity, and frequency of these events. Often it is also possible to reconstruct historical scenarios. These can then also be used in combination with modeling results, either as input in the models (e.g. terrain parameters, flood marks) as well as for validating models (e.g. validating flood models for particular scenarios with the result of community maps made for the same events.)
- The **mapping of damage** caused by these historic events. Even though the events may have happened some time ago and the damages might not be visible anymore, local communities can still identify where, what and how much was damaged. Furthermore they indicate how much they were affected in terms of their livelihood, access to basic services etc.
- The manner in which they **perceive** the various hazard events that have happened. It may not always be very straightforward to link the magnitude of the hazard events with the degree of manageability, which is an indication how the local communities experienced and perceived the severity of the event. For instance small events that happened close to each other might have caused more problems than larger event that happen less frequently. For example, figure 4.30 shows the manageability classes that were derived together with local communities regarding the flood threat in their area. Classes were made not of water depth or duration, but these were combined into manageability classes based on community-derived criteria.
- The **coping strategies**: the way in which local people dealt with the effects of the event.

The use of participatory mapping for hazard assessment also has a number of drawbacks which should be taken into consideration:

- Local knowledge is local: people have best knowledge on their own small area. The reliability decreases when they are asked about situations in nearby locations where they don't go regularly.
- Local knowledge of historical events is limited. If there is a series of hazard events that have affected them (e.g. landslides, floods), it will be difficult to remember them in the correct way. They become often mixed, and merge into one picture, which makes it difficult to analyze the effect of events with different magnitude. Normally the largest event is remembered for the longest period.
- The local knowledge might be ambiguous and different people might give quite varying opinions on past hazard scenarios. Therefore the investigator has to corroborate the information by interviewing many people, or organize workshops where the information is discussed with a whole group.
- It is not possible to use local knowledge to evaluate events that have not happened before, or that happened so long ago that the local communities do not have a clear memory of. For instance the effect of a 1/200 year earthquake is very difficult to evaluate with the local community if the last one has happened more than 60 years ago.

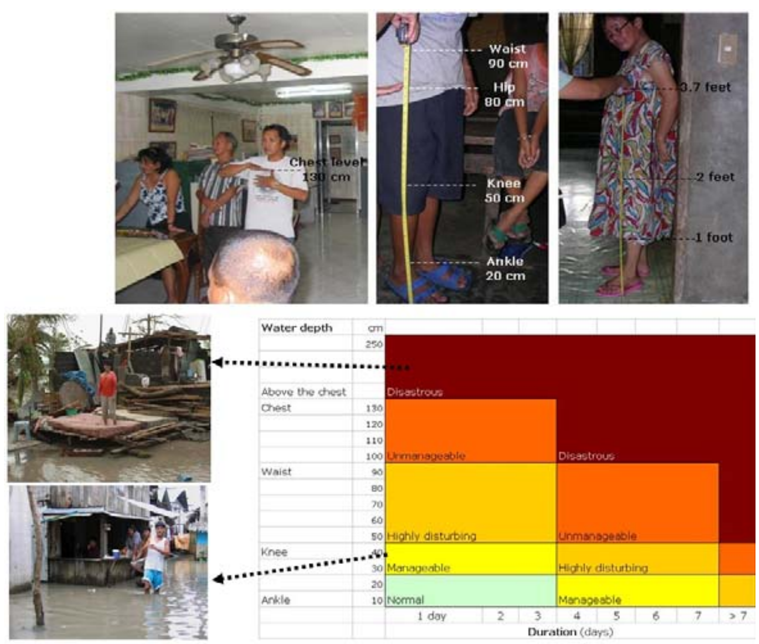


Figure 4.30: Hazard maps are based on the criteria that the community indicates regarding their perception of the severity of the hazard, in so-called "manageability" classes.

4.5.4 Participatory mapping of elements at risk

This session dealt with a number of aspects related to elements at risk mapping. Although elements at risk information may be derived from existing data sources such as cadastral and census data, there is always a need to collect additional information to characterize the elements at risk for vulnerability assessment. Furthermore in case existing data are not available it is actually the primary source of elements at risk information for mapping the following aspects:

- **Buildings:** Correct delineation of buildings from image interpretation is difficult, even when using high resolution images. Figure 4.32 gives an example of the difficulty to delineate individual buildings in dense urban areas. For collecting information on building types, construction materials, land ownership, and the checking of urban land use, normally stratified samples are taken, as it is often too time consuming to do a complete house-by-house survey. Figure 4.32 also shows the input screen used in Mobile GIS for building mapping.
- **Population characterization:** mapping of population characteristics such as socioeconomic status, livelihood, income level, dependency ratio (ratio between income earners and rest of the household), family size, commuting patterns.
- **Basic infrastructure:** access to drinking water, sanitary facilities, but also community services such as health (hospitals and health centers) institutional (neighborhood offices), educational (schools), religious (churches, mosques and temples), areas for recreation and open spaces which can be used for evacuation purposes.
- **Mapping of environmental problems:** waste disposal situation, the presence of environmental problems like stagnating water, polluted areas etc.

Participatory mapping covering large areas can also be done by selected people from the local community, which are trained to do the survey, or by involving students from a nearby university. However, care should be taken in that case that the quality of the survey is constant, and a system of quality checking should be built in.

Figure 4.32: Example of the use of mobile GIS for building mapping. The buildings have been digitized before on a high-resolution image, and the boundaries are checked in the field. With ArcPad a number of input screens have been defined for the collection of the attribute data. For each attribute a selection can be made from a list of possibilities, and estimations on percentages are checked to avoid errors in data input. The lower part shows the output table that will be linked

Task 4.11: RiskCity exercise on the use of Participatory mapping information (duration 3 hours)
At this point it is good to go back to the RiskCity case study and have a look how Participatory mapping can be used in the context of RiskCity. Of course in the framework of this course it is not possible to collect this type of information yourselves. Therefore we have done this already for you in two neighborhoods of the city. One that is flood prone and the other which is landslide prone. You can select which one of the two aspects you would like to work on.

Carry out the RiskCity exercise on Participatory mapping.

4.5.5 Participatory mapping in vulnerability and capacity assessment

In this section we will not expand too much on the aspects related to vulnerability and capacity, as this is the topic of the following session. We just would like to indicate here that the vulnerability and capacity analysis is the core of the community-based approaches, as the type of information that is needed to investigate this can only be obtained by dialogue and discussion with the local communities. Table 4.15 gives a summary of the information that was collected in a study on flood risk management for two neighborhoods (barangays) in the flood prone area of Naga city in the Philippines.

Table 4.15 Summary of the information that was collected using participatory mapping for a flood risk study in the Philippines (Source: Peters, 2008)

Components of the conceptual model for flood risk assessment		**Logical model: Elements and indicators used to spatially represent the conceptual model**	
Geo-Hazard	Flood	Water depth Duration Velocity	-Group/individual experiences about past events -Hydrological modelling
Vulnerability	*Exposure*	Location	-Surface elevation of the terrain -Location in relation to nearby elevated areas -Location in relation to elements susceptible to strong winds (antennas, large/robust trees, advertisement boards)
		Quality of the built environment	-Building types -Development level
		Quality of the Natural environment	-Waste management -Presence and origin of stagnated waters
	Resistance	Socioeconomic status	-Household composition -Occupations (type of activity, location) -Number of working people -Dependency ratio -Access to basic services (health, education, water, sanitation) -Access to resources during 'normal' times (land, goods and savings) -Access to resources during 'crisis' times (warnings, evacuation, relief)
	Coping	Mechanisms for risk management according to daily life aspects	-Coping mechanism before, during and after flooding related to : housing, livelihood, food, health, sanitation, safety of belongings, mobilization and overall safety.
Risk		Past, present and future scenarios for flood events with different return periods	- Flood scenarios for different events - Vulnerability of the elements under analysis - Implementation of socioeconomic development scenarios

4.5.6 Participatory mapping for disaster relief support

The last aspect covered here is the use of GIS for disaster relief. There are a number of initiatives in this field:

- **MapAction**, http://www.mapaction.org/index.html is a UK-based charity, staffed by specialist volunteers, whose core role is supporting humanitarian operations through provision of spatial data collection and mapping capabilities in the field. Large-scale maps focused on specific relief requirements through sectoral overlays, maps formatted to specific needs of aid agencies, Interactive GIS technology on web based servers, enabling on-line queries, enhance existing baseline maps in the field through computer-linked GPS/GIS systems.

- **GISCorps** is since 2003 an URISA program and operates entirely on a volunteer basis. GISCorps volunteers reside in different states across the USA and use a twiki site to work collaboratively. Emergency & relief work in: Andaman Islands., India Tsunami. and with Global MapAid, post-tsunami; Katrina USA MI & LA, Afghanistan. http://www.giscorps.org/
- **Global MapAid**, a non-profit organization, was initiated with a view of supplying specialist maps to emergency & humanitarian aid workers. The group consists of experienced aid workers, GIS analysts, web developers, and core volunteers from Stanford University. The focus is to map humanitarian crises hotspots by capturing data to assist predominantly in slow onset disasters such as food security, drought, HIV monitoring and orphanage survey refugee programs but also when necessary in rapid onset disasters such as floods. GMA's mission is to assist aid efforts by providing and assisting in the provision of mapping and corresponding communications systems for aid agencies, e.g. UN World Food Program. http://www.globalmapaid.rdvp.org/

Task 4.12: Summary on the use of Participatory mapping for disaster risk assessment (duration 15 minutes)

After reading this session and after you did the RiskCity exercise on the use of Participatory mapping information, it is good to make a summary of what you have learned.
Please do that by filling in the following table, and explain briefly your choices.

Hazard type	Location as point	Spatial extent	Historical events	Frequency	Causes	Damage	Vulnerabi lity
Floods							
Landslides							
Earthquake							
Volcanic eruptions							
Bush fires							
Township fires							
Storms							
Pest outbreak							
Drought							

Finally, please note down the advantages and disadvantages of Participatory mapping

Selftest

In order to evaluate whether you have understood the concepts that were presented in this session. Please make the following test, and check the answers in Blackboard.

Question 4.1: Spatial data for elements at risk
Which minimal spatial information is required in order to make an estimation of the vulnerability of buildings?
A) Building footprints
B) A high-resolution image (e.g. Ikonos)
C) Mapping units
D) Wards

Question 4.2: Elements at risk
Which of the following statements is relevant for <u>high potential loss facilities</u>?
A) A park can be used as an evacuation area
B) Hazardous chemical industries might produce an additional disaster once they are damaged by a hazard event.
C) Restaurants might have more people during a small period in the week.
D) Residential areas might have a higher number of casualties during the night.

Question 4.3: Participatory GIS
Participatory GIS for disaster risk assessment has the following advantages and disadvantages:
A) It involves community participation, but may not capture all possible hazard scenarios, due to the limited historical time-span of collective knowledge of the community.
B) It leads to the extraction of local (indigenous) knowledge, but unfortunately doesn't display this in the right projection system, and therefore cannot be used in GIS.
C) It allows the inclusion of local interests and priorities, but unfortunately doesn't formalize this information, so it might get lost soon.
D) It is a nice method to collect information from the population, which an expert can use to validate his scientific models, but it is not reliable.

Question 4.4: Elements at risk : urban land use
In order to make a good risk assessment, the classification of urban land use is important because:
A) It determines the types of buildings, and their vulnerability
B) It determines the population density
C) It determines the population distribution, during different time periods
D) All of the above.

Question 4.5: Elements at risk
Which attribute related to buildings is most important for the risk assessment, and why?
A) Urban land use, because from this attribute you can derive several other attributes, especially related to the density of population in day and nighttime scenarios.
B) The building contents because that is important in order to determine structural damage
C) The number of floors, because this determines the vulnerability of the population
D) The roof type, because that can be observed using satellite imagery.

Further reading:

Elements at risk classification.

- We recommend you to read the technical manual of HAZUS related to the inventory of assets for loss estimation. This manual is provided on the background directory of session 4 on the course DVD or blackboard site.

Some ITC PhD theses on this topic are:

- A.L. Montoya, I. Masser (Promotor), N. Rengers (Promotor), H.F.L. Ottens (Promotor) (2002) Urban disaster management : a case study of earthquake risk assessment in Cartago, Costa Rica . PhD thesis Utrecht University. document http://www.itc.nl/library/Papers/MONTOYA.pdf
- Botero Fernandez, V., Ottens, H.F.L. (promotor) , van Westen, C.J. (promotor) and Sliuzas, R.V. (promotor) (2009) Geo - information for measuring vulnerability to earthquakes : a fitness for use approach. Enschede, Utrecht, ITC, University of Utrecht, 2009. ITC Dissertation 158, 191 p. ISBN: 978-90-6164-272-5. http://www.itc.nl/library/papers_2009/phd/botero.pdf
- Peters Guarin, G., Frerks, G. (promotor) , van Westen, C.J. (promotor) and de Man, W.H.E. (promotor) (2008) Integrating local knowledge into GIS based flood risk assessment, Naga city, The Philippines. Wageningen, Enschede, Wageningen University, ITC, 2008. ITC Dissertation 157, 352 p. ISBN: 978-90-8585-295-7. http://www.itc.nl/library/papers_2008/phd/peters.pdf

Other related literature:

- Ebert, A., Kerle, N. and Stein, A. (2009) Urban social vulnerability assessment with physical proxies and spatial metrics derived from air- and spaceborne imagery and GIS data. In: Natural hazards : journal of the international society for the prevention and mitigation of natural hazards, 48 (2009)2, pp. 275-294. http://intranet.itc.nl/papers/2009/isi/kerle_urb.pdf
- Montoya L. Geo-data Acquisition through Mobile GIS and Digital Video: an Urban Disaster Management perspective (2003) In: Environmental Systems and Software, 18(10) Elsevier, pp. 869-876

Participatory GIS

- *For a good overview of the various methodologies please visit the webpage of the ProVention consortium: http://www.proventionconsortium.org/?pageid=43*
  This is a well-organised, annotated overview of Community Risk Assessment (CRA) approaches and methods, many of which are highly relevant to PGIS issues, applications and methods. This 'Guide to Handbooks and Guidelines' reviews the products of many agencies and NGOs, including Asian Disaster Preparedness Centre (ADPC); Oxfam, ActionAid; Centre for Disaster Preparedness Philippines, International Hurricane Research Centre, Florida; South Pacific Disaster Reduction Programme of the UN Dept of ESA; and the Philippines National Red Cross Society.
  Likewise there is a cross-indexed user-friendly guide to PRA and other survey tools for community spatial information, including hazard mapping; resource mapping; risk mapping; and gendered risk mapping. (NB of course the term 'mapping' in this context does not always mean just representation of geospatial information) The website also includes many case studies.

- A good overview of publication related to PGIS for disaster risk assessment, prepared Mike McCall can be found in ***:***
  http://www.proventionconsortium.org/themes/default/pdfs/CRA/PGIS_Sept08.pdf

Guide book
Session 5:
Vulnerability assessment

Cees van Westen & Nanette Kingma

Objectives:

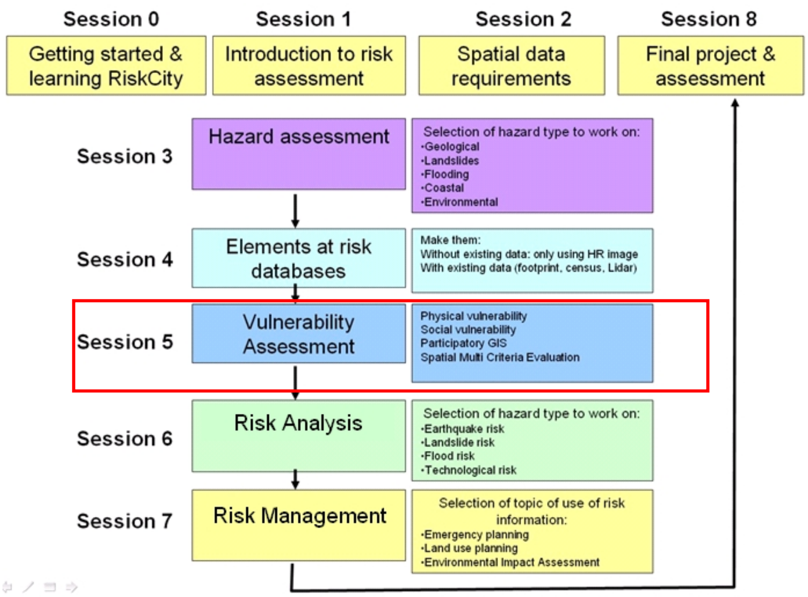
After this session you should be able to:

- Understand the types of vulnerability: physical, social, economic and environmental;
- Understand the complexity in approaches used for vulnerability and the varyibng ways in which it is defined.
- Indicate the ways in which vulnerability can be expressed.
- Outline the main approaches used for flood, earthquake and landslide vulnerability assessment
- Understand the concepts of Spatial Multi Criteria Evaluation for vulnerability assessment;
- Carry out Spatial Multi Criteria Evaluation in GIS

This chapter might be one of the most "fuzzy" ones of the book, as the concept of vulnerability is defined in many different ways. Therefore we will start this chapter by looking at the various definitions and approaches that are used to "capture" vulnerability. Most of the session deals with methods to express and quantify physical vulnerability. We will look at methods for creating vulnerability curves and matrices for flooding, earthquake and landslides. A separate section deals with the analysis of population vulnerability. In the last part of the session we will look at methods that are used to quantify the entire spectrum of vulnerability. This is mostly done with indicators, and Spatial Multi-Criteria Evaluation (SMCE) is one of the main tools used. The session ends therefore with a RiskCity exercise on the use of SMCE.

Section	Topic	Task	Time required		
5.1	Introduction		Day 1	0.5	0.5
5.2	Defining vulnerability			0.35	0.5
		Task 5.1: Vulnerability, coping capacity and resilience		0.15	
5.3	Conceptual frame-works of vulnerability			1.00	1.0
5.4	Types of losses and vulnerability			0.35	0.5
		Task 5.2: Linking loss types with vulnerability		0.15	
5.5	Expressing vulnerability			0.35	0.5
		Task 5.3: Methods for expressing vulnerability	Day 2	0.15	
5.6	Measuring physical vulnerability			1.35	3.5
		Task 5.4: Vulnerability methods		0.15	
		Task 5.5: Vulnerability curves from damage data		1.00	
		Task 5.6: Expert opinion & vulnerability curves		0.25	
		Task 5.7: Watch Shaketable test on Youtube		0.25	
		Task 5.8: European flood vulnerability methods		0.50	
5.7	Comprehensive vuln. assessment		Day 3	0.50	0.5
5.8	Spatial Multi Criteria Evaluation			0.50	4.5
		Task 5.9: RiskCity exercise on the use of SMCE		4.00	
		Total	**3 days**	**11.5 hours**	

5.1 Introduction



This session deals with one of the most complicated components of multi-hazard risk assessment: vulnerability. It is complicated because the concept of vulnerability has a wide range of interpretations. The concept of vulnerability originated from the social sciences in response to the pure hazard oriented perception of disaster risk in the 1970s. Here the vulnerability was mostly related to buildings & structures at risk and how these buildings & structures were damaged by hazards, due to physical forces exterted by ground motion, wind, water, etc. The damage was rated on a scale of 0 (no damage) to 1 total damage. Since that time different discilpines are working with the concept of vulnerabilityand and the concept of vulnerability has broadened (see figure 5.1), by not only looking at buildings and structures but more to human beings. As mentioned in session 1.2.2 the study of disaster and risk has gone through an interesting evolution during the past decades. A set of paradigms has ruled the study of disasters and risk in the past decades.

Paradigms of risk and vulnerability

$$R \approx H$$
$$R \approx H \times V$$
$$R \approx H \times V / C$$
$$R \approx H(v, c) \times V(h, c) / C(h, v)$$

Technocratic or Behavioral paradigm:
The first approaches to risk were the ones that assimilated it to hazard or focused mainly on it, carried out especially by professionals of the natural sciences (geologists, engineers, meteorologists, etc.). According to Blaikie et al (1994), until the emergence of the idea of vulnerability to explain disasters, there was a range of prevailing views. None of which really dealt with the issue of how society creates the conditions in which people face hazards differently. The first approach was unapologetically naturalist, in which all blame was apportioned to ‘the violent forces of nature’. Governments and individuals relied upon physical protection against the hazards.

Physical Vulnerability or Structural paradigm:
The concept of vulnerability entered the risk scene. Protection was defined not only according to the physical protection systems built, but also according to the people’s behavior. This inclusion of people’s behavior led to the design and use of early warning systems and educational programs about hazards and how to protect against them. This paradigm lasted for a couple of decades and was even used during the Yokohama Strategy and Plan of Action for a Safer World (1994), where all the efforts were aimed towards increasing our scientific knowledge about the causes and consequences of natural hazards and facilitate its wider application to reducing vulnerability of disaster-prone communities. This perspective included overall development, attacking root causes, and capacity building.

Complexity paradigm:
A new understanding of the complex interaction between nature and society has emerged, and as such, a new complex approach to understanding risk has to be undertaken. Vulnerability is not only about groups or individuals, but is also embedded in complex and social relations and processes.

5.2 Defining vulnerability.

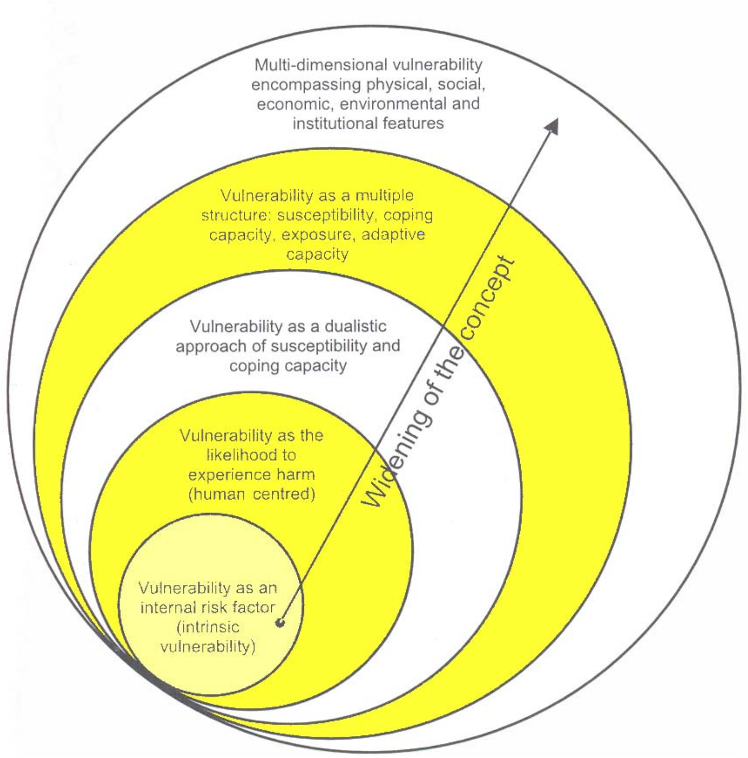


Figure 5.1 Key spheres of the concept of vulnerability. Source: Birkmann, 2006)

Multiple definitions and different conceptual frameworks of vulnerability exist, because several distinct groups have different views on vulnerability. Academic staff from different disciplines, Disaster management agencies, development corporations, climatic change organization etc. An overview is given on the website of the ProVention Consortium (http://www.proventionconsortium.org/) and in the book on Vulnerability edited by Birkmann (2006). Birkmann writes about the paradox of aiming to measure vulnerability if we cannot yet define vulnerability precisely.
Some of the definitions are given in the box below. The first definition is still related only to physical vulnerability while in the other definitions we find that vulnerability is influenced by several factors, mostly mentioned are physical, economic, social and environmental factors.
The definitions of vulnerability of Provention and Blaikie clearly show that besides vulnerability the elements at risk also have capacities. According to the UN, in their report Living with Risk (UN/ISDR , 2004), risk is rooted in conditions of physical, social, economic and environmental vulnerability that need to be assessed and managed on a continuing basis (Figure 5.2).

General definitions of vulnerability:
Vulnerability is:

- "The degree of loss to a given element at risk or set of elements at risk resulting from the occurrence of a natural phenomenon of a given magnitude and expressed on a scale from 0 (no damage) to 1 (total damage)" (UNDRO, 1991)
- "Exposure to risk and an inability to avoid or absorb potential harm (Pelling, 2003). In this context, he defines physical vulnerability as the vulnerability of the physical environment; social vulnerability as experienced by people and their social, economic, and political systems; and human vulnerability as the combination of physical and social vulnerability" (in Vilagrán de León, 2006)
- "The characteristics of a person or group in terms of their capacity to anticipate, cope with, resist and recover from impacts of a hazard" (Blaikie, Cannon et al. 1994).
- "The degree of susceptibility and resilience of the community and environment to hazards" (EMA, 1995).
- "A human condition or process resulting from physical, social, economic and environmental factors, which determine the likelihood and scale of damage from the impact of a given hazard" (UNDP, 2004).

Vulnerability is:

- "The conditions determined by physical, social, economic and environmental factors or processes, which increase the susceptibility of a community to the impact of hazards "(UN-ISDR)

- "The intrinsic and dynamic feature of an element at risk that determines the expected damage/harm resulting from a given hazardous event and is often even affected by the harmful event itself. Vulnerability changes continuously over time and is driven by physical, social, economic and environmental factors" (UNU-EHS, 2006)

- "The potential to suffer harm or loss, related to the capacity to anticipate a hazard, cope with it, resist it and recover from its impact. Both vulnerability and its antithesis, resilience, are determined by physical, environmental, social, economic, political, cultural and institutional factors" (Provention Consortium, 2007)

- "The degree to which a system is susceptible to, or unable to cope with adverse effects of climate change, including climate variability and extremes". Vulnerability is a function of the character, magnitude, and rate of climate variation to which the system is exposed, its sensitivity, and its adaptive capacity" (IPCC,2001:165).

- Vulnerability = (Exposure) + (Resistance) + Resilience

  With: Exposure: at risk property and population;
  Resistance: Measures taken to prevent, avoid or reduce loss;
  Resilience: Ability to recover prior state or achieve desired post-disaster state.

What is common from the definitions is that vulnerability is:

- **Multi-dimensional** (e.g. physical, social, economic, environmental, institutional, and human factors define vulnerability);
- **Dynamic** (vulnerability changes over time);
- **Scale-dependent** (vulnerability can be expressed at different scales from human to household to community to country resolution;
- **Site-specific** (each location might need its own approach).

Below a number of vulnerability types are defined, based also on figure 5.2. These definitions will be used as the working definitions within this chapter and book. In the RiskCity exercises we will concentrate mostly on physical vulnerability and to a lesser extent also on social vulnerability.

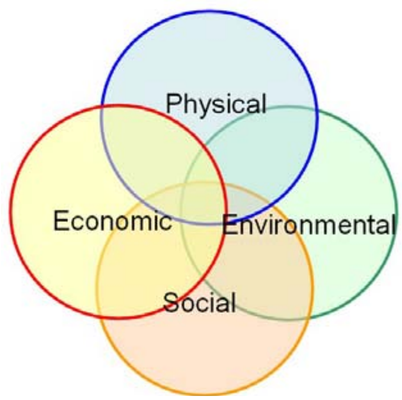


Figure 5.2 Factors, Influencing vulnerability (Source: UN-ISDR).

Vulnerability types:

- **Physical Vulnerability**: meaning the potential for physical impact on the built environment and population. The degree of loss to a given element at risk or set of elements at risk resulting from the occurrence of a natural phenomenon of a given magnitude and expressed on a scale from 0 (no damage) to 1 (total damage)".
  - Vulnerability is analyzed per group of constructions (i.e. structural types) having similar damage performance;
  - It is an intrinsic quality of a structure and it does not depend on location.
- **Economic vulnerability**: the potential impacts of hazards on economic assets and processes (i.e. business interruption, secondary effects such as increased poverty and job loss) Vulnerability of different economic sectors,
- **Social vulnerability**: the potential impacts of events on groups such as the poor, single parent households, pregnant or lactating women, the handicapped, children, and elderly; consider public awareness of risk, ability of groups to self-cope with catastrophes, and status of institutional structures designed to help them cope.
- **Environmental vulnerability**: the potential impacts of events on the environment.

Coping capacity and resilience.
Besides vulnerabilities, elements at risk posses also capacities to cope with hazards. A large variety of definitions exist on capacity, coping and resilience, which are used in the different models of vulnerability and risk.

"**Capacity** is a combination of all strength and resources available within a community or organization that can reduce the level of risk, or the effect of a disaster. It may include physical, institutional, social or economic means as well as skilled personal or collective attributes such as leadership and management. Capacity may also be described as capability" (UN-ISDR, 2004)

In general, this involves managing resources, both in normal times as well as during crises or adverse conditions. Some examples of capacity are:

- Ownership of land;
- Provisions made in advance to pay for potential damages for instance by mobilizing insurance repayments, savings or contingency reserves
- Adequate food and income sources;
- Family and community support in times of crisis;
- Local knowledge;
- Good leadership & management.

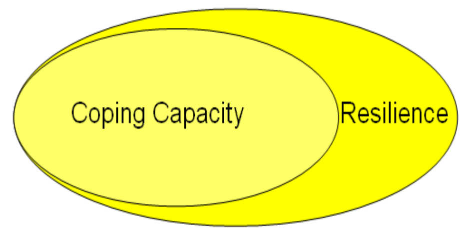


Figure 5.3 Coping capacity and resilience. Source: (Thywissen 2006)

The strengthening of coping capacities usually builds resilience to withstand the effects of natural and human-induced hazards. According to Thywissen (2006) resilience is in general a more encompassing term than coping capacity (See figure 5.3).

Definitions of resilience / resilient

- "Resilience is the capacity of a system, community or society potentially exposed to hazards to adapt, by resisting or changing in order to reach and maintain an acceptable level of functioning and structure. This is determined by the degree to which the social system is capable of organizing itself to increase its capacity for learning from past disasters for better future protection and to improve risk reduction measures".(UN-SDR 2004) See also : http://www.undp.org/cpr/disred/documents/publications/rdr/english/glossary.pdf
- "Not just the absence of vulnerability. Rather it is the capacity, in the first place, to prevent or mitigate losses and then, secondly, if damage occurs to maintain normal living conditions and thirdly, to manage recovery from the impact". (Buckle et al., 2000)
- "Resilience is the flip side of vulnerability – a resilient system or population is not sensitive to climate change and has the capacity to adapt" (IPCC 2001)
- "Resilience to disasters means a locale can withstand an extreme natural event with a tolerable level of losses. It takes mitigations actions consistent with achieving that level of protection" (Mileti 1999) in: K. Thywissen in Birkmann 2006

Task 5.1: Vulnerability, coping capacity and resilience (duration 10 minutes)

After reading the definitions of vulnerability, coping capacity and resilience, determine for yourself what the main differences are.

5.3 Conceptual frameworks of vulnerability

In the last decades different frameworks on vulnerability were developed. In this section we will look at a number of them. A good overview is given by Birkmann, 2006.

5.3.1 The Double Structure of Vulnerability:
Chambers (1989) defined an external and internal side of vulnerability. The external side: related to exposure to external shocks and stresses; and the internal side: associated with defenselessness, incapacity to cope. Shocks relate to often sudden and sometimes unpredictable events like, floods, earthquakes, epidemics, etc. Stresses, in contrast, relate to shortages, declining resources etc. They refer to pressures which are typically continuous, cumulative and more predictable, such as seasonal. At the livelihood level, vulnerability can be related to assets and how people manage them. But assets such as labour and human capital, although vulnerable, are also the key elements in coping with shocks and stresses. Bohle (2001) expanded on the concept of vulnerability of Chambers. Vulnerability is seen as having two sides: an internal side and an external side (see figure 5.4). The external side related to the **exposure to risks** and shocks and is influenced by *Political Economic approaches* (e.g. social inequalities, assets control by upper classes), *Human Ecology Perspectives* (population dynamics and capacities to manage the environment) and the *Entitlement Theory* (relates vulnerability to the incapacity of people to obtain or manage assets via legitimate economic means). The internal side is called **coping** and relates to the capacity to anticipate, cope with, resist and recover from the impact of a hazard and is influenced by the *Crisis and Conflict Theory* (control of assets and resources, capacities to manage crisis situations and resolve conflicts), *Action Theory Approaches* (how people act and react freely or as a result of societal, economical or governmental constraints) and *Models of Access to Assets* (mitigation of vulnerability via access to assets) .

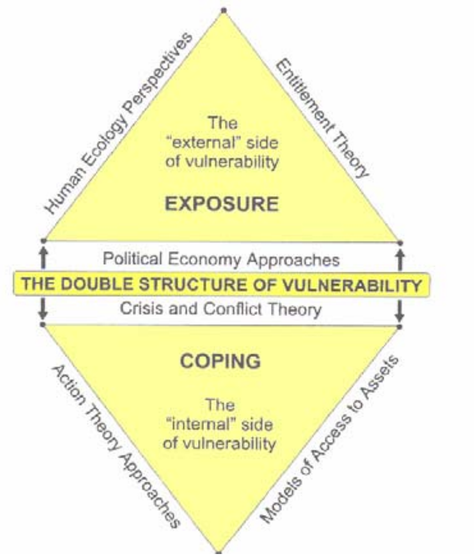


Figure 5.4 Bohle's conceptual Framework for vulnerability analysis. (Source: Bohle, 2001 in Birkmann, 2006)

The concept indicates that vulnerability cannot adequately be characterized without considering coping and response.

5.3.2 Vulnerability is defined as a component within the context of risk.
In the conceptual framework of Davidson, adopted by Bollin et al 2003, risk is seen as the sum of hazard, exposure, vulnerabilities and capacity measures. Hazard is characterized by probability and severity; exposure elements are structures, population and economy; capacity and measures is concerned with physical planning, management, social- and economic capacity (see figure 5.5).

Figure 5.5: Conceptual framework to identify disaster risk. (Source: Davidson, 1997; Bollin et al.,2003)

5.3.3 The school of climate change.

This school developed the Risk-Hazard (RH) model (Turner, Kasperson et al., 2003). In this model the impact of a hazard is seen as a function of exposure of a system to the hazard event and the response of the system as shown in figure 5.6 where the concept of vulnerability is commonly implicit.

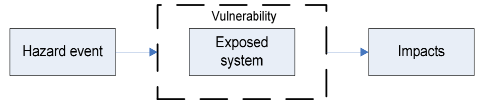


Figure 5.6 RH model (Source: Turner et al., 2003)

A more elaborate model of Turner et al., 2003; is given in figure 5.7. The model / system operates at multiple spatial (the world, region and place), functional and temporal scales, where interactions take place. Vulnerability is registered not by exposure to hazards (perturbations and stresses) alone but also resides in the sensitivity and resilience of the system experiencing such hazards (Turner et al., 2003) (see figure 5.7). The sensitivity to exposure is defined by the human-environmental conditions. The human-environmental conditions e.g. social and biophysical capital, influence the coping mechanisms, when the impact is experienced, also influencing the coping mechanisms adjusted or created because of the experience (Turner et al, 2003). In some cases coping responses lead to adaptation and changes in the human-environmental conditions.

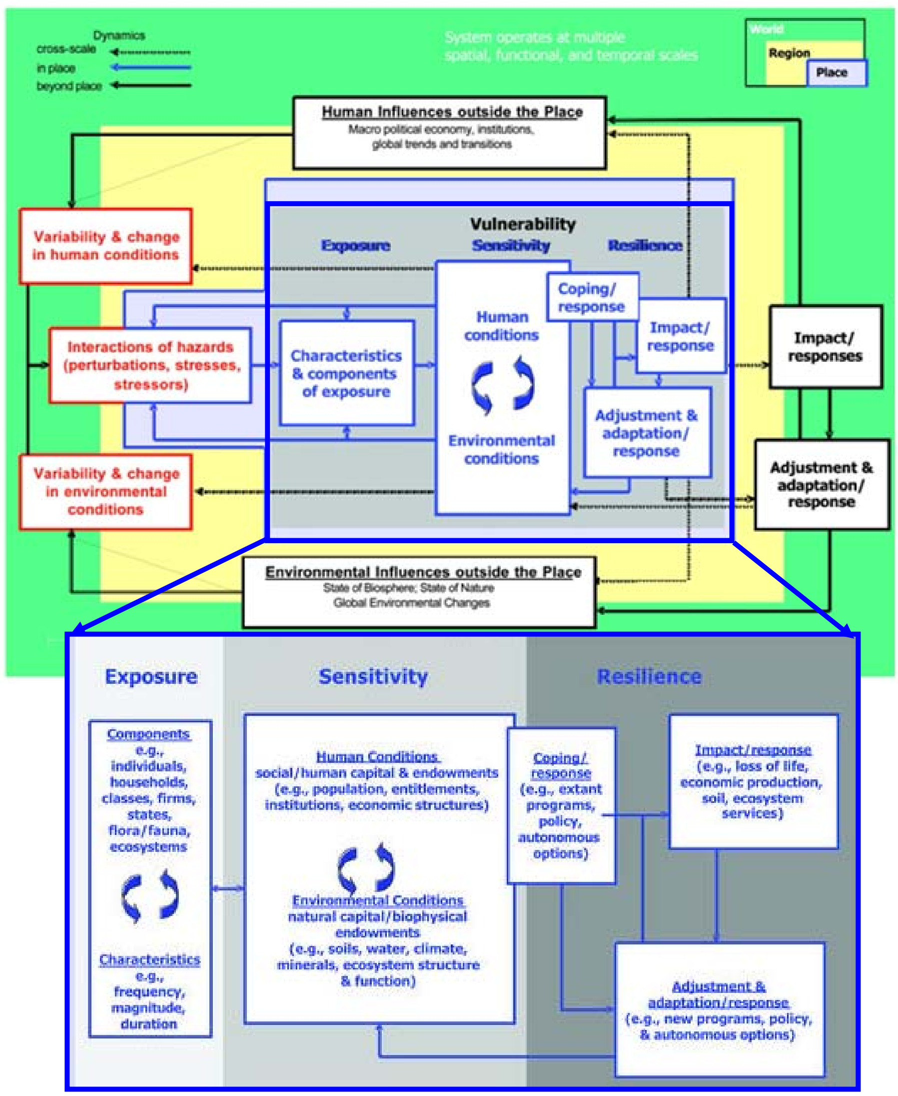


Figure 5.7: Vulnerability framework: multiscale (Source:Turner et al, 2003: http://www.pnas.org/content/100/14/8074.full.pdf+html)

5.3.4 Pressure and Release (PAR) Model:

Blaikie et al (1994) and Wisner et al., 2004 presented the Pressure and Release (PAR) model that shows vulnerability as a social product of a chain of factors. Disasters are caused by opposing forces, on the one hand by a progression of vulnerability, from root causes to dynamic pressures to unsafe conditions and by the hazard event on the other hand (figure 5.8). Vulnerability is defined as the characteristics of a person or group in terms of their capacity to anticipate, cope with, resist and recover from impacts of a hazard.

Livelihood is defined as the command an individual, family or other social group has over an income and/or bundles of resources that can be used or exchanged to satisfy its needs.

The aim is to understand and explain the disasters that people face caused by hazard events, like floods and earthquakes etc. The vulnerability can be caused for instance by limited access to resources or causes of political & social background, not just directly related to the hazard event itself. The release idea, the reduction of disaster: to relieve the pressure, vulnerability has to be reduced and even address the underlying causes.

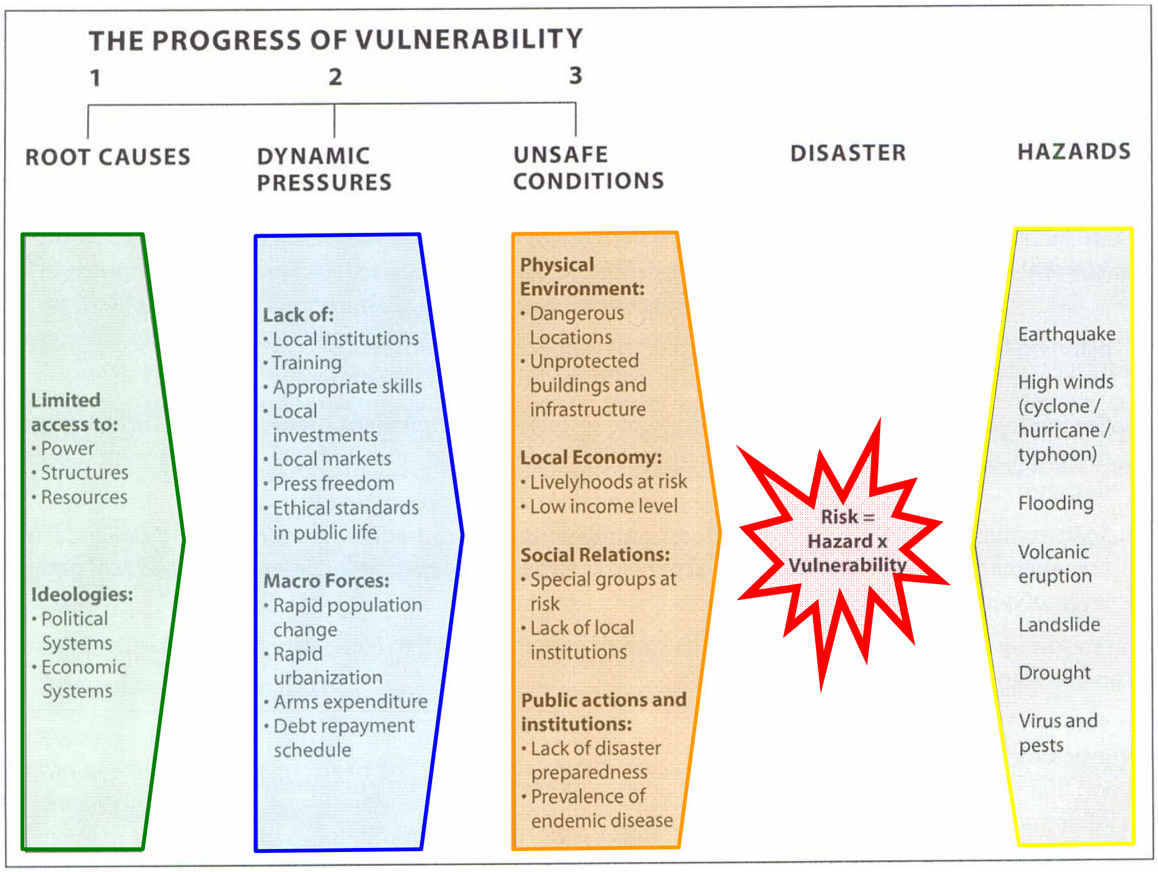


Figure 5.7 The PAR model (Source: Blaikie, Cannon et al, 1994)

Root causes are related to economic, demographic, and political processes as a function of economic structure, legal definitions of rights, gender relations, and other elements of the ideological order and reflect the distribution of power in a society (Blaikie, Cannon et al. 1994). Dynamic pressures are processes and activities that 'translate" the effects of root causes into the vulnerability of unsafe conditions (Blaikie, Cannon et al. 1994). Unsafe conditions: are the specific form in which vulnerability of a population is expressed in time and space in conjunction with a hazard (Blaikie, Cannon et al. 1994). According to Blaikie et al, key characteristics of vulnerable groups in society are socioeconomic group, caste, ethnicity, gender; disability; age and seniority.

5.3.5 Pelling model

In the framework for vulnerability proposed by Pelling (2003) human vulnerability is defined by: exposure, resistance and resilience. Exposure is related to the location and characteristics of the hazard; resistance is related to the economical, psychological, and physical health, as well as the capacity of individuals or communities to withstand the impact of the event and is related with livelihoods; resilience is defined as the ability to cope with or adapt to the hazard stress through preparedness and spontaneous adaptations once the event has manifested itself.

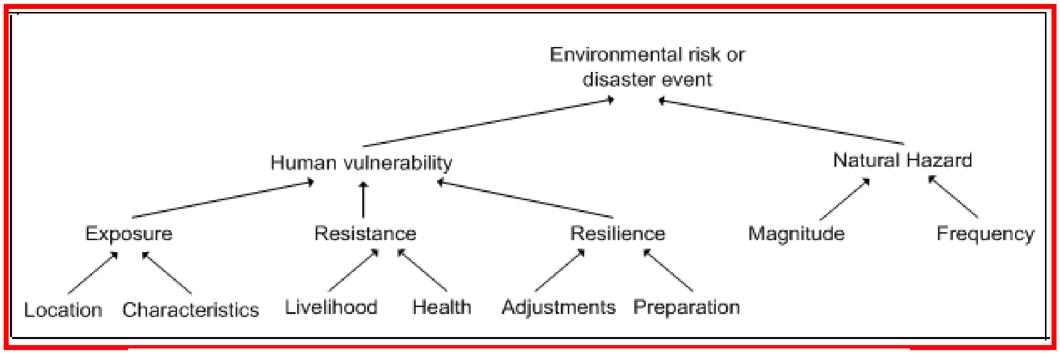


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Figure 5.8: Exposure, resistance, resilience model (Pelling, 2003)

5.3.6 UNU –EHS: BBC framework.

The United Nations University - Institute for Environment ad Human Security (UNU-EHS) developed two frameworks for vulnerability. The onion framework (Bogardi and Birkmann 2004), has a natural event sphere, an economic (monetary) sphere and a social (disutility sphere) crossed by an "opportunity"(or probability) axis and a "reality" axis (certainty). The BBC frame-work (figure 5.9) is a combination of existing models, and is mainly based on the conceptual work of Bogardi and Birkmann (2004) and Cardona (1999). According to the authors it tries to link vulnerability, human security and sustainable development. It underlines the need to view vulnerability as dynamic, focusing on vulnerabilities, coping capacities and potential intervention tools to reduce it (feedback-loop system) (Birkmann, 2006). Environmental, social and economic spheres are considered in defining vulnerability, coping capa-cities, risk and their vulnerability/risk reduction measures.

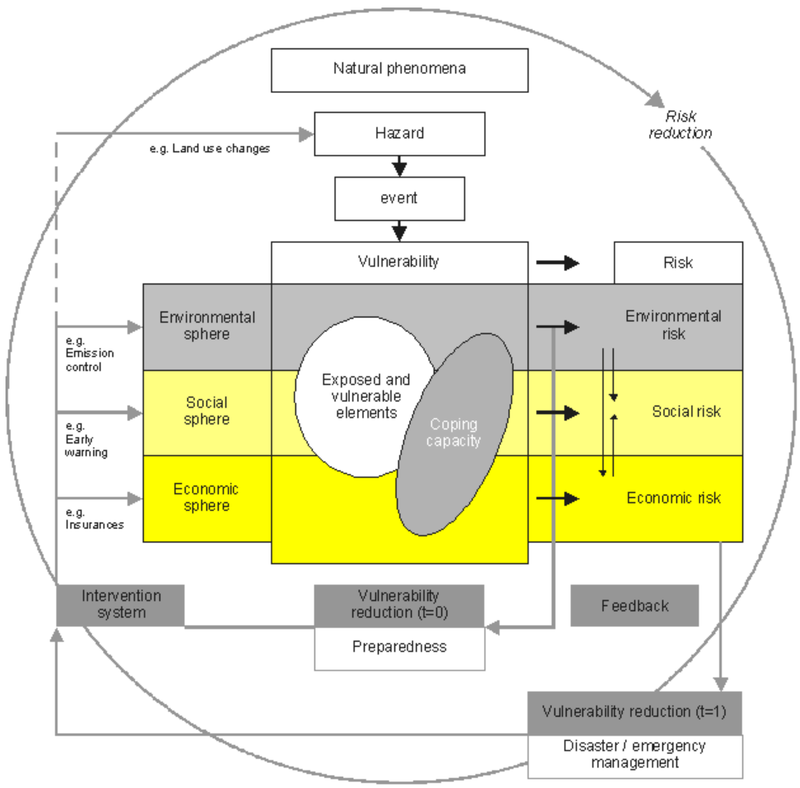


Figure 5.9: The BBC conceptual framework. (Source: Bogardi and Birkmann, 2004)

The conceptual models described above are mainly tools for explaining vulnerability, and for awareness purposes, but have limited use for measuring vulnerability. There exist limited guidelines on how to assess the different components.

5.4 Types of losses and vulnerability

There are many different types of losses that can be evaluated. These can be either direct or indirect, and can be human-social, physical, economic and cultural/environmental. Table 5.1 gives an overview with examples. The ones indicated in red are those that are most frequently evaluated.

	Human - social	Physical	Economic	Cultural Environmental
Direct losses	• Fatalities • Injuries • Loss of income or employment • Homelessness	• Structural damage or collapse to buildings • Non-structural damage and damage to contents • Structural damage infrastructure	• Interruption of business due to damage to buildings and infrastructure • Loss of productive workforce through fatalities, injuries and relief efforts • Capital costs of response and relief	• Sedimentation • Pollution • Endangered species • Destruction of ecological zones • Destruction of cultural heritage
Indirect losses	• Diseases • Permanent disability • Psychological impact • Loss of social cohesion due to disruption of community • Political unrest	• Progressive deterioration of damaged buildings and infrastructure which are not repaired	• Economic losses due to short term disruption of activities • Long term economic losses • insurance losses weaken-ing the insurance market • Less investments • Capital costs of repair • Reduction in tourism	• Loss of biodiversity • Loss of cultural diversity

Table 5.1: Overview of types of losses

Factors to be considered in vulnerability quantification are:

- Different elements at risk with their characteristics:
- Different types of vulnerability: physical, social, economical, environmental.
- Different levels of scale. Different levels of scale require often different methods. E.g. in the analytical models the data requirement increases with more complex methods.
- Different hazard types. Not all methods of vulnerability quantification are used for the different hazard types.
- Different hazard intensities and indicators for hazard intensity. Table 5.2 gives an overview of indicators for 3 hazard types.

Flooding	**Landslides**	**Earthquakes**
Water depth Flow velocity Flow duration Wave height Time of onset Water-level ascend rate	Ground movement-displacements Velocity of ground movement Run-out distance Impact forces from rock falls	Mercalli intensity Peak ground acceleration Peak ground velocity Permanent ground displacement Spectral acceleration

Table 5.2: Hazard indicators that can be used in vulnerability assessment

Task 5.2: Linking loss types with vulnerability quantification (15 minutes)

Compare the losses indicated in table 5.1, the vulnerability factors that are in table 5.2, the elements at risk information discussed in session 2.
Is it possible to make vulnerability quantifications for indirect losses? Select one of the loss categories in table 5.1 and think of a way how these could be analyzed using the hazard indicators in table 5.2.

5.5 Expressing vulnerability

Vulnerability can be expressed or presented in various ways.

Vulnerability indices based on indicators of vulnerability; mostly no direct relation with the different hazard intensities. These are mostly used for expressing social, economic and environmental vulnerability. See also 5.5.

Vulnerability curves that are constructed on the basis on the relation between hazard intensities and damage data. They provide a relation in the form of a curve, with an increase in damage for a higher level of hazard intensity. Different types of elements at risk will show different levels of damage given the same intensity of hazard. This is illustrated in figure 5.10, where the red line indicates an element at risk with a lower vulnerability than the green line. This method is mostly applied for physical vulnerability. Vulnerability curves are also named damage functions, or stage-damage curves. Vulnerability curves can be subdivided into two types:

- **Relative curves**: they show the percentage of property value as the damaged share of the total value to hazard intensity.
- **Absolute curves**: show the absolute amount of damage depending on the hazard intensity; i.e. the value of the asset is already integrated in the damage function.

Fragility curves provide the probability for a particular group of element at risk to be in or exceeding a certain damage state under a given hazard intensity. In figure 5.10 there are four damage states defined (complete destruction, extensive damage, moderate damage, and slight damage). Given a particular level of hazard intensity, these four stages have different probabilities. For instance the left dotted line has 0 probability to be moderately damaged or worse. The middle dotted line indicated that the chance of being slightly damaged or more is very high, whereas the chance of complete damage is still 0. Fragility curves are used often in earthquake loss estimation, mostly for physical loss estimation.

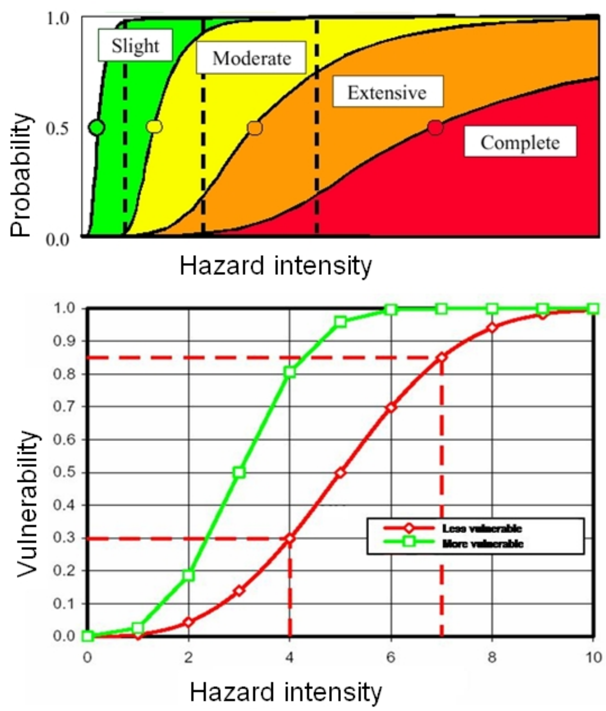


Figure 5.10: Fragility curves (above) and vulnerability curve (below)

Vulnerability table: the relation between hazard intensity and degree of damage can also be given in a table. In that case the smooth vulnerability curve is actually divided into a number of hazard intensity classes, and for each class the corresponding degree of damage is given. This is frequently done in earthquake vulnerability when the hazard intensity is expressed as Modified Mercalli Intensity, which is an ordinal scale that doesn't have intermediate values between two intensities.

Task 5.3: Methods for expressing vulnerability (10 minutes)

What are the pro's and cons of relative and absolute damage functions?
Can you think of an example for these for a particular hazard type?

5.6 Measuring physical vulnerability

Measuring physical vulnerability is increasingly seen as an effective step towards risk reduction and the promotion of a culture of disaster resilience (Kasperson et al., 2005). Also the Hyogo Framework for Action stresses the need to develop indicators of vulnerability as a key activity, and underlines the fact that the impacts of disasters on social , economic and environmental conditions must be examined through such indicators (*http://www.unisdr.org/eng/hfa/hfa.htm*). Since vulnerability is, multi-dimensional, dynamic in time, scale-dependent and site-specific, different indicators are selected in the different vulnerability assessments studies. In the text below a number of methods are presented. We will concentrate here on methods used for measuring physical and social vulnerability.

5.6.1 Methods for physical vulnerability assessment

Physical vulnerability refers to the potential for physical impact on the built environment and population. This aspect is relatively "easily" quantified because it depends directly on the physical impact of a hazard event and relates to the characteristics of the element at risk and the intensity and magnitude of the hazard. See also Figure 1.12.

Group	Method	Description
Empirical methods	**Analysis of observed damage**	Based on the collection and analysis of statistics of damage that occurred in recent and historic events. Relating vulnerability to different hazard intensities.
	Expert opinion	Based on asking groups of experts on vulnerability to give their opinion e.g. on the percentage damage they expect for the different structural types having different intensities of hazard. In order to come to a good assessment of the vulnerability, many experts have to be asked and this is time consuming, and subjective in general. Re-assessments of vulnerability after building upgrading or repair are difficult to accommodate.
	Score Assignment	Method using a questionnaire with different parameters to assess the potential damages in relation to different hazard levels. The score assignment method is easier to update e.g. if we think about earthquake vulnerability before and after application of retrofitting.
Analytical models	**Simple Analytical models**	Studying the behavior of buildings and structures based on engineering design criteria, analyzing e.g. seismic load and to derive the likelihood of failure, using computer based methods from geotechnical engineering. Using e.g. shake tables and wind tunnels, as well as computer simulation techniques.
	Detailed Analytical methods	Using complex methods. It is time consuming, needs a lot of detailed data and will be used for assessment of individual structures.

Table 5.3: Overview of methods used for measuring physical vulnerability

Figure 5.11 gives a schematic overview of the methods used for physical vulnerability assessment

Expenditure	Increasing computational effort →				
Application	Building stock				Individual buildings
Methods	Observed Vulnerability	Expert Opinions	Simple Analytical Methods	Score Assignments	Detailed Analysis procedures

Figure 5.11: Methods for the assessment of vulnerability of elements at risk (Lang 2002. Source: BRGM, 2005)

Task 5.4: Vulnerability methods (duration 10 minutes)

Consider which of the methods would be most appropriate to use for obtaining vulnerability information in the following cases:

- *A national scale flood loss assessment in a situation where no prior flood data is available.*
- *The analysis of the vulnerability of hospitals in an earthquake threatened city.*
- *Landslide vulnerability assessment in an urban area with frequent landslides.*

Direct observations

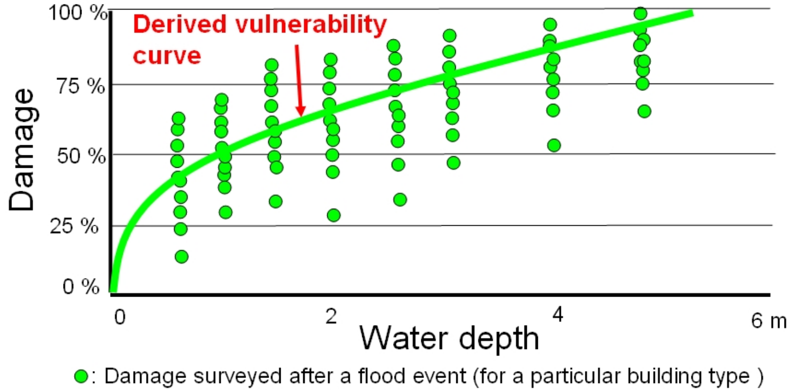


Figure 5.12: Illustration of the use of damage surveys for the generation of vulnerability curves.

For events that are relatively frequent and widespread it is possible to collect information on the degree of physical damage to buildings or infrastructure after the event has occurred. This method is particularly suited for flooding and for earthquakes, which normally affect many buildings that are of the same type, and allow to generate large enough samples in order to make a correlation between the intensity/magnitude of the hazard (e.g. modified mercalli intensity, ground acceleration, water depth etc) in order to make a statistical correlation with the degree of damage and derive a vulnerability curve. Figure 5.12 gives an illustration of the principle. The range of damage results for the same intensity depends on the definition of the building types. If the building types are very similar, also the degree of damage that will be observed is more similar than for buildings that have a large variation within the group.

Damage assessment can be done using different tools:

- Remote Sensing can be useful for mapping the extent of the hazard phenomena, especially in the case of flooding. This, in combination with information from a Digital Elevation Model, and from a flood model (See session 3) allows you to obtain a good idea of the flood extent and the flood parameters (depth especially). Satellite images, aerial photographs, etc taken during the disaster event, or shortly after are important inputs.
- In some cases rapid monitoring using video cameras might be a good tool , especially for the rapid mapping of earthquake damage (see figure 5.13)
- For the assessment of damage Participatory GIS approaches can be a very useful tool, as mentioned in session 4.
- Existing data bases: Munich Re and Swiss Re data bases for natural catastrophes MR NatCat SERVISE

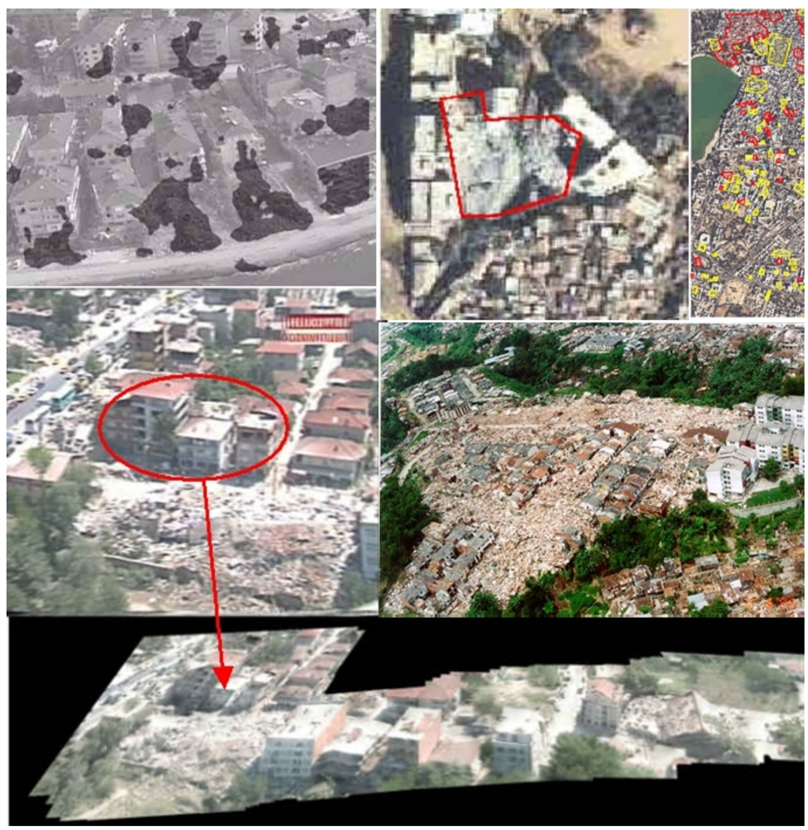


Figure 5.13: different approaches for using Remote Sensing data for rapid damage assessment, such as video images, oblique photographs, and high resolution satellite imagery (Source: Derya Osirik, ITC MSc student)

(NatCat) includes more than 20,000 entries on material and human loss events worldwide (Munich Re,2003)

- In most of the cases however, detailed damage surveys need to be carried out with the help of checklists.

Task 5.5: RiskCity exercise: derivation of vulnerability curves using damage data (duration 2 hours)

In this exercise you will analyze damage data from RiskCity which has been collected using Participatory mapping after a major flood event. The input for the analysis consists of a point map in GIS, which is linked to a table. The table looks like the one below.

X	*Y*	*Building type*	*Flood height*	*Damage*
		Wood		
		Masonry		

The aim of this exercise is to make vulnerability curves for buildings present in the area

Go to the exercise book and follow the instructions there.

Expert Opinion

In many situations expert opinion will be the most feasible option for obtaining vulnerability information, either because there is no prior damage information, not enough funding to apply analytical methods or because building classifications used elsewhere do not reflect the local building stock and a local classification is then deemed more appropriate. This method involves the consultation of a group of experts on vulnerability to give their opinion e.g. on the percentage damage they expect for the different structural types having different intensities of hazard. In order to come to a good assessment of the vulnerability, many experts have to be asked and this is time consuming, and subjective in general. Re-assessments of vulnerability after building upgrading or repair are difficult to accommodate.

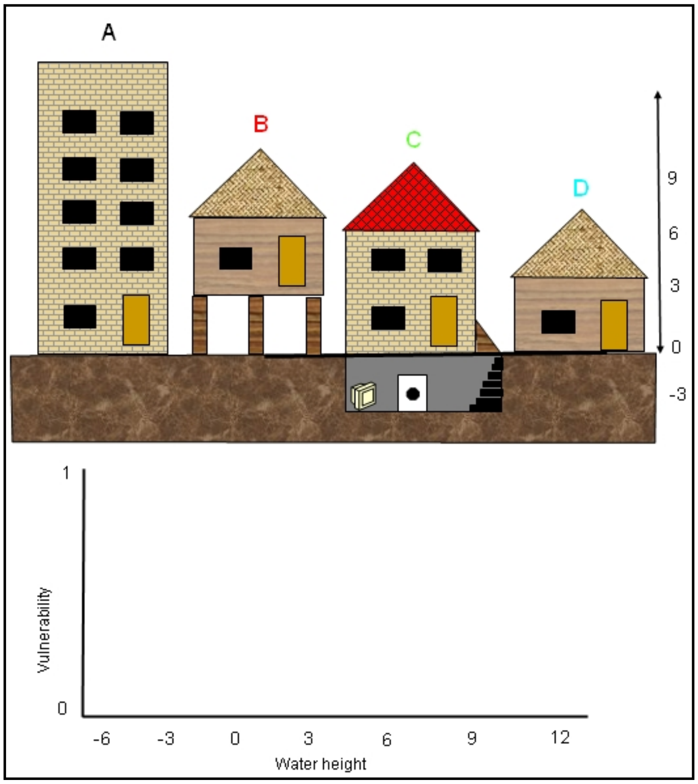


Figure 5.14: It is possible to make a reasonable estimate of the vulnerability of these 4 buildings.

Task 5.6: Expert opinion in generating a vulnerability curve (duration 15 minutes)

In the figure above there are 4 different buildings, each with different characteristics. Imagine the flood will take place in the area, and the waterlevel is rising slowly but constantly. How would the four buildings be affected?
Draw 4 approximate vulnerability curves in the graph.

Analytical methods

Analytical methods study the behavior of buildings and structures based on engineering design criteria, analyzing e.g. seismic load and derive the likelihood of failure, using computer based methods from geotechnical engineering. Analytical methods use for example shake tables and wind tunnels, as well as computer simulation techniques. In the analytical methods the information on the intensity of the hazard should be also more detailed. For instance in the case of earthquake vulnerability analysis of buildings it is important to have geotechnical reports to establish the value of the effective peak acceleration coefficient, the value of the effective peak velocity-related acceleration coefficient and the soil profile type. Also spectral acceleration should be obtained. One of the commonly used tests is done with a shake table. This is a device for shaking structural models or building components with a wide range of simulated ground motions, including reproductions of recorded earthquakes time-histories.

Task 5.7: Watch Shaketable test on Youtube (duration 15 minutes)

There are many examples on the Internet of shaketests with building models on shaketable, to investigate the behaviour of buildings under different earthquake accelerations.
For instance:
The collapse of an adobe building:
http://www.youtube.com/watch?v=AL7Kh31tB2M&NR=1
Collapse of conventional wooden building:
http://www.youtube.com/watch?v=kc652Zp5qWk&feature=related
Woodframe building, very flexible:
http://www.youtube.com/watch?v=otyLaENTkHE&feature=related
See the softstory effect in a 6 floor building:
http://www.youtube.com/watch?v=3z4YLUqOysI&feature=related
Very large simulation with realsize RCC building:
http://www.youtube.com/watch?v=O2XMfOXVOvo

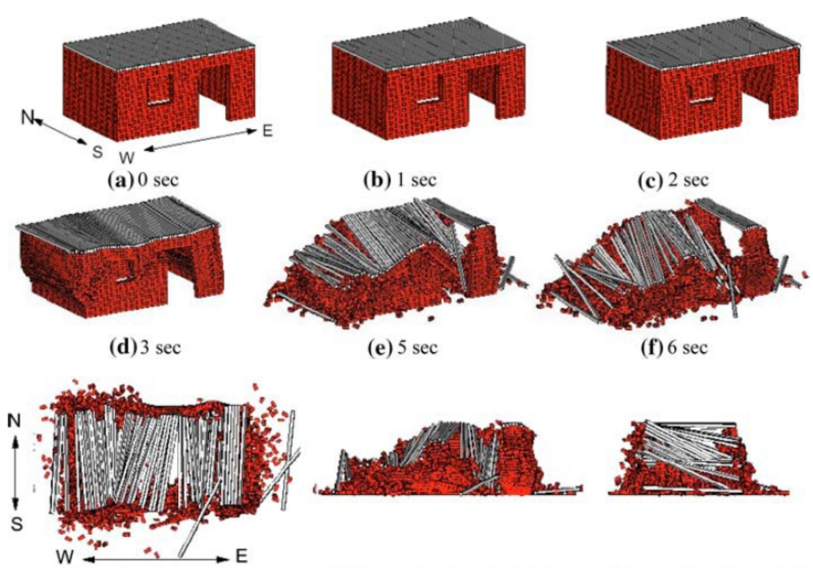


Figure 5.15: Example of a numerical simulation of a masonry building under an earthquake, comparable to the Bam earthquake (Source: Furukawa and Ohta, 2009)

In combination with shake table tests, building behavior is increasingly modelled with the aid of computer simulation programmes, with for instance finite element methods. For example Figure 5.15 shows an example of the modeled collapse of masonry structures during an earthquake which has been analyzed using a three-dimensional distinct element method. This is a numerical analysis technique, in which positions of elements are calculated by solving equations of motion step by step. Both individual and group behavior can be simulated. The structure is modeled as an assembly of distinct elements connected by virtual springs and dashpots, where elements come into contact.

5.6.2 Earthquake vulnerability assessment.

Earthquake vulnerability curves are generated using any of the methods indicated in table 5.3. They differ in terms of the hazard indicator used and the building types. Vulnerability curves have been generated for many parts of the world (See figure 5.16)

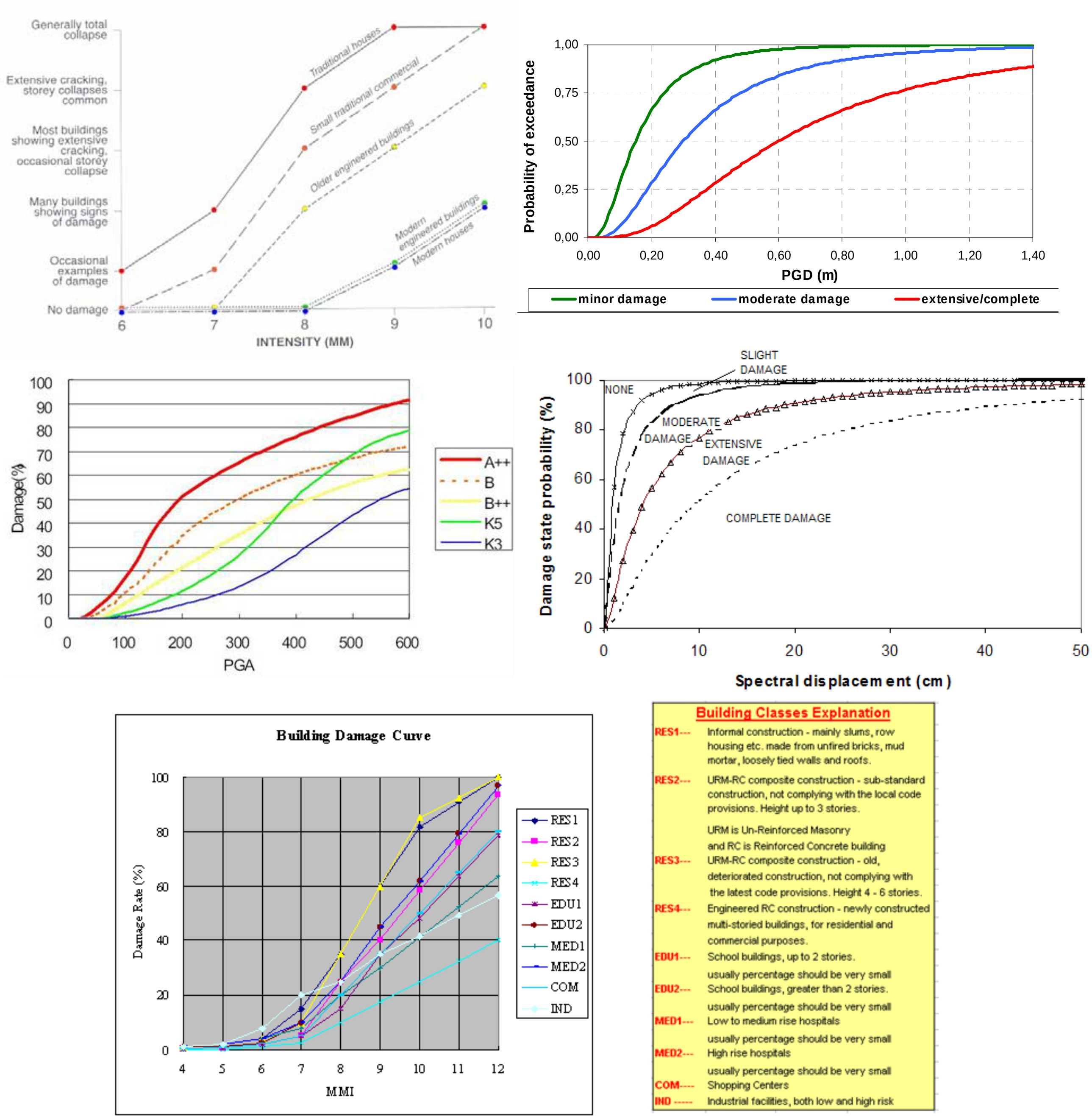


Figure 5.16 Different types of vulnerability and fragility curves for earthquakes. Upper right: general relationships between earthquake intensity on the Modified Mercalli scale and building damage based on the effects of the 1995 Kobe earthquake (Source: Alexander Howden Group Ltd and institution of Civil Engineers 1995). Upper right: fragility curve for roads in Greece (Source: Pitilakis, Greece) Middle left: Relationship between Peak Ground Acceleration and damage for typical building types in Nepal (Source: NSET, Nepal). Middle right: fragility curves for building based on spectral displacement (Source: HAZUS). Below: building damage curves and building classification as used in the Radius method for earthquake loss estimation.

Different buildings can respond in widely differing manners to the same earthquake ground motion. Conversely, a given building will act differently during different earthquakes. This phenomenon highlights the need to concisely represent the building's range of responses to ground motion of different frequency contents. Such a representation is known as a response spectrum. A response spectrum is a graph that plots the maximum response values of acceleration, velocity and displacement against period and frequency (see figure 5.17). Such response spectra are very important in earthquake engineering.

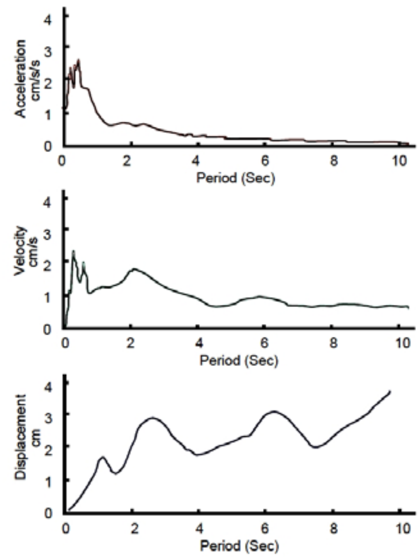
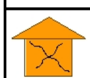


Figure 5.17: Simplified response spectra (Source: Montoya, 2003)

The HAZUS methodology for earthquake loss estimation makes use of the response spectra. The site-dependent response spectrum of the ground motion is employed as a demand spectrum in the method. The methodology uses a technique to estimate inelastic building response as the intersection of the building capacity curve and the response spectrum of shaking demand at the building's location (demand spectrum). It uses a building capacity curve , which is a plot of a building's lateral load resistance as a function of a characteristic lateral displacement (i.e., a force-deflection plot). For each type of building a fragility curve is made. Each fragility curve is defined by a median value of the demand parameter (e.g., spectral displacement) that corresponds to the threshold of that damage state and by the variability associated with that damage state. See figure 5.18.

s

Damage State		Description
	**Slight**	Small plaster cracks at corners of door and window openings and wall-ceiling intersections; small cracks in masonry chimneys and masonry veneers. Small cracks are assumed to be visible with a maximum width of less than 1/8 inch (cracks wider than 1/8 inch are referred to as "large" cracks).
	**Moderate**	Large plaster or gypsum-board cracks at corners of door and window openings; small diagonal cracks across shear wall panels exhibited by small cracks in stucco and gypsum wall panels; large cracks in brick chimneys; toppling of tall masonry chimneys.
	**Extensive**	Large diagonal cracks across shear wall panels or large cracks at plywood joints; permanent lateral movement of floors and roof; toppling of most brick chimneys; cracks in foundations; splitting of wood sill plates and/or slippage of structure over foundations.
	**Complete**	Structure may have large permanent lateral displacement or be in imminent danger of collapse due to cripple wall failure or failure of the lateral load resisting system; some structures may slip and fall off the foundation; large foundation cracks. Three percent of the total area of buildings with Complete damage is expected to be collapsed, on average.

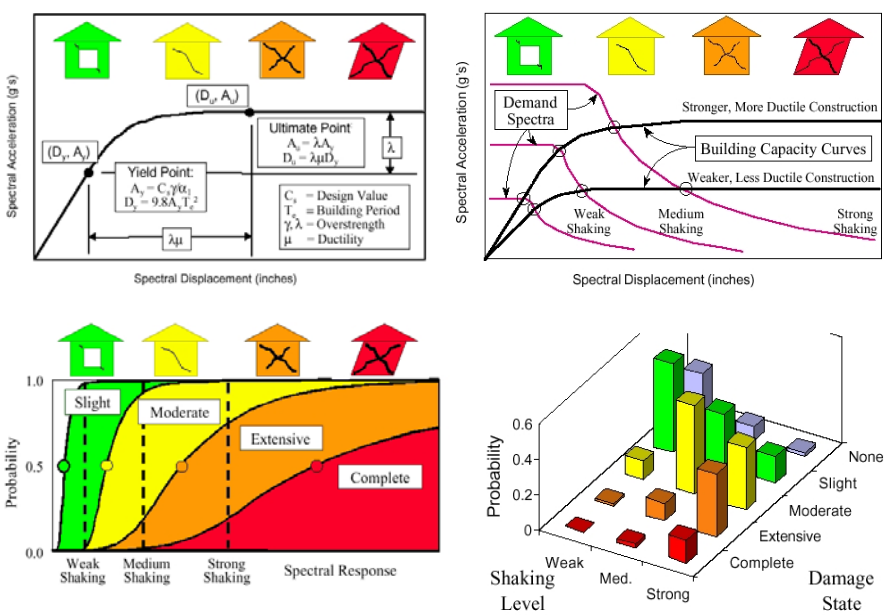


Figure 5.18: HAZUS method for earthquake loss estimation of buildings.

5.6.3 Flood vulnerability assessment

Flood damage functions describe the relationship between hydraulic parameters and the relative damage or damage factor of the element at risk. Three different scale levels are defined micro, meso and macro. Figure 5.19 indicates the relation of the relevant food model with the relavant damage function scale level.

Below 3 examples are given on the use of vulnerability information in flood risk assessment.

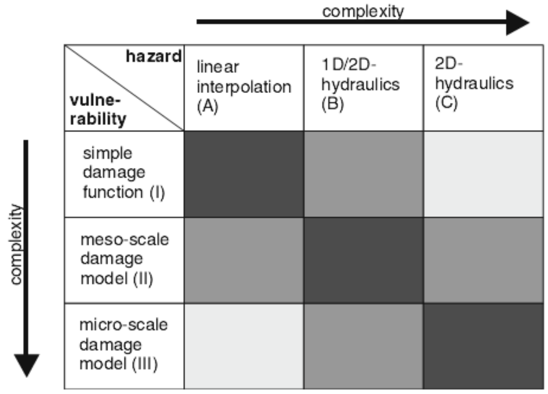


Figure 5.19: The comparative model matrix. Dark colours represent match in complexity, light colours a mismatch. (Source: Apel et al, 2009.)

Flood example 1: United Kingdom Flood data base and damage functions of the Flood Hazard Research Centre (FHRC) from Middlesex University.

This method deals with the derivation of damage curves from synthetic damage data. The main variables used are: depth of flood water within the buildings and the depth and extent of floodwater on the floodplain. Velocity is assumed to cause in rare cases structural failure. The data base has 100 residential and more than ten non residential property types. Costs relate to restoration to pre-flood conditions, but do not always allow for full replacement. Absolute damage functions are used.

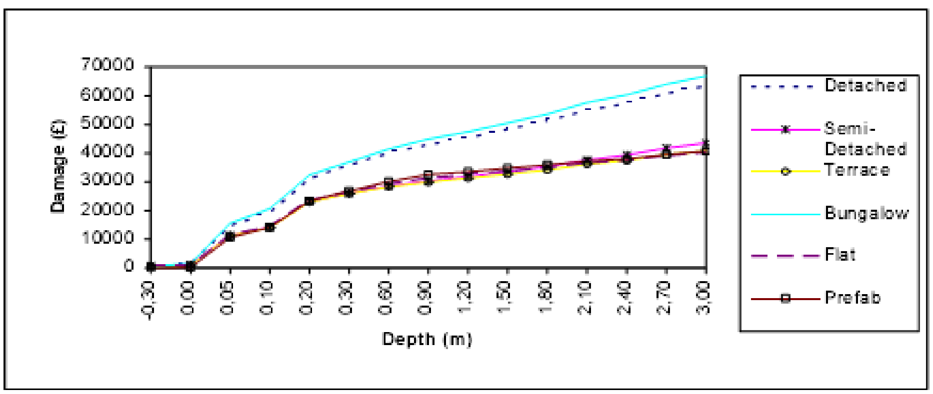


Figure 5.12 Synthetic depth-damage curves for different residential house types (Source: Penning-Rowsell et al. 2003).

Flood example 2: HOWAS data base from Germany and derived damage functions.

This is a typical example of the use of actual (observed) flood damage data. Nine flood events are considered over a period between 1978 and 1994. The assessment of damages was carried out by insurance adjusters and can be interpreted as replacement costs. Howas derived absolute depth-damage functions. An example of a HOWAS damage function is indicated in figure 5.13. With expert knowledge the function can be made suitable for different building structural types. If you can read German it might be worthwhile to visit the website: http://nadine-ws.gfz-potsdam.de:8080/howasPortal/client/start\

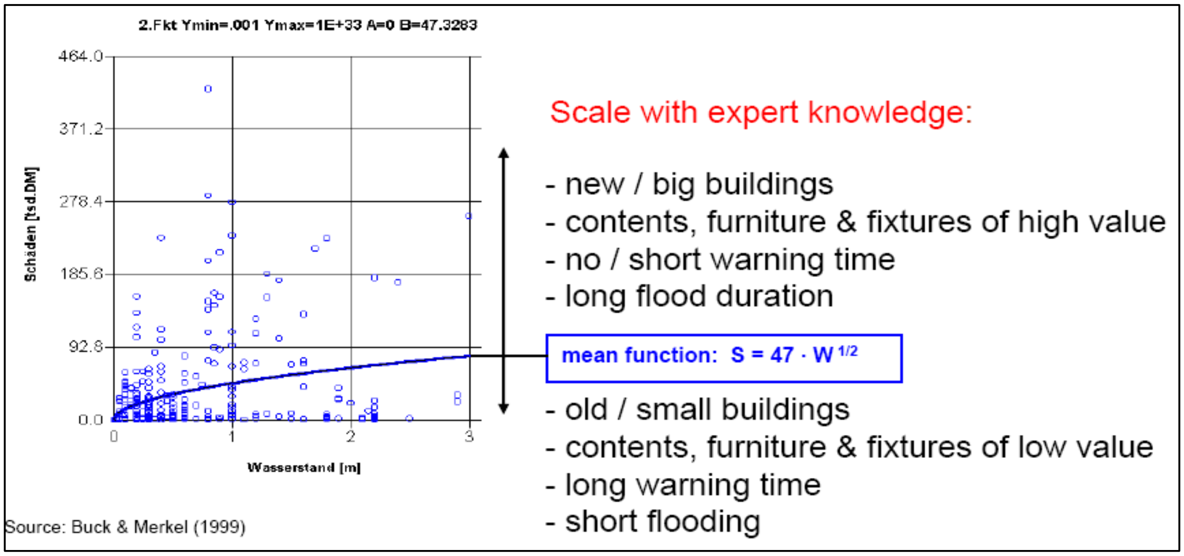


Figure 5.13 Example for a damage function from the HOWAS database.

Flood example 3: Damage functions of the Dutch Standard Method

This method has been developed for the typical type of flooding in the Netherlands: inundation of polder areas.

Flood characteristics are defined by using 1D/2D hydraulic models that require detailed digital elevation models and dike breach scenario's (where the dike breaches, how large is the breach, how fast the water enters). Here the output are time-series maps of water depth and flow velocity. Especially inundation depth is needed for the damage evaluation. In case of residential buildings impacts of velocity and waves are also considered. Regarding casualties, three different inundation characteristics are taken into account: velocity, rise rate and inundation depth. The method uses land use data in a grid of 100 by 100 meter for the entire country, which is made from a mix of different data sources. Official aggregated land use data is supplemented by geomarketing data on buildings and employees in economy, as well as by official data on the street and railway network.

The Dutch standard method (2004) has eleven relative depth-damage functions which are derived synthetically and are based on both damage data and expert judgment. The damage functions are mostly depth-damage functions. Only the damage factor for residential buildings additionally takes into account a critical velocity of inundation and the impact of waves caused by storms (Kok et al. 2004). The method is developed for meso-scale and uses aggregated land use data (See http://www.floodsite.net/) . Damage categories considered are buildings, population, infrastructure, cars and agriculture. Damage is calculated for each grid cell using a dedicated software (HIS-SSM) with GIS capabilities. Examples of the damage function are given in figures 5.14, respectively for low- rise dwellings, intermediate dwellings and high rise dwelling.

Task 5.8: Evaluate European flood vulnerability assessment methods (20 minutes)

Read the following material: Floodsite report: Evaluating flood damages: guidance and recommendations on principles and methods. Chapter 3.section3.4.4.2 and section 3.6 Messner F. et al 2007. You can find it in background reading or online:

www.floodsite.net/html/partner_area/project_docs/T09_06_01_Flood_damage_guidelines_D9_1_v2_2_p44.pdf

Define the different scale levels of the methods of the UK, Germany and the Netherlands.
What land use data these methods use?
How are the values of assets determined?

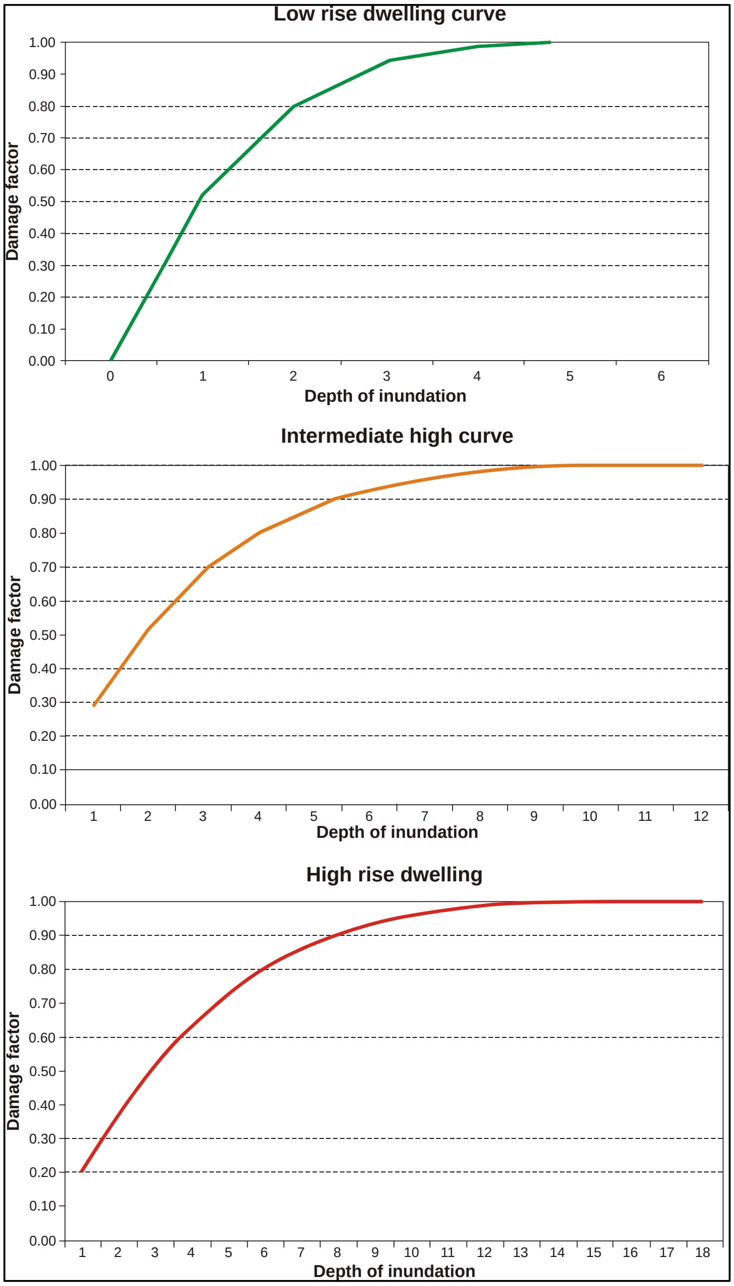


Figure 5.14 Depth-damage function of the Dutch standard method 2004 for low rise, intermediate and high rise dwellings. (Source; Huizinga,et al. , 2004).

5.6.4 Landslide vulnerability assessment

Mass movement vulnerability is much more difficult to analyze than flood or earthquake vulnerability. This has the following reasons:

- **Lack of useful hazard intensity scales**. As shown in session 4.3.3 mass movements are a wide variety of processes (fall, slide, flow, creep, spread) that may occur under different conditions and with different velocities. Therefore it is very difficult to find good scales for expressing the hazard intensity of landslides. Attempts have been made to use velocity, impact (rockfall), depth (debris flow)

Figure 5.15: Landslide vulnerability: being hit by a rockfall while driving

or volume as hazard indicators, but still there is no universal hazard intensity scale that is applicable everywhere.

- **Lack of historical damage databases**. Mass movements generally occur as isolated features that do not cover very large areas, and therefore it is difficult to use direct observations of damage in order to build vulnerability curves. It is not really possible to use aggregated damage data over large areas, because the hazard types are different and the elements at risk are very different.
- **V = 1**. Mass movements very often result in collapse or burial of the buildings that are directly in the path or on top of a fast moving landslide, therefore very often a vulnerability of 1 is used.

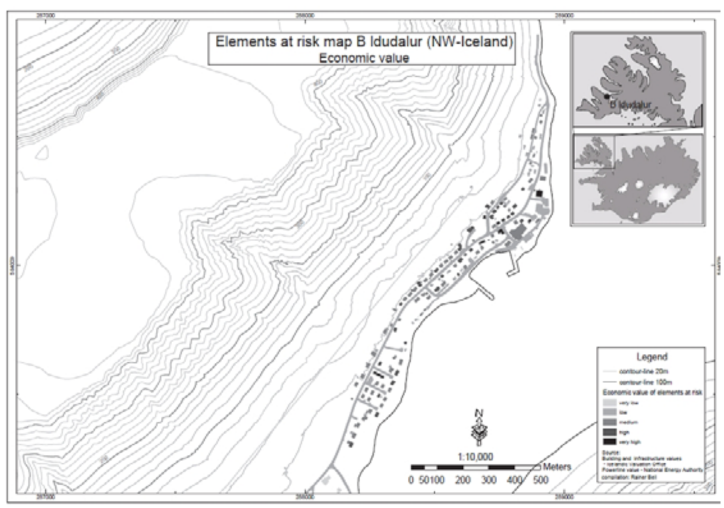
In practice most of the methods for landslide vulnerability assessment use an expert opinion approach. Table 5.4 represents the type of expert-based information that is often used in landslide vulnerability assessment.

Element at risk	**Damage Intensity**	**Type of damage**	**Vulnerability (0-1)**
Buildings	I	Slight non-structural damage, stability not affected, furnishing or fitting damaged	0.01 – 0.1
	II	Cracks in the wall, stability not affected, reparation not urgent	0.2 – 0.3
	III	Strong deformations, huge holes in wall, cracks in supporting structures, stability affected, doors and windows unusable, evacuation necessary	0.4 – 0.6
	IV	Structural breaks, partly destructed, evacuation necessary, reconstruction of destructed parts	0.7 – 0.8
	V	Partly or totally destructed, evacuation necessary, complete reconstruction	0.9 – 1.0
Roads	I	Slight damage of road	0.05 – 0.3
	II	Damage of roadway, reparation using 10 m3 material	0.3 – 0.6
	III	Damage of roadway, reparation using 100 m3 material	0.5 – 0.8
	IV	Destruction of roadway	0.8 – 1.0
Population	I	Moral disadvantage	0.002
	II	Psychological problems	0.003-0.005
	III	Severe physical injury. Invalidity	0.04 – 0.1
	IV	Death	1.0

Table 5.4: Vulnerability of various elements at risk according to the type of damage through landslides (Glade 2003 – modified after Leone et al. 1996)

Figure 5.16 shows an example of a landslide risk study carried out in Iceland, where the vulnerability was evaluated for debris flows, rockfall and snow avalanches, based on expert opinion and supported by historical information and basic run out modeling. The vulnerability is evaluated for all major classes of the elements at risk in the area: buildings, population (outside or in buildings), power lines, and roads. The study also evaluated the values of the elements at risk, and combined them with the vulnerability in order to calculate individual risk.

The vulnerability values obtained in the Iceland study cannot be directly used in other areas, as they are based on the local situation.



Magnitude / Process	low					medium					high				
	V_{po}	V_{str}	V_p	V_{pe}	V_{pep}	V_{po}	V_{str}	V_p	V_{pe}	V_{pep}	V_{po}	V_{str}	V_p	V_{pe}	V_{pep}
Debris flow	1.0	0.2	0.1	0.2	0.02	1.0	0.4	0.2	0.3	0.06	1.0	0.6	0.5	0.5	0.25
Rock fall	1.0	0.1	0.1	0.2	0.02	1.0	0.2	0.3	0.4	0.12	1.0	0.4	0.5	0.5	0.25
Hazard / Process	low					high(1)					high(2)				
	V_{po}	V_{str}	V_p	V_{pe}	V_{pep}	V_{po}	V_{str}	V_p	V_{pe}	V_{pep}	V_{po}	V_{str}	V_p	V_{pe}	V_{pep}
Snow avalanche	1.0	0.3	0.3	0.5	0.15	1.0	0.1	0.3	0.1	0.03	1.0	0.8	1.0	1.0	1.0

Figure 5.16: Vulnerability study in Iceland. Vpo = vulnerability of a power line, Vstr = vulnerability of roads and infrastructures, Vp = vulnerability of properties (buildings), Vpe = vulnerability of people and Vpep = vulnerability of people in buildings. Source: Bell and Glade 2003)

Table 5.5 presents some general vulnerability values for residents, buildings and roads for landslides in three different situations, derived by expert opinion.

Process	Vulnerability of		
	Residents	Buildings	Roads
Landslides on hill slopes	0.05	0.25	0.3
Susceptible to proximal debris flows	0.9	1	1
Susceptible to distal debris flows	0.05	0.1	0.3

Table 5.5: Vulnerability of various elements at risk with respect to landslides including debris flows (Glade 2003 – modified after Michael-Leiba et al. 2000)

There have been attempts to derive vulnerability curves for landslides. Figure 5.16 is an example from Cuba, where the vulnerability of three different building types was evaluated for debris flow. This was done after analyzing a historical debrisflow and evaluation of the thickness of the debrisflow material in relation to the degree of loss. However, this didn't give enough information, so the main input for the vulnerability curves came again from expert opinion.

Figure 5.17 shows results from several studies that are based on observed damages due to debrisflows.

Currently analytical methods are developed for the generation of vulnerability curves for landslides. Particularly for rockfall impact and debrisflows these tools are very promising, and are, apart from the expert derived methods, the best option. For instance for the evaluation of the structural vulnerability of a building due to a rock impact, the probability of collapse can be analyzed by combining the probability of building collapse with the impact probability. The impact of a rock block on the structural components of a building (columns) can be modeled and the stability of the structure after the impact can be analyzed. Landslide vulnerability assessment is still in its infant stages, and needs to obtain more attention in order to be able to produce quantitative assessments of landslide risk.

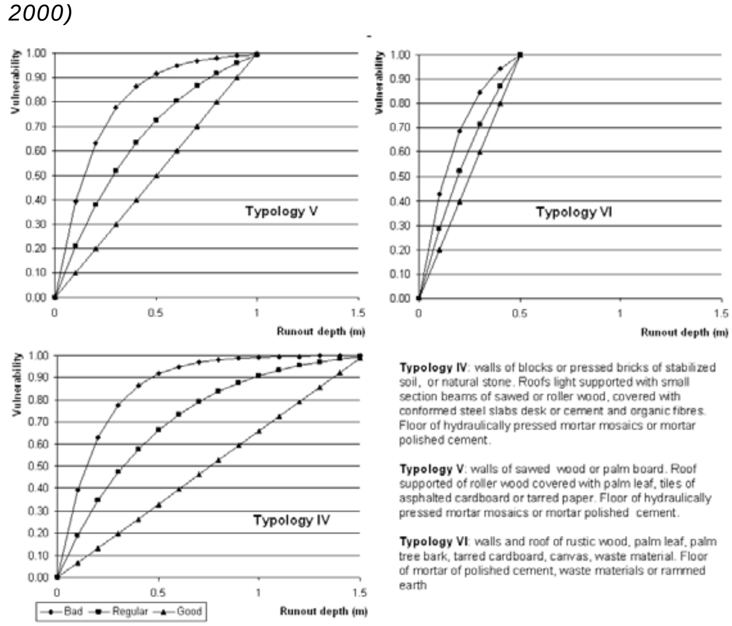


Figure 5.16: Vulnerability curves for debrisflows derived from expert opinion and supported by historical damage data for three building types in Cuba. (Source: Castellanos and Van Westen,

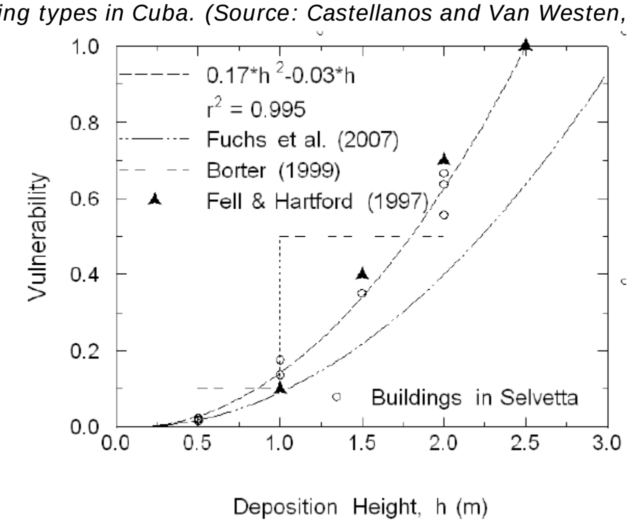


Figure 5.17: Debrisflow vulnerability curves from different studies (Source: Akbas et al, 2009)

Building structure	**Resistance**	**Rockfall magnitude**		
		Low	**Medium**	**High**
Lightest structure (wood)	None	0.2	1	1
Light structure	Very weak	0.15	0.5	0.9
Mixed structure (concrete and wood)	Weak	0.1	0.3	0.8
Brick walls, concrete	Medum	0.08	0.25	0.7
Reinforced concrete	Strong	0.05	0.2	0.5
Reinforced	Very strong	0	0.1	0.3

Table 5.6: Vulnerability of buildings according to the magnitude of rock fall (Glade 2003 – modified from Heinimann 1999).

5.6.5 Population loss estimation.

The vulnerability of population can be subdivided in the direct physical vulnerability of the population (injury, casualties, and homelessness) which will be evaluated here, and the indirect social vulnerability and capacity, which will be dealt with in the next section.
One of the very important next steps after a building vulnerability study is to analyze the effect of the damage of the building on the population inside of the building. For the evaluation of population losses, a first step is to define population injury severity classes. Table 5.7 gives the classification which is used in the HAZUS methodology.

Injury Severity Level	Description Of Injury
Severity 1	Requiring basic medical aid without requiring hospitalization
Severity 2	Requiring a greater degree of medical care and hospitalization, but not expected to progress to a life threatening status
Severity 3	Pose an immediate life threatening condition if not treated adequately and expeditiously. The majority of these injuries are the result of structural collapse and subsequent entrapment or impairment of the occupants.
Severity 4	Instantaneously killed or mortally injured

Table 5.7: Injury severity levels as indicated in the HAZUS methodology.

Several methods exist for linking of building damage to these severity levels. Table 5.8 gives the information used in HAZUS for earthquake vulnerability of people. HAZUS doesn't make similar estimates for flooding and hurricanes due to lack of data.

Structural damage	Structural type	Affected people (values are in percentage)			
		Severity 1	Severity 2	Severity 3	Severity 4
Complete (collapse)	Most structural types	40	20	3-5	5-10
	Masonry	40	20	5	10
Complete (no collapse)	Most structural types	5	1	0.01	0.01
	Masonry	10	2	0.02	0.02
Extensive	Most structural types	1	0.1	0.001	0.001
	Masonry	2	0.2	0.002	0.002
Moderate	Most structural types	0.20 – 0.25	0.025 – 0.03	0	0
	Masonry	0.35	0.4	0.001	0.001
Slight	Most structural types	0.05	0	0	0
	Masonry	0.05	0	0	0

Table 5.8: Population vulnerability used in the HAZUS method for earthquake losses.

Table 5.9 give the estimate used in Canada by the NHEMATIS method for loss estimation. Here the data is linked to the percentage of building damage.

Percentage of building damage	Fraction of population affected		
	Minor injuries	Major injuries	Dead
0.00	0	0	0
0.50	3/100,000	1/250,000	1/1,000,000
5.00	3/10,000	1/25,000	1/100,000
20.00	3/1,000	1/2.500	1/10,000
45.00	3/100	1/250	1/1,000
80.00	3/10	1/25	1/100
100.00	2/5	2/5	1/5

Table 5.9: Population vulnerability values used in the Nhematis method.

The severity levels and the percentages of affected people should be combined with the temporal distribution patterns of the population, which were discussed in session 4.4. This allows then to model in a GIS the distribution of people indoors and outdoors in different periods of the day, and to use this as input in loss estimation scenarios, where the percentage of damaged buildings (following table 5.7) or the percentage of buildings per structural damage class (following table 5.8) will determine the population affected. Figure 5.18 gives an example of this for the city of Lalitpur in Nepal, related to earthquake losses.

Also for landslides population vunerability curves have been made based on expert opinion. Table 5.10 Presents results on population vulnerability for the Hong Kong area for landslides, which are based on an extensive database of slope failures and associated injuries and casualties.

Location	Description	Population vulnerability (individuals)		
		Data range	Recommended	Comments
Open Space	Struck by rock fall	0.1 -0.7	0.5	May be injured but unlikely to cause death
	Buried by debris	0.8 – 1.0	1	Death by asphyxia
	Not buried but hit by debris	0.1 – 0.5	0.1	High chance of survival
Vehicle	Vehicle is buried/crushed	0.9 – 1.0	1	Death almost certain
	Vehicle damaged only	0.0 – 0.3	0.3	High chance of survival
Building	Building collapse	0.9 – 1.0	1	Death almost certain
	Inundated building with debris	0.8 – 1.0	1	Death is highly likely
	Inundated building with debris but person is not buried	0.0 – 0.5	0.2	High chance of survival
	Debris strikes building only	0.0 – 0.1	0.05	Virtually no danger

Table 5.10: Vulnerability of a person being affected by a landslide in open space, in a vehicle and in a building (Table 2, Glade 2003 – modified after Wong et al. 1997)

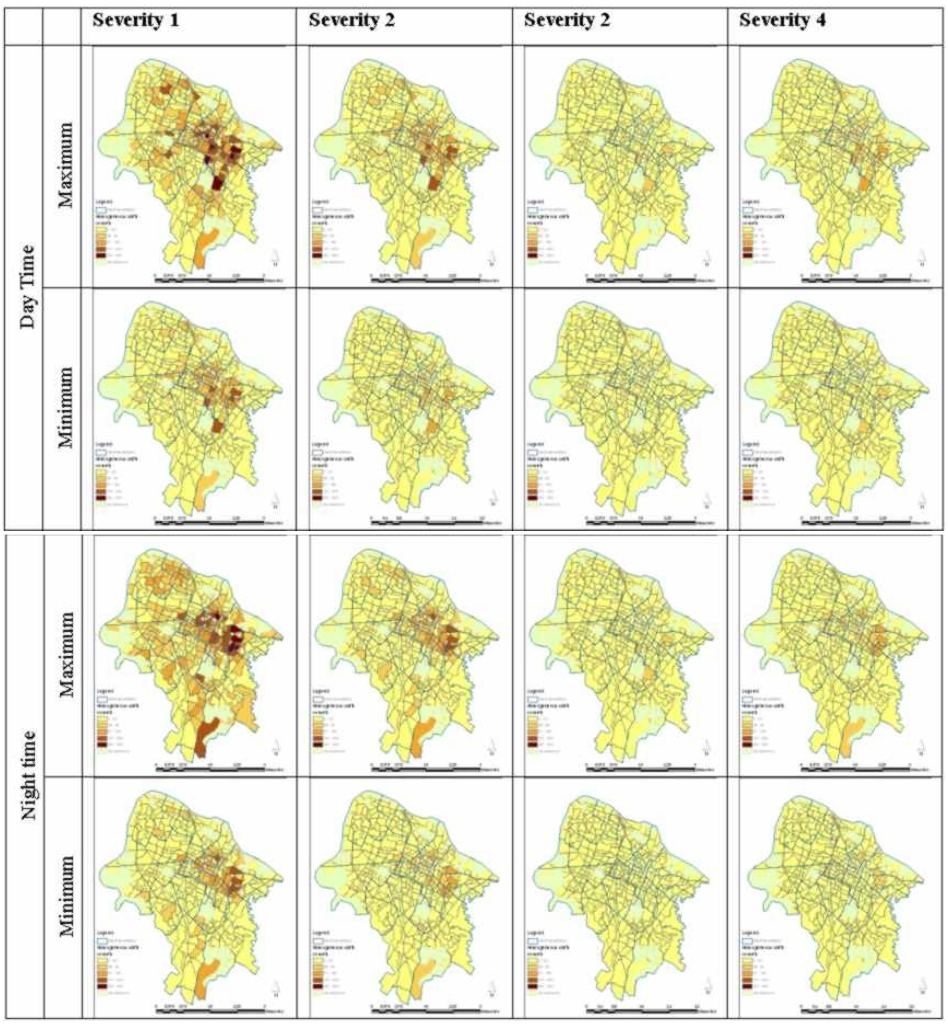


Figure 5.18: Population loss estimation for Lalitpur, Nepal, for two temporal scenarios (daytime and nighttime) and for the four severity levels defined in table 5.6 (Source: Islam MSc ITC, 2004)

5.7 Comprehensive vulnerability assessment

In the previous section we have concentrated mainly on the methods used for assessing physical vulnerability, mostly using vulnerability curves or tables that relate the expected damage with the hazard intensity. As we have seen in the introduction of this session, vulnerability encompasses much more than that (see section 5.2). In this section we will look at methods that have a much wider scope in defining vulnerability. These methods mostly use indicators, based on expert opinion. We will do this by showing some examples.

Example 1: Villagrán de León (2006): " sectoral approach"; Expert opinion method working with vulnerability indices.

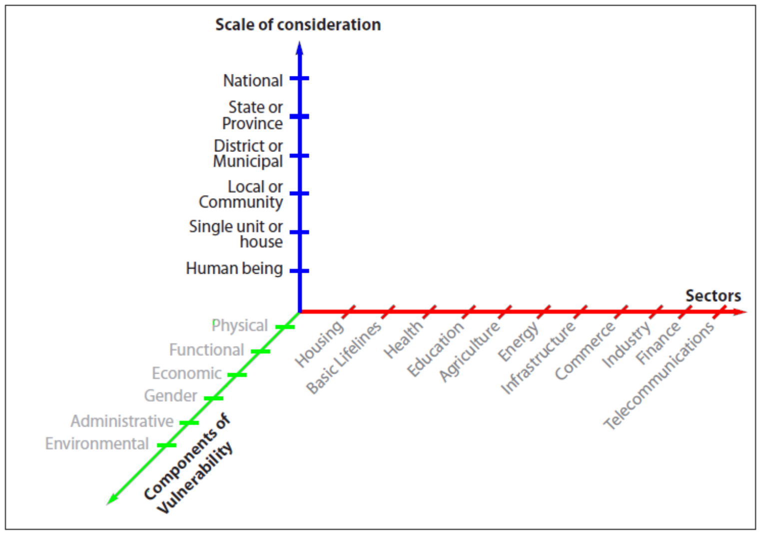


Figure 5.19: Framework for vulnerability. (Source: Villagrán de León, 2006).

Villagrán de León (2006) developed a framework for decomposing vulnerabilities (figure 5.19). He distinguishes 3 dimensions of vulnerability; the scale or geographical level (from human being to national level), the various sectors of society ("elements at risk "), and 6 components of vulnerability ("types of vulnerability"). Hazard intensity is not further specified, the method is based on a very high magnitude event. This sectoral approach, proposed from a policy point of view, seems useful since it promotes assigning responsibilities for reducing vulnerabilities to those private or public institutions in charge of the sector (Villagrán de Leon 2006). The method uses matrices to calculate a vulnerability index, which is grouped in 3 classes (high, medium and low). The example shown in figure 5.20 considers the housing as elements at risk, and looks at physical vulnerability at the scale of a single building for a high hazard level of volcanic eruptions.

The indicators do not show how vulnerability depends on magnitude of the hazard. As can be seen in figure 5.20 the vulnerability is defined by 6 characteristics / parameters of the house that are rated based on their construction material, method, and design into 3 classes. (See also Session 4: Elements at Risk). Per characteristic a weight is given with respect to the other characteristics. Here the wall material is defined as most important parameter contributing to the vulnerability of the house. The 3 subclasses are based on historic research of volcanic impacts on housing in Central America.

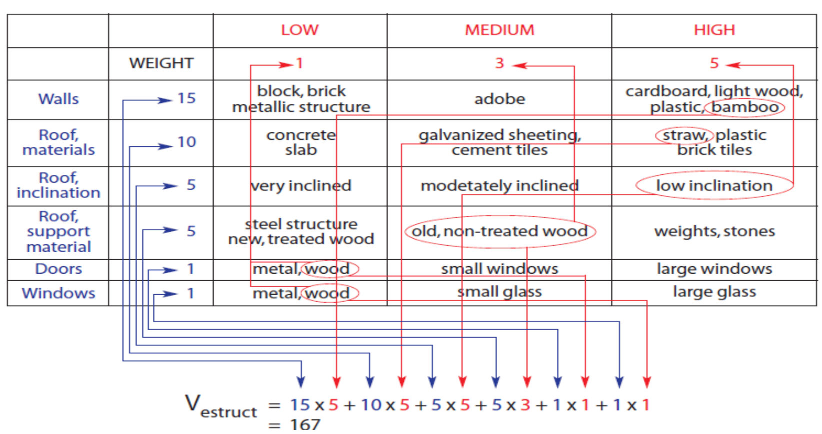


Figure 5.20: Matrix to asses the structural vulnerability index of a house in regarding volcanic eruptions. (Source: Villagran de Leon)

Degree of structural vulnerability	Numerical range
Low	37–80 points
Medium	81–130 points
High	131–185 points

Example 2. Framework of the German Technical Cooperation Agency – GTZ (2004): for defining vulnerability at Local Level.

The GTZ framework is an expert-opinion index method, for defining physical, social, economic and environmental vulnerability at local level (Community scale). It uses the conceptual framework of Davidson, adopted by Bollin et al (in: Birkmann 2006)(see figure 5.5). Each type of vulnerability is characterized by a number of indicators, as indicated in table 5.11). The main aim is to define a Community-Based Risk Index by identifying and quantifying the main risk characteristics (exposure, vulnerability, management capacities) within a community. It has the function of comparing risk between different communities, as well as the goal of identifying whether the level of risk is primarily an outcome of the hazard, the exposure, the vulnerability or the capacity component (see Bollin and Hidajat, 2006).

Physical/demographic	Social	Economic	Environmental
Population density Demographic pressure Insecure settlements Access to basic services	Level of poverty Degree of illiteracy Attitude Decentralization Community participation	Local resource base Diversification Small enterprises Accessibility	Forest area Degraded area Over-used area

Table 5.11: Indicators proposed by H. Hahn to assess vulnerability. Source:(Hahn, Villagrán De León et al. 2003)

The model assigns 3 possible values (low=1, medium=2 or high=3) to the each of the indicators, and uses weights for the vulnerability index when calculating it for each type of hazard. The different indicators were weighted according to their importance for the specific hazard. The final index is representative for the community as a whole. An example is given below for the calculation of an earthquake vulnerability index the municipality of Villa Canales in Guatemala.

Table 5.12 gives an overview of the whole concept of the community based disaster risk index including the index of vulnerability. The 37 indicators are scored and weighted (as indicated above) and one final risk index is produced (see figure 5.21). Depending on the scaled indicator values, the factor indices vary between 0 and 100. This was achieved by distributing a total of 33 weighting points according to the assumed importance of the indicators for each factor (Bollin and Hidajat, 2006). The aim is to compare risk with other communities and to analyze risk within the community. (See Bollin and Hidajat, 2006). Furthermore, it highlights the determining factors of risk, for example whether risk originates primarily from the hazard or whether the vulnerability or the lack of capacity is the major concern.

Indicator		Weight	Value	Product
V1	Population density	3	1	3
V2	Demographic pressure	3	3	9
V3	Insecure settlements	1	1	1
V4	Access to basic services	1	2	2
V5	Poverty level	2	2	4
V6	Illiteracy rate	2	2	4
V7	Attitude	3	2	6
V8	Decentralization	1	2	2
V9	Community participation	2	2	4
V10	Local resource base	3	3	9
V11	Diversification	2	3	6
V12	Small enterprises	2	2	4
V13	Accessibility	2	2	4
V14	Forest area	2	2	4
		33	29	62

Table 5.11 Indicators for the city of Villa Canales in Guatemala Source:(Hahn, Villagrán De León et al. 2003)

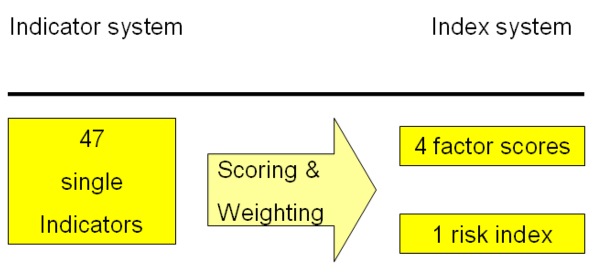


Figure 5.21 defining the final risk index.

Main factor	Indicator name	Indicator
EXPOSURE		
Structures	(E1) Number of housing units (E2) Lifelines	Number of housing units (living quarters) % of homes with piped drinking water
Population	(E3)Total resident population	Total resident population
Economy	(E4) Local gross domestic product (GDP)	Total locally generated GDP in constant currency
VULNERABILITY		
Physical/ demographic	(V1) Population Density (V2) Demographic pressure (V3) Unsafe settlements (V4) Access to basic services	People per km2 Population growth rate Homes in hazard prone areas (ravines, river banks, etc) % of homes with piped drinking water
Social	(V5) Poverty level (V6) Literacy rate (V7) Attitude (V8) Decentralization (V9) Community participation	% of population below poverty level % of adult population that can read and write Priority of population to protect against a hazard Portion of self-generated revenues of the total budget % voter turn out at last communal elections
Economic	(V10) Local resource base (V11) Diversification (V12) Small businesses (V13)Accessibility	Total available local budget in US$ Economic sector mix for employment % of businesses with fewer than 20 employees Number of interruption of road access in last 30 years
Environmental	(V14) Area under forest (V15) Degraded land (V16) Overused land	% of area of the commune covered with forest % of area that is degraded/eroded/desertified % of agricultural land that is overused
CAPACITY MEASURES		
Physical planning and engineering	C1) Land use planning (C2) Building codes (C3) Retrofitting/ Maintenance (C4) Preventive structures (C5) Environmental management	Enforced land use or zoning regulations Applied building codes Applied retrofitting and regular maintenance Expected effect on impact-limiting structures Measures that promote and enforce nature conservation
Societal capacity	(C6)Public awareness programs (C7) School curricula (C8) Emergency response drills (C9) Public participation (C10)Local risk management/ emergency groups	Frequency of public awareness programmes Scope of relevant topics taught at school Ongoing emergency committee with public representatives Grade of organization of local groups
Economic capacity	(C11) Local emergency funds (C12) Access to national emergency funds (C13) Access to intl. emergency funds (C14) Insurance market (C15) Mitigation loans (C16) Reconstruction loans (C17) Public works	Local emergency funds as % of local budget Release period of national emergency funds Access to international emergency funds Availability of insurance for buildings Availability of loans for disaster risk reduction measures Availability of reconstruction credits Magnitude of local public works programmes
Management and institutional capacity	(C18) Risk management/emergency committee (C19) Risk map (C20) Emergency plan (C21) Early warning system (C22) Institutional capacity building (C23) Communication	

Table 5.12: Community based disaster risk indicators. (Source: Bollin/Hidajat 2006)

The vulnerability indicators, defining the physical, economic, social and environmental vulnerability can be aggregated and combined into an overall vulnerability value (see figure 5.22). One very suitable tool for combining and weighing the different vulnerability factors is Spatial Multi Criteria Evaluation. SMCE can also be used for hazard assessment, using an expert based approach as was mentioned in session 3.

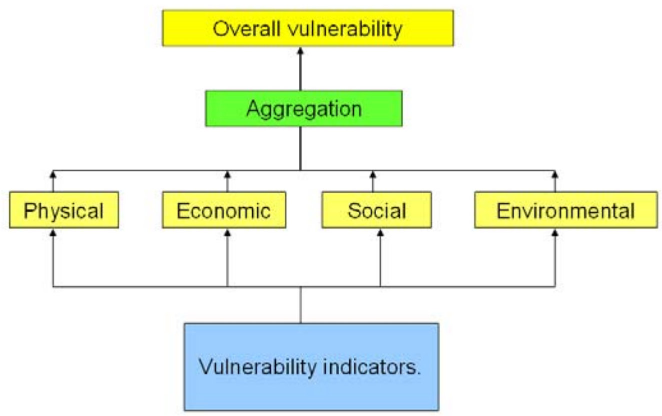


Figure 5.22: A model to integrate the vulnerability components into an overall vulnerability.

5.8 Spatial Multi Criteria Evaluation for vulnerability assessment.

The theoretical background for the multi-criteria evaluation is based on the Analytical Hierarchical Process (AHP) developed by Saaty (1980). The AHP has been extensively applied on decision-making problems (Saaty and Vargas 2001), and extensive research has been carried out to apply AHP to risk assessment. For implementing the semi-quantitative model, the SMCE module of ILWIS-GIS can be used. The SMCE application assists and guides users when performing multi-criteria evaluation in a spatial manner (ITC 2001).The input is a set of maps that are the spatial representation of the criteria, which are grouped, standardised and weighted in a 'criteria tree.' The output is one or more 'composite index map(s),' which indicates the realisation of the model implemented.

	C_1 (w_1	C_2 w_2	C_3 w_3	… …	C_n w_n)
A_1	a_{11}	a_{12}	a_{13}	…	a_{1n}
A_2	a_{21}	a_{22}	a_{23}	…	a_{2n}
.	.	.	.	.	.
.	.	.	.	.	.
.	.	.	.	.	.
A_m	a_{m1}	a_{m2}	a_{m3}	…	a_{mn}

$$a_{ij} = v_{ij}^{*} \prod_{L=0}^{h} w_j^L$$

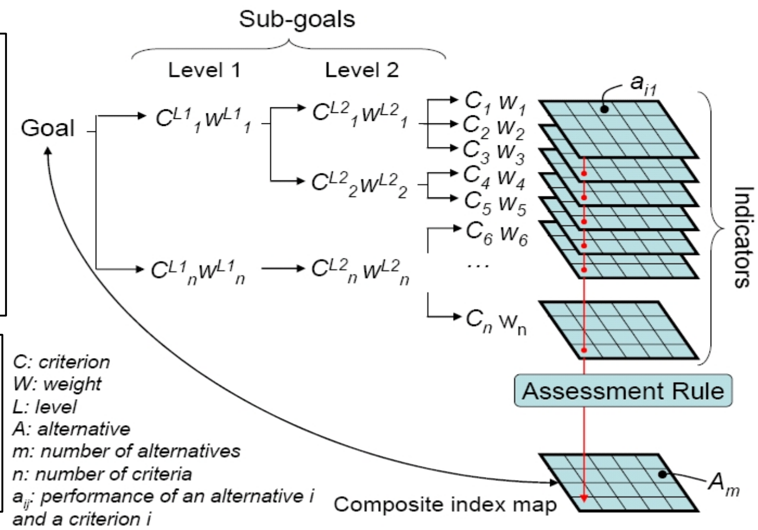


Figure 5.23. Schematic procedure for spatial multi-criteria evaluation based on the analytical hierarchical process

From a decision-making perspective, multi-criteria evaluation can be expressed in a matrix as shown in Figure 6.8. The matrix A contains the criteria in one axis (C_1 to C_n), and a list of possible alternatives, from which a decision has to be taken on the other axis (A_1 to A_m). Each cell in the matrix (a_{ij}) indicates the performance of a particular alternative in terms of a particular criterion. The value of each cell in the matrix is composed of the multiplication of the standardised value (between 0 and 1) of the criterion for the particular alternative, multiplied by the weight (W_1 to W_n) related to the criterion. Once the matrix has been filled, the final value can be obtained by adding up all cell values of the different criteria for the particular alternative (e.g. a_{11} to a_{1n} for alternative A_1).

For implementing this matrix according to the AHP, three principles steps need to be considered. The first one decomposes the problem (and the weights) into a hierarchical structure. The second one considers the weighting process, employing the pairwise comparisons of the criteria, and the synthesis is related to the multiplications among the hierarchical levels. Additionally, in the spatial implementation of this procedure, every criterion (C_j) becomes a raster layer, and every pixel (or set of pixels) of the final composite index map eventually becomes an alternative *Aj*. The goal (risk index) has been decomposed into criteria levels C_{L1} and C_{L2}. The intermediate levels are often indicated as sub-goals or objectives (e.g. in level 1, the sub-goals are a 'hazard index' and a 'vulnerability index'). Each criterion of each level will also have an assigned weight. Therefore, the values for the layers of the intermediate levels are obtained through the summation of the performance for the alternative at lower levels. As the criteria consist of raster maps, their spatial performance (a_{ij}) and the alternative (A_i) will be identified for particular raster cells.

The composite risk index map is obtained by an assessment rule (sometimes also called decision rule), which is calculated by adding up the performance of all cell values of the different criteria (a_{ij}) for the particular alternative. However, the performance of every element in the matrix (a_{ij}), is obtained in a different way:

In this equation, v_{ij} refers to the standardised value of criterion (C_j) for alternative (A_i), and weight w^L_j refers to the weight of criterion (C_j) for level L (0–h levels). During the analysis, it could be desirable (and sometimes necessary for a better definition of the weights w^L_j) to produce the intermediate criteria maps. In this case, Eq. 1 should not be applied because weights need to be multiplied with the standardised values only up to the specific level of the intermediate maps. The intermediate maps might also be combined using different methods. When designing vulnerability indicators, it is necessary to take into account the socio-economic conditions, which may vary from country to country. In general, vulnerability can be divided in four different types, such as physical, social, economic and environmental (UNPD 2004), which can be combined in order to derive a qualitative index.

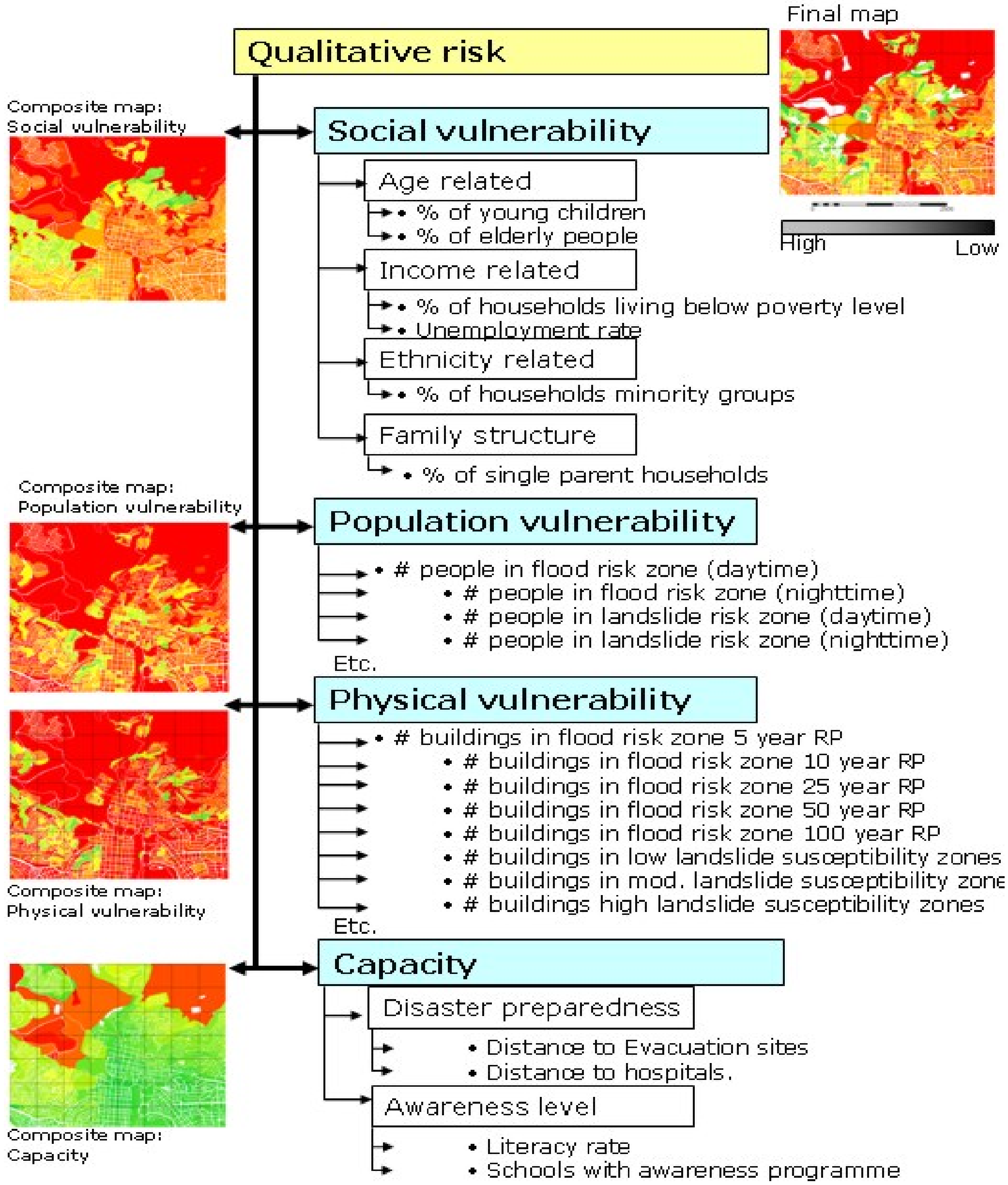


Figure 5.24: Example of a criteria tree used for spatial multi-criteria evaluation for qualitative risk assessment which will be used in the RiskCity exercises.

Task 5.9: RiskCity exercise on the use of Spatial Multi Criteria Evaluation (duration 3 hours)

To illustrate the use of Spatial Multi Criteria Evaluation in vulnerability/ capacity assessment and quantitative risk assessment, we have made an exercise on the evaluation of indicators for RiskCity. Go to this RiskCity exercise and follow the instructions there.

Selftest

In order to evaluate whether you have understood the concepts that were presented in this session. Please make the following test, and check the answers in Blackboard.

Question: Vulnerability
Which indicators could be used to measure social vulnerability?
A) Age, gender, literacy rate
B) Age, building type, number of floors
C) Biodiversity, species, ecological indicators
D) Production, import, export

Question: Vulnerability curve
A vulnerability curve:
A) Displays the probability that one single building (with a particular design, construction types, and number of floors) might be damaged, given a particular magnitude/intensity of the hazard event.
B) Displays the duration that a particular element at risk cannot be used after the occurrence of a hazardous event
C) Display the relation between the percentage of damage, to a group of elements at risk with the same characteristics, and the magnitude/intensity of the hazard event.
D) Display the probability of a potentially damaging phenomenon within a given period of time and a given area.

Question: Secondary losses
Losses due to disasters can be subdivided in primary and secondary losses, and can be of social, physical and economic nature. An example of secondary human/social losses of disasters is:
A) Injuries and fatalities
B) Increase of social tension and crime rate in a society
C) Financial losses that have to be paid by insurance companies
D) Capital costs of response and relief.

Question: Spatial Multi Criteria Evaluation
What are the main advantages and disadvantages of using Spatial Multi-Criteria Evaluation (SMCE) in Risk Assessment?
A) With SMCE you can calculate physical vulnerability and quantitative risk, but you cannot include social vulnerability or capacity.
B) With SMCE you can incorporate social vulnerability and capacity into a qualitative risk assessment; however, it does not allow quantifying the actual risk in losses and probability.
C) With SMCE you can analyze costs and benefits, based on quantitative risk assessment, but it does not allow the evaluation of different alternatives.
D) With SMCE you can evaluate different alternatives, but you cannot include expert-based weight values.

Question: losses.
Losses due to disasters can be subdivided in primary and secondary losses, and can be of social, physical and economic nature. Give an example of losses in the following categories and briefly explain how these losses could be evaluated:
A. Secondary human/social losses due to earthquakes

B. Secondary economic losses to landslides

Further reading and references:

Some of the key publications on vulnerability are:

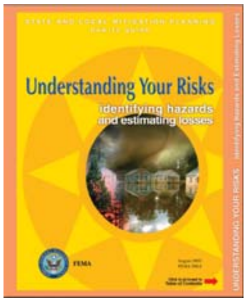
Birkmann, J. (2006:1). Measuring vulnerability to promote disaster-resilient societies:Conceptual frameworks and definitions. Measuring vulnerability to natural hazards : towards disaster resilient societies. J. Birkmann. Tokyo, United Nations University Press: 9-54.

Blaikie, P., T. Cannon, et al. (1994). At risk : natural hazards, people's vulnerability and disasters. London etc., Routledge

Pelling, M. (2003) The Vulnerability of Cities. Natural disasters and Social Resilience. Earthscasn Publications, London.

UN - ISDR (2004). Living with Risk, UN. http://www.unisdr.org/eng/about_isdr/bd-lwr-2004-eng.htm

Wisner, B., Blaikie, P., Cannon, T., Davis, I. (2004) At Risk: Natural Hazards, People's Vulnerability and Disaster, Routledge, London, 479 pp



FEMA guide

There is a very useful guide prepared by FEMA called "Understanding your risks" that guides you through the various phases of a risk assessment. This guide is not ment for the use of GIS, but it is a very useful background reading document. The guide is also in the background materials of the course. You can also access it on: http://www.fema.gov/plan/mitplanning/howto2.shtm

Other references cited in the text:

ADPC 2004. Buildig Disaster Risk Reduction in Asia: A Way forward ADPC Looks Ahead to 2015. ADPC, Bangkok, Thailand

Apel, H., Aronica, G. T., Kreibich, H., and Thieken A. H.(2009) Flood risk analyses—how detailed do we need to be? Nat Hazards (2009) 49:79–98

Birkmann, J. (2005). Danger need not spell disaster – But how vulnerable are we? Research Brief of the United Nations University, United Nations University. No. 1/2005,.

Bogardi, J. and J. Birkmann (2004). Vulnerability Assessment: the first step towards sustainable risk reduction. Disasters and Society - From hazard assessment to risk reduction. D. Malzahn and T. Plapp. Berlin, Logos Verlag: 75-82.

Bohle, H.G (2001) "Vulnerability and Critivallity: Perspectives from Social geography", IHDP update 2/2001, Newsletter of the International Human Dimensions Programme on Global Environmental Change: 1-

Bollin, C., Hidajat, R., 2006. Community-based disaster risk index: pilot implementation in Indonesia. In: Birkmann, J. (Ed.), Measuring Vulnerability to Natural Hazards—Towards Disaster Resilient Societies. UNU-Press, Tokyo, New York, Paris.

Bollin, C., Cárdenas, C., Hahn, h., Vatsa, K.S., (2003) Natural Disaster network; Disaster Risk management by Communities and Local Governments, Washington, d.C.: Inter-American Development Bank

Botero Fernandez, V., Ottens, H.F.L. (promotor) , van Westen, C.J. (promotor) and Sliuzas, R.V. (promotor) (2009) Geo - information for measuring vulnerability to earthquakes : a fitness for use approach. Enschede, Utrecht, ITC, University of Utrecht, 2009. ITC Dissertation 158, 191 p. ISBN: 978-90-6164-272-5

Buck W, Merkel U. (1999) Auswertung der HOWAS – Datenbank (Analysis of the HOWAS data base), Institut fu¨r Wasserwirtschaft und Kulturtechnik (IWK) der Universita¨t Karlsruhe, Karlsruhe, Report Nr. HY 98/15

BRGM, 2005 RISK-NAT (Module 4): Methods and tools for risk evaluation Progress report. BRGM 54041_FR

BRIENE M, KOPPERT S, KOOPMAN A, VERKENNIS A (2002), Financiele onderbouwing kengetallen hoogwaterschade, NEI B.V.

Buckle, Marsch and Smale (2000) New approaches to Assessing Vulnerability and resilience"Australian Journal of Emergency Management, Winrter 2008: 8-156

BUWAL/BWW/BRP, 1997. Berücksichtigung de Massen bewegungsgefahren bei raumwirksamen Tätigkeiten. Bundesamnt f Bundesamnt für Unwelt, wald und Lnadschaft (BUWAL), Bundesamnt für Wasserwirtschaft (BWR) , Bundesamnt für Raumplannung (BRP). Bern Empfehlungen, EDMZ 310.023d.

Cardona, O.D. (1999) Environmental Management and Disaster Prevention: Two Related topics: A Holistic Risk Assessment and management Approach, in: J.Ingleton, ed., Natural Disaster Management, London: Tudor Rose.

Cardona, O.D. (2003), "The need for rethinking the concept of vulnerability from a holistic perspective: a necessary review and criticism for effective risk management", in Bankoff, G., Frerks, G., Hillhorst, D. (Eds),Mapping Vulnerability: Disasters, Development and People, Earthscan, London, pp.37-51.

Clark, G.E. et al.,1998. Assessing the vulnerability of coastal communities to extreme storms: the case of Revere, MA., USA. Mitigation and Adaptation Strategies for Global Change, 3(1):59-82.

Cutter, S.L. (1993), Living with Risk, Edward Arnold, London, .

utter, S.L., B.J. Boruff, and W.L. Shirley. 2003. “Social Vulnerability to Environmental Hazards.”Social Science Quarterly84(1): 242-261.

Davidson, R. (1997) An Urban earthquake Risk Index, The John A Blume Earthquake Engineering Center, department of Civil engineering, report No 121, Standford: Stanford University.

European Spatial Planning Observation Network (2003). Glossary of terms., Copyright © GTK Webmaster http://www.gsf.fi/projects/espon/glossary.htm.

FloodSite, E. P.-R. Frank Messner, Colin Green, Volker, et al. (2007). Evaluating flood damages: guidance and recommendations on principles and methods, Co-ordinator: HR Wallingford, UK

Flageolet, J.C., (1999) Landslide hazard - a conceptual approach in risk viewpoint. In: R. Casale and C. Margiotinni (eds) Floods and Landslides : Integrated Risk Assessment (Berlin: Springer Verlag) 3-18

Furukawa, Aiko and Ohta, yutaka (2009) Failure process of masonry buildings during earthquake and associated casualty risk evaluation. Nat Hazards (2009) 49:25–51

Gewalt M, Klaus J, Peerbolte E.B, Pflügner W, Schmidtker F, Verhage L, (1996) EUROflood _ Technical Annex 8 Economic Assessment of Flood Hazards.

Geoscience Australia 2008. Australian Government

Glade T (2003), Vulnerability Assessment in landslide risk Analysis, Die Erde, 134(2), 123-146.

Glade, T. Anderson, M., and Crozier M.J. (2005) Eds, Landslide Hazard and Risk. Wiley

Granger, K. (2000) Community risk in Mackay A multi hazard risk assessment . Cities Project Chapter 1. Urban Geohazard Risk Assessment online: http://www.ga.gov.au/image_cache/GA4178.pdf

Hahn, H., J. C. Villagrán De León, et al. (2003). Indicators and Other Instruments for Local Risk Management for Communities and Local Governments. Document prepared as part of the documents related to the Project: Local Risk Management for Communities and Local Governments. G. f. I. The German Technical Cooperation Agency. http://www.ga.gov.au/hazards/risk/vulnerability.jsp

Huizinga, H.J., Dijkman, M., Waterman, R., en Barendregt, A. , 2004. HIS- Schade en Slachtoffer Module Versie 2.1, Systeemdocumentatie. HKV LIJN IN WATER en Geodan IT. November 2004.

Imiriland (2002) Identification and Mitigation of Large Landslide Risks in Europe . Project Imiriland D 16. relevant criteria to assess vulnerability and risk. Regione Piemonte in collaboratione with Politecnico di Torino, École polytechnique fédérale de Lausanne, C.N.R. di geoscienze e georisorse di Torino.(ppt)

Imiriland (2004) Identification and Mitigation of Large Landslide Risks in Europe. Project Imiriland : Advances in Risk Assessment Editors: Bonnard Ch, Forlati F, Scavia C.

ITC (2001). ILWIS 3.0 Academic - User's Guide. Enschede, Netherlands, ITC.

Intergovernmental Panel for Climate Change (IPCC) (2001) Climate Change 2001. Synthesis report: A contribution of Working Groups I, II, and III to the third assessment report . R.T Watson, et al eds, Cambridge/New York Cambridge University Press

Kasperson, J.X., Kasperson, R.E., Turner, B.L. II, Schiller, A.M.D., Hsieh, W. (2005), "Vulnerability to global environmental change", in Kasperson, J.X., Turner, B.L. II, Schiller, A.M.D., Hsieh, W. (Eds),Social Contours of Risk. II: Risk Analysis

Corporations and the Globalization of Risk, Earthscan, London, pp.245-85.
Kok, M., Huizinga, H.J., Vrouwenvelder, Barendrecht A (2004). Standaard methode
2004, Damage and Casualties caused by Flooding, Client: Highway and Hydraulic engineering department.
Lang K, 2002 Seismic vulnerability of existing buildings. PhD thesis Insiturte of Structural Engineering, Swiss federal Institute of Technology.
MATE/METL, 1999. plans de Prevention des Risques Naturels (PPR): Risques de Mouvement de Terrain. Ministère de de l'Amenagement du Territoire et de l'Environment (MATE), Ministère de l'Equipement, des Transport et du Logement (METL). Paris: La documentation Francaise.
Messner F, Meyer V, (2005) Flood damage, vulnerability and risk perception – challenges for flood damage research, UFZ Discussion Paper 13/2005
Maquaire, O., Thiery, Y and Malet J.P. Current practices and assessment tools of landslide vulnerability inmountainous basins – identification of exposed elements with a semi_automatic procedure.
Mejia Navarro,M & Garcia, L.A., 1996 Natural Hazard and risk Assessment using Decision Support System. Application. Environmental and Engineering Geosciences 2 (3): 299-324
Mileti, D.S. (1999 Disasters by Design: A Reassessment of Natural Hazards in the United States, Brookfield: Rothstein Associates.
Penning-Rowsell E.C. , Johnson C, Tunstall S, Morris J, ChattertonJ, Cokera A, Green C, (2003) The benefits of flood and coastal defence techniques and data for 2003, flood hazard Research Centre, Middlesex University.
Remondo, J., Bonachea,J., and Cendrero, A. (2008)Quantitative landslide risk assessment and mapping on the basis of recent occurrences Geomorphology 94 (2008) 496–507
Saaty, T. L. (1980). The analytic hierarchy process: planning, priority setting, resource allocation, McGraw-Hill.
Saaty, T. L. and L. G. Vargas (2001). Models, methods, concepts & applications of the analytic hierarchy process, Kluwer Academic Publishers.
Silvano,S., 2002 An EU-funded project: ALARM Assessment of Landslide Risk and Mitigation in Mountains Area. EVGI-2001-00018; http//ivm.vu.nl/alarm
Schneiderbauer S, and EhrlichD, (2004) risk, hazard and People's vulnerability to Natural hazards: A review of definitions , Concepts and data, Brussel: European Commission_Joint research Centre (EC-JRC)
Stiemen S., Fäh D.,Giardini D., Bertogg M.and Tschudi, S., (2004) reliability of building inventories in seismic prone regions. Bulletin of Earthquake Engineering, 2(3), 361-388
Thywissen, K. (2006). Core terminology of disaster reduction . Measuring vulnerability to Natural Hazards Towards disaster resilient societies. J. Birkmann, UN University Press.
Turner, B. L., 2nd, R. E. Kasperson, et al. (2003). "A framework for vulnerability analysis in sustainability science." Proceedings Of The National Academy Of Sciences Of The United States Of America 100(14): 8074-8079.
UNDP (2004). Reducing Disaster Risk a challenge for development. A Global Report. . United Nations Development Programme Bureau for Crisis Prevention and Recovery.
United Nations (1993). Agenda 21: Programme of Actions for Sustainable Development. . UNCED. 3-14 June 1992 Rio Janeiro, United Nations.
UN - ISDR (2004). Living with Risk, UN.
UNDRO (1991) Mitigation natural Disasters Phennomena, Effects and Options. A manual for planner.
Villagrán de Leon, J. C. (2006). Vulnerability A Conceptual and Methodological Review. UNU-EHS. UNU. No 4/2006.
Victoria, Lorna P. 2002. Community based Approaches to Disaster Mitigation In: Proceedings Regional Workshop on Best Practices in Disaster Mitigation, 24-26 September 2002, Indonesia

Guide Book
Session 6:
Risk Analysis

Cees van Westen

Objectives

After this session you should be able to:

- Understand the procedures for loss estimation
- Carry out a qualitative risk assessment combining susceptibility and vulnerability
- Carry out a quantitative risk assessment using risk curves
- Use GIS for risk assessment for two different hazard types
- Use GIS for multi-hazard risk assessment for buildings and population
- Use ILWIS for exploring the dataset and evaluating the risk situation in RiskCity

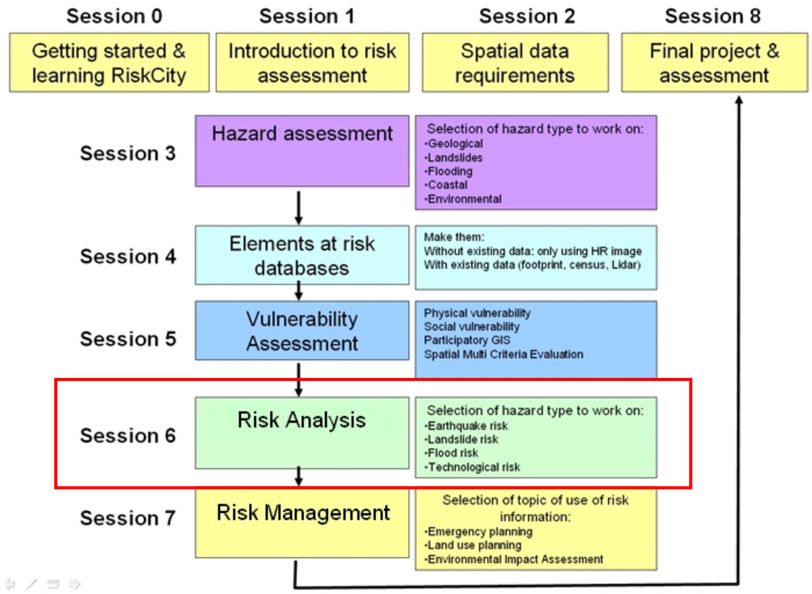
In this session you will look at the various methods that can be used for risk assessment. We will look first at the concepts of risk assessment and the different ways in which risk can be expressed. Then we will look at three different types of approaches for risk assessment: qualitative methods using risk matrices, semi-quantitative methods using indices and spatial multi-criteria evaluation, and quantitative methods using a probabilistic approach.
In this chapter there are also a number of exercises using Excel for learning the method, and there are several RiskCity exercises:

- Exercise 6a: Qualitative risk assessment
- Exercise 6b: Flood risk assessment
- Exercise 6c: Landslide risk assessment
- Exercise 6d: Earthquake risk assessment
- Exercise 6e: Technological risk assessment
- Exercise 6f: Multi-hazard risk assessment

You can make a choice regarding which of the hazard types you would like to work on. In any case 6a and 6f are for everyone, but you can choose two topics from 6b to 6e depending on your interest. At the end of the session we will give a short self test, in which the main concepts are tested.

Part	Topic	Task	Time required		
6.1	Basic concept of risk analysis	Reading text	Day 1	0.75	1 h
		Task 6.1: Basic risk calculation		0.25	
6.2	Types of risk	Reading text		0.90	2 h
		Task 6.2: Types of losses		0.25	
		Task 6.3: Population risk calculation		0.25	
		Task 6.4: Calculate F-N curves		0.50	
		Task 6.5: Calculate relative risk		0.10	
6.3	Qualitative risk assessment	Reading text	Day 2	0.50	1.5 h
		Task 6.6: RiskCity exercise: qualitative risk assessment		1.00	
6.4	Semi-quantitative risk assessment	Reading text		0.75	1.5 h
		Task 6.7: DRI Index		0.25	
		Task 6.8: Evaluating Global hotspots data with GIS		0.5	
6.5	Quantitative risk assessment	Reading text	Day 3	2.00	10 h
		Task 6.9: Calculation of a risk curve		0.50	
		Task 6.10: Calculate seismic risk		0.50	
			Day 4		
		Task 6.11: RiskCity exercise on quantitative risk assessment: choice option: Flood, Landslide, Earthquake or Technological risk.		2.00	
		Task 6.12: RiskCity exercise on Multi hazard risk assessment		3.00	
		Total	**4 days**		**16 h**

6.1 Basic concept of risk analysis



This session deals with the central theme of this course: risk analysis. This is the next in line of the chain of previous steps related to the identification of the hazards, the hazard assessment, generation of elements at risk data bases, and the vulnerability assessment. The risk assessment consists of two components: risk analysis and risk evaluation. In this session we will look specifically at the risk analysis part. Risk evaluation will be dealt with in the next session.

To start with some working definitions:

Risk Assessment is the process of making a decision or recommendation on whether existing risks are tolerable and present risk control measures are adequate, and if not, whether alternative risk control measures are justified or will be implemented. Risk assessment incorporates the risk analysis and risk evaluation phases
Risk Analysis deals with the use of available information to estimate the risk caused by hazards to individuals or populations, property or the environment, from hazards. Risk analyses generally contain the following steps: definition of scope, danger (threat) identification, estimation of probability of occurrence to estimate hazard, evaluation of the vulnerability of the element(s) at risk, consequence identification, and risk estimation.
Risk evaluation is the stage at which values and judgment enter the decision process, explicitly or implicitly, by including consideration of the importance of the estimated risks and the associated social, environmental, and economic consequences, in order to

There are many ways in which risk, and the individual components of risk, has been defined in literature. In session 1 we have used two equations that represent risk. The first equation represents risk in a qualitative manner:

Risk = Hazard * Vulnerability / Capacity [6.1]

This equation is only conceptual, but allows to incorporate the multi-dimensional aspects of vulnerability, and capacity. In this approach indicators are used to characterize vulnerability and capacity, for instance by relating it with population characteristics as we have seen in the section on vulnerability. These indicators are often integrated with hazard indicators using Spatial Multi-Criteria Evaluation. The result of the equations will show risk only as relative qualitative classes, and allows to compare risk levels between different communities, neighborhoods, cities or even countries. In section 6.2 the techniques for qualitative risk assessment will be treated.
The other approach is called the quantitative one, which tries to quantify the risk according to the risk definition given in session 1. As explained in session 1 this equation has the basic form:

Risk = Hazard * Vulnerability * Amount of elements-at-risk [6.2]

The equation given above is not only a conceptual one, but can also be actually calculated with spatial data in a GIS to quantify risk from hazards. The way in which the amount of elements-at-risk are characterized (e.g. as number of buildings, number of people, economic value or the area of qualitative classes of importance) also defines the way in which the risk is presented. The hazard component in the equation actually refers to the probability of occurrence of a hazardous phenomenon with a given intensity within a specified period of time (e.g. annual probability).
For calculating risk quantitatively using equation 1 the vulnerability is limited to physical vulnerability of the elements-at-risk considered, determined by the intensity of the hazard event and the characteristics of the elements-at-risk (e.g. building type). Table 1 gives a more in-depth explanation of the various components involved.
In order to calculate the specific risk (see table 6.1) equation 6.2 can be modified in the following way:

$$R_S = P_T * P_L * V * A \quad [6.3]$$

in which:

- **P_T** is the temporal (e.g. annual) probability of occurrence of a specific hazard scenario (H_s) with a given return period in an area;
- **P_L** is the locational or spatial probability of occurrence of a specific hazard scenario with a given return period in an area impacting the elements-at-risk. ;
- **V** is the physical vulnerability, specified as the degree of damage to a specific element-at-risk E_s given the local intensity caused due to the occurrence of hazard scenario H_S
- **A** is the quantification of the specific type of element at risk evaluated. It is important to indicate here that the amount can be quantified in different ways, and that the way in which the amount is quantified also the risk is quantified. For instance the amount can be given in numbers, such as the number of buildings (e.g. number of buildings that might suffer damage), number of people (e.g. injuries/ casualties/affected), the number of pipeline breaks per kilometre network, etc. The elements at risk can also be quantified in economic terms.

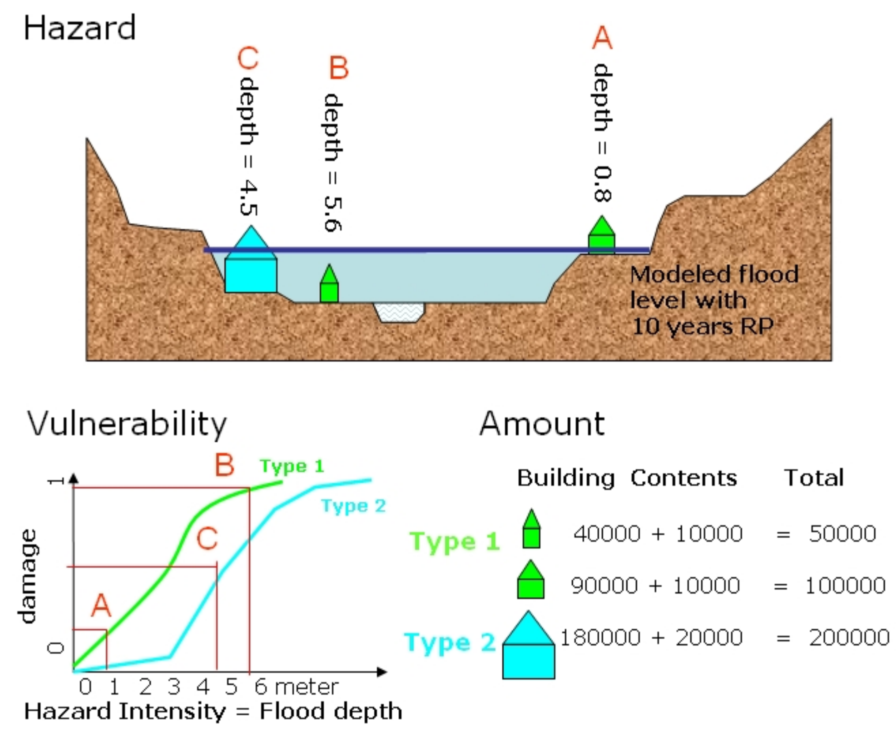
In order to evaluate these components we need to have spatial information as all components of equation [6.3] vary spatially, as well as temporally. The temporal probability of occurrence of the hazard scenario (P_T) has also a spatial component. For example a flood with a given return period has a certain extension, and spatial variation of intensity. The equation [6.3] also contains a term (P_T) indicating the spatial probability of occurrence and impact. This is not relevant for all types of hazards, and in many cases this probability can be indicated as 1, given a specific hazard scenario (e.g. the area that will be flooded given a return period of 50 years). However, for other types of hazards, such as landslides, the location of future events cannot be identified exactly, because the areal unit used in assessing hazard is not always identical to the area specifically impacted by the hazard. For instance, the chance of occurrence of landslides within the high susceptibility zone can be calculated as the ratio of the landslide area to the high susceptible area, multiplied by the ratio of the area of the element of interest to the high susceptible area. The intensity of the hazard varies from place to place (e.g. flood depth, or landslide volume), and the exposure of the elements-at-risk varies. Note that in many risk approaches the term 'exposure of elements-at-risk' is included in the risk equation. When using a GIS approach this is actually redundant information, as a GIS overlay of the hazard footprint with the elements-at-risks will immediate include only the exposed elements-at-risk in the risk equation. The procedure is illustrated in figure 6.2, which shows an example of a floodplain with 3 different buildings (elements at risk) of two different construction types. As discussed in Session 5, these two types of buildings will have a different degree of vulnerability, given the same level of flooding.

Table 6.1: List of terms and definitions used in the GIS-based risk assessment presented in this chapter (based on IUGS, 1997; UN-ISDR, 2004).

Term	Definition	Equations & explanation
Natural hazard (H)	A potentially damaging physical event, phenomenon or human activity that may cause the loss of life or injury, property damage, social and economic disruption or environmental degradation. This event has a probability of occurrence within a specified period of time and within a given area, and has a given intensity.	$\mathbf{P_T}$ is the temporal (e.g. annual) probability of occurrence of a specific hazard scenario (H_s) with a given return period in an area; $\mathbf{P_L}$ is the locational or spatial probability of occurrence of a specific hazard scenario with a given return period in an area impacting the elements-at-risk
Elements-at-risk (E)	Population, properties, economic activities, including public services, or any other defined values exposed to hazards in a given area". Also referred to as "assets".	$\mathbf{E_s}$ is a specific type of elements-at-risk (e.g. masonry buildings of 2 floors)
Vulnerability (V)	The conditions determined by physical, social, economic and environmental factors or processes, which increase the susceptibility of a community to the impact of hazards. Can be subdivided in physical, social, economical, and environmental vulnerability.	**V** is the physical vulnerability, specified as the degrees of damage to E_S given the local intensity caused due to the occurrence of hazard scenario H_S It is expressed on a scale from 0 (no damage) to 1 (total loss)
Amount of elements-at-risk (A_E)	Quantification of the elements-at-risk either in numbers (of buildings, people etc), in monetary value (replacement costs etc), area or perception (importance of elements-at-risk).	**A** is the quantification of the specific type of element at risk evaluated (e.g. number of buildings)
Consequence (C)	The expected losses (of which the quantification type is determined by A_E) in a given area as a result of a given hazard scenario.	**C** is the "specific consequence", or expected losses of the specific hazard scenario which is the multiplication of $V_S * A_{ES}$
Specific risk (R_S)	The expected losses in a given area and period of time (e.g. annual) for a specific set of elements-at-risk as a consequence of a specific hazard scenario with a specific return period.	$R_S = H * V * A$ $R_S = H * C$ $R_S = P_T * P_L * V * A$
Total risk (R_T)	The probability of harmful consequences, or expected losses (deaths, injuries, property, livelihoods, economic activity disrupted or environment damaged) resulting from interactions between natural or human-induced hazards and vulnerable conditions in a given area and time period. It is calculated by first analyzing all specific risks. It is the integration of all specific consequences over all probabilities.	$R_T \approx \sum (R_T) = \sum (H_S * V * A)$ Or better: $R_T = \int (V_S * A_{ES})$ - For all hazard types - For all return periods - For all types of elements-at-risk. It is normally obtained by plotting consequences against probabilities, and constructing a risk curve. The area below the curve is the total risk.

Based on the analysis of historic flood damage for buildings with the same characteristics, flood vulnerability curves have been made, which reflect the relation between the flooddepth and the degree of damage. For this particular section of the flood plain a critical flood depth has been defined, based on inundation modeling as described in session 4. Given the historical discharge information, a flood with the level indicated in figure 6.2 is expected to occur on average every 10 years (the Return period is given as 10 years.). Therefore the annual probability is 0.1 (1/return period). The three elements at risk not only differ in type, but also in their economic value (Amount). For the flood risk estimation both the building value as well as the content value is used.

The approach indicated in table 6.1 is related to the estimation of physical vulnerability, and its use in quantitative risk assessment. It can also be used as the basis for estimating population losses and economic losses. Later on in this session we will see how we can use this approach for probabilistic risk assessment, which calculates the probable losses for many scenarios with different return periods. However, the principle is the same. Hazard information is combined with vulnerability information to produce estimated losses.



Element at risk		Temporal Probability	Amount (economic value)	Vulnerability	**Specific risk**
A		0.1	100000	0.1	1000
B		0.1	50000	1	5000
C		0.1	200000	0.5	10000
					16000

Figure 6.2: Example of a risk estimation for a floodplain with 3 elements at risk of two different types.

Task 6.1: Risk calculation (duration 15 minutes)

A. What would be the annual risk of the buildings in the example in figure 6.2 if all buildings were of type 1?

B. What would be the annual risk of the buildings in the example in figure 6.2 if the return period of the event was 25 years?

C. What would be the annual risk of the buildings in the example in figure 6.2 if the return period of the event was 25 years, after 10 year with an increase in house prices of 10 % per year?

Risk assessments should be (ADPC, 2005):

- **Multi-hazard**: the same area may be threatened by different types of hazards. In the RiskCity exercises we look at four different types: landslides, flooding, earthquakes and technological hazards. Each of these hazard types has different areas that might be impacted by hazard scenarios. Each of the hazard scenarios also might have different magnitudes (see session 3 for a description of the methods used to estimate hazards). For instance water depth and velocity in the case of flooding, acceleration and ground displacement in the case of earthquakes. These hazard magnitudes would also have different impacts on the various elements at risk, and require therefore different vulnerability curves (as discussed in session 5). The scenarios will also have different probabilities of occurrence. Therefore it is important to identify the range of hazards and the impact of these hazards on current and planned investments, on different groups of people, and their ability to resist and cope with the impact of hazards.
- **Multi-sectoral**: hazards will impact different types of elements at risk (See session 4), and it is therefore important to calculate the total effect on them including rural areas and urban areas. In rural areas the impact on agriculture will be very important, but also on the rural population, the transportation network, tourism, mining sector and on the natural environment (protected areas, forests, wetlands etc). In urban areas it is most important to consider the building types, transportation and communication networks, economic activities, people's livelihood, health and education systems, and people's awareness and commitment to protecting themselves. In both situations the risk of current landuse can be estimated, but it is also important to estimate the effect of future planning scenarios. We will look at this aspect later in the RiskCity exercise in session 7.
- **Multi-level**: risk assessment can be carried out at different levels. In session 3 the various levels of hazard assessment were identified. Depending on the objectives of the risk study it is possible to differentiate between national, provincial and local policies, plans and activities to see how they have contributed to increased or reduced risk, their strengths and weaknesses in dealing with risks, and what resources are available at different levels to reduce risks.
- **Multi-stakeholder**: risk assessment should involve the relevant stakeholders, which can be individuals, businesses, organizations, and authorities.
- **Multi-phase**: risk assessment should consider actions for response, recovery, mitigation, and preparedness

Types of risk assessment.

Risk assessments can be carried out with a range of methods, that can be broadly classified into:

- **Qualitative methods**: this results in qualitative descriptions of risk in terms of high, moderate and low. These are used when the hazard cannot be expressed in quantitative terms (the hazard information does not allow to express the probability of occurrence, or it is not possible to estimate the magnitude), and/or when the vulnerability cannot be expressed quantitatively.
- **Semi-quantitative methods**: semi-quantitative techniques express risk in terms of risk indices. These are numerical values, often ranging between 0 and 1, but these do not have a direct meaning of expected losses, but are merely relative indications of risk. Also in this case risk is expressed in a relative sense. These two types of risk are estimated using qualitative risk assessment methods, which will be further explained in section 6.3.
- **Quantitative methods**: they express the risk in quantitative terms either as probabilities, or expected losses. They can be deterministic/scenario-based (looking at a particular scenario) or probabilistic (taking into account the effect of all possible scenarios).

In the next section we will first look at the types of risk before dealing with these three methods of risk assessment.

6.2 Types of risk

Risk is the product of probability and expected losses. Expected losses can be subdivided in many different ways. One of the first and most relevant subdivisions is between direct and indirect losses.

- **Risk for direct losses**: risk assessment that includes those losses resulting directly from the impact of the hazard, for instance buildings that are flooded, or that collapse due to an earthquake, wind damage to infrastructure
- **Risk for indirect losses**: risk assessment that also includes the losses that result due to the event but not by a direct impact, but due to loss of function, for example, disruption of transport, business losses or clean up costs

In both these loss categories, it is possible to make another subdivision:

- **Tangible losses**: loss of things that have a monetary (replacement) value, for example, buildings, livestock, infrastructure etc.
- **Intangible losses**: Loss of things that cannot be bought and sold, for example, lives and injuries, cultural heritage, environmental quality, biodiversity etc.

Yet another subdivision of losses is possible between:

- **Private losses**: losses that affect elements at risk that are privately owned, such as residential buildings and their contents, or businesses. These losses impact private people or companies and their should have them covered by insurance or cope with them by themselves.
- **Public losses**: losses that affect public elements at risk, such as educational sector, institutional sector, lifelines, infrastructure, etc. These losses should be borne by the entire community. In case of large disasters, the community will also take the burden of private losses to homeowners, depending on the government policy.

Task 6.2: Types of losses (duration 15 minutes)
Give an example of the following types of losses:

A. *Tangible, direct, private losses due to an earthquake*
B. *Intangible, indirect, public losses due to a wildfire*
C. *Tangible, indirect losses due a flood in an agricultural area*
D. *Intangible, direct losses due a hurricane.*

Since losses are very diverse, also risk can be expressed in many different ways. The first main differentiation is between qualitative, semi quantitative and quantitative risk (see table 6.2). Risk can be expressed quantitatively, if there is enough information on the individual components of hazard, vulnerability and elements at risk. This can be expressed as a probability value, for a given loss outcome. For instance, the probability of being hit by a rockfall while driving on the road. The Amount part of the risk equation can be expressed in different ways, for instance as:

- **Property risk**: indicating the number of buildings that might be partially damaged / severely damaged or collapsed.
- **Economic risk**: indicating the amount of money that is likely to be lost as a consequence of hazardous phenomena
- **Population risk**: indicating the risk fatality or injury to an individual (individual risk) or to a group of individuals (societal risk)

Table 6.2 Different ways of expressing risk

General	Type	Principle	
Qualitative	**Qualitative**	Based on relative risk classes categorized by expert judgment. Risk classes: High, Moderate and Low	
	Semi-quantitative	Based on relative ranking and weights assignments by a given criteria. Risk index: ranked values (0-1, 0-10 or 0-100). (dimensionless)	
Quantitative	**Probability**	Probabilistic values (0-1) for having a predefined loss over a particular time period	
	Economic risk	Quantification of the expected losses in monetary values over a specific period of time	
		Probable Maximum Loss (PML)	Probable Maximum Loss (PML) The largest loss believed to be possible in a defined return period, such as 1 in 100 years, or 1 in 250 years.
		Average Annual Loss (AAL)	Expected loss per year when averaged over a very long period (e.g., 1,000 years). Computationally, AAL is the summation of products of event losses and event occurrence probabilities for all stochastic events in a loss model.
		Loss Exceedance curve (LEC)	Risk curve plotting the consequences (losses) against the probability for many different events with different return periods.
	Population risk	Quantification of the risk to population	
		Individual risk	The risk of fatality or injury to any identifiable (named) individual who live within the zone impacted by a hazard; or follows a particular pattern of life that might subject him or her to the consequences of a hazard.
		Societal risk	The risk of multiple fatalities or injuries in society as a whole: one where society would have to carry the burden of a hazard causing a number of deaths, injury, financial, environmental, and other losses.

6.2.1 Population risk

Population risk can be expressed as individual risk or societal risk. Individual risk is the risk of fatality or injury to any identifiable (named) individual who lives within the zone impacted by a hazard, or follows a particular pattern of life that might subject him or her to the consequences of a hazard. Table 6.3 gives an example of individual risk for different causes. Individual risk can be calculated as the total risk divided by the population at risk. For example, if a region with a population of one million people experiences on average 5 deaths from flooding per year, the individual risk of being killed by a flood in that region is 5/1,000,000, usually expressed in orders of magnitude as 5×10−6.

Table 6.3:Individual risk

Cause	Probability / year	Cause	Probability / year
All causes (illness)	1.19E-02	Rock climbing	8.00E-03
Cancer	2.80E-03	Canoeing	2.00E-03
Road accidents	1.00E-04	Hang-gliding	1.50E-03
Accidents at home	9.30E-05	Motor cycling	2.40E-04
Fire	1.50E-05	Mining	9.00E-04
Drowning	6.00E-06	Fire fighting	8.00E-04
Excessive cold	8.00E-06	Police	2.00E-04
Lightning	1.00E-07	Accidents at offices	4.50E-06

Societal risk is the risk of multiple fatalities or injuries in the society as a whole, and where society would have to carry the burden of a hazard causing a number of deaths, injury, financial, environmental, and other losses.

Task 6.3: Population risk calculation (duration 15 minutes)

What is the risk of being killed by a rock fall while driving on the road from A to B?

- There are 500,000 cars driving on the road per year, there are 100 accidents due to rockfall on the road each year, 1 in 10 results in death, the average number of persons per car is 2.

A. The number of deaths per year is:
B. The individual risk of having an accident is
C. The individual risk of being killed is:
D. The societal risk is:

Societal risk is generally expressed by f-N or F-N curves (See figure 6.4). When the frequency of events which causes at least N fatalities is plotted against the number N on log log scales, the result is called an F-N curve. The difference between the frequency of events with N or more fatalities, F(N), and that with N+1 or more, F(N+1), is the frequency of events with exactly N fatalities, usually represented by f(N), with lower-case f. Because f(N) must be non-negative, it follows that F(N) ≥ F(N+1) for all N, so that FN-curves never rise from left to right, but are always falling or flat. The lower an FN-curve is located on the FN-graph, the safer is the system it represents, because lower FN-curves represent lower frequencies of fatal events than higher curves. The value F(1) is the frequency of accidents with 1 or more fatalities, or in other words the overall frequency of fatal accidents. This is the left-hand point on FN-curves, where the curve meets the vertical axis (usually located at N = 1 with logarithmic scales).
If the frequency scale is replaced by annual probability, then the resultant curve is called f-N curve. F-N curves can be constructed based on historical data in the form of number of events (floods, landslides, etc) and related fatalities. They can also be based on different future risk scenarios, in which for a number of events with different magnitudes the number of casualties is estimated using the methods that will be explained in this chapter. Then the F-N curve displays the future risk. The curves can be constructed for different spatial units. These can be country, province, municipality, but also a community or even a building block within a neighborhood. F-N curves are very important because they form the basis for developing societal acceptability and tolerability levels. This will be treated in session 7, in the section dealing with risk evaluation.

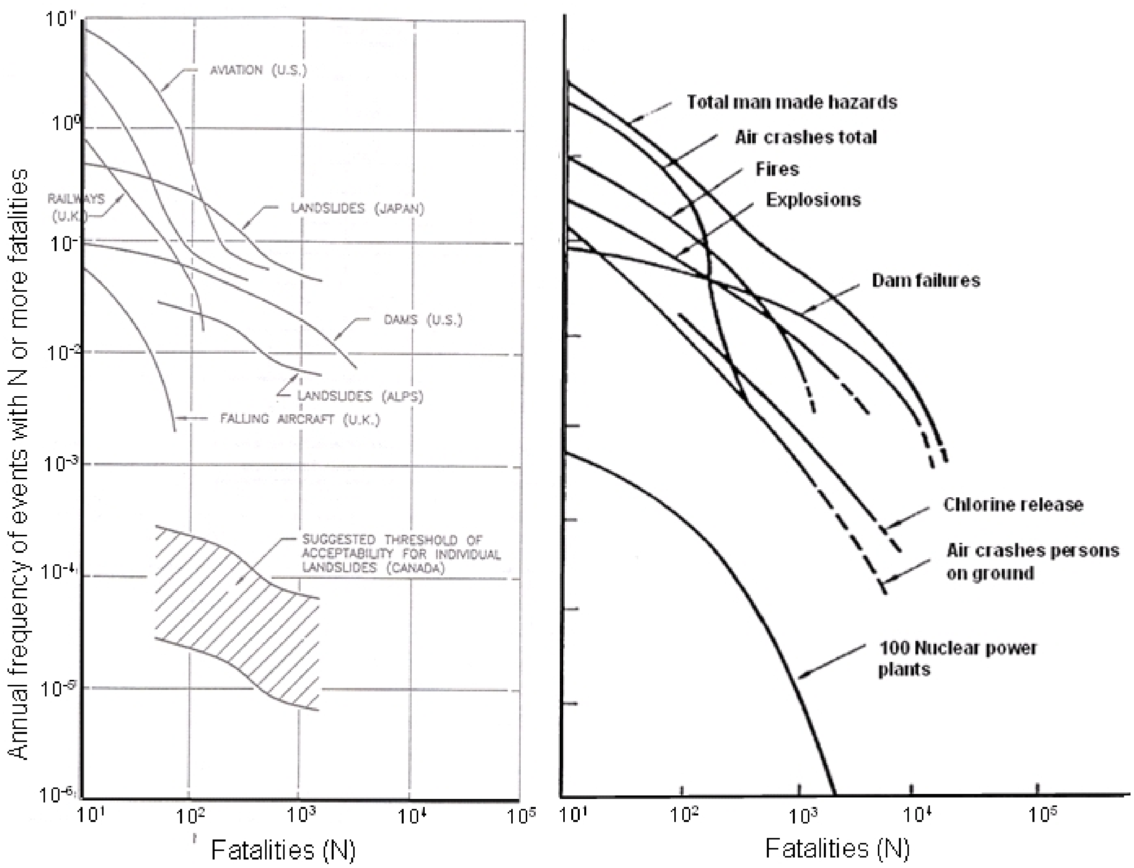


Figure 6.4: Left: F-N curves showing the number of fatalities against annual frequency. For natural and man-made hazards

Task 6.4: Calculate F-N curves (duration 30 minutes)
In this exercise you will calculate F-N curves for accidents that have occurred in Europe in the period 1967 to 2001. Three different types of accident data area available: for roads, railroad and aviation. The analysis is based on empirical data, collected from historical accidents records. In the excel file task 6.4 you can find the data, and the general schedule for generating the F-N curve. The figure below shows the structure of the Excel file.
To calculate the F-N curve take the following steps:

1. First calculate the total number of fatalities for road, railroad and aviation accidents by multiplying the number of events with the fatality class. Also calculate the average number of fatalities per year..
2. The calculate the cumulative number of events, starting with the lowest one in the table (related to 146 fatalities) and summing them up upwards.
3. Then calculate the cumulative frequency of events per year, by dividing the cumulative number by the number of years.
4. Plot these values in the graph indicated at the bottom of the spreadsheet in a log-log manner, with Fatalities (N) or the X-axis, and the cumulative frequency per year on the Y-Axis.
5. Compare the results. What can you conclude on the:
   - Severity of the accident type
   - Frequency of the accident type

What are the shortcomings of such a way of representation?
This example was taken from the following source:
http://www.hse.gov.uk/research/rrpdf/rr073.pdf

	Road	Rail	Aviation
From	1969	1967	1967
To	2001	2001	2001
Period	33	35	35

	Number of events			Fatalities			Cumulative number of events			Cumulative frequency per year		
Fatalities	Road	Rail	Aviation	Road	Rail	Aviation	Road	Rail	Aviation	Road	Rail	Aviation
1	151,722	2,284	330									
2	9,350	78	178									
3	1,612	16	50									
4	443	9	46									
5	138	6	7									
6	39	3	10									
7	9	3	1									
8	5	0	2									
9	6	2	0									
10	5	2	1									
11	0	1	2									
12	0	1	1									
13	5	1	1									
17	0	0	1									
20	1	0	1									
31	0	2	0									
32	1	0	0									
35	0	1	0									
43	0	1	0									
45	0	0	1									
47	0	0	1									
48	0	0	1									
49	0	1	0									
55	0	0	1									
63	0	0	2									
66	0	0	1									
72	0	0	1									
88	0	0	1									
104	0	0	1									
112	0	0	1									
118	0	0	1									
146	0	0	1									
Total	163,336	2,411	644	0	0	0						
per year	4949.6	68.9	18.4	0.0	0.0	0.0						

Relative risk is a term used originally in epidemiology to indicate the ratio between the probability of the event occurring in an exposed group versus a non-exposed group. This would be the case for example of people developing a certain disease which are exposed to a certain chemical during an industrial accident.

$$RR = \frac{p_{\mathrm{exposed}}}{p_{\mathrm{non-exposed}}} \quad [6.5]$$

In table 6.4 this would be indicated as:

Relative Risk = (E+ / (E+ + E-)) / (N+ / (N+ + N-)) [6.6]

Table 6.4: Relative risk calculation

	Exposed group	Non-exposed group
Cases with positive outcome	E+ = 300	N+ = 3
Cases with negative outcome	E- = 1000	N- = 1000

Related to that is the so-called **Odds ratio**:

Odds ratio = (E+ + N+) / (E- + N-) [6.7]

Task 6.5: Calculate relative risk and odds ratio (duration 5 minutes)
Calculate the relative risk and the odds ratio for the values from table 6.3
Relative risk = 300/1100 / 10/1010 =
Odds ratio =

6.2.2 Economic losses

There are several ways to express economic losses. The Probable Maximum Losses (PML) is the largest loss believed to be possible in a defined return period, such as 1 in 100 years, or 1 in 250 years. In figure 6.5 (left) the PML for 1 in 1000 years is 1400. The risk can also be represented as a curve, in which all scenarios are plotted with their return periods or probability and associated losses. Such a risk curve is also called the Loss Exceedance Curve (LEC). Figure 6.5 shows two ways to represent such a curve. The left one has the advantage that it is better visible which return periods have the largest contribution to losses. The right curve can be used directly to calculated the Average Annual Losses (AAL). This is done by calculating the area under the curve (See also section 6.5.5).

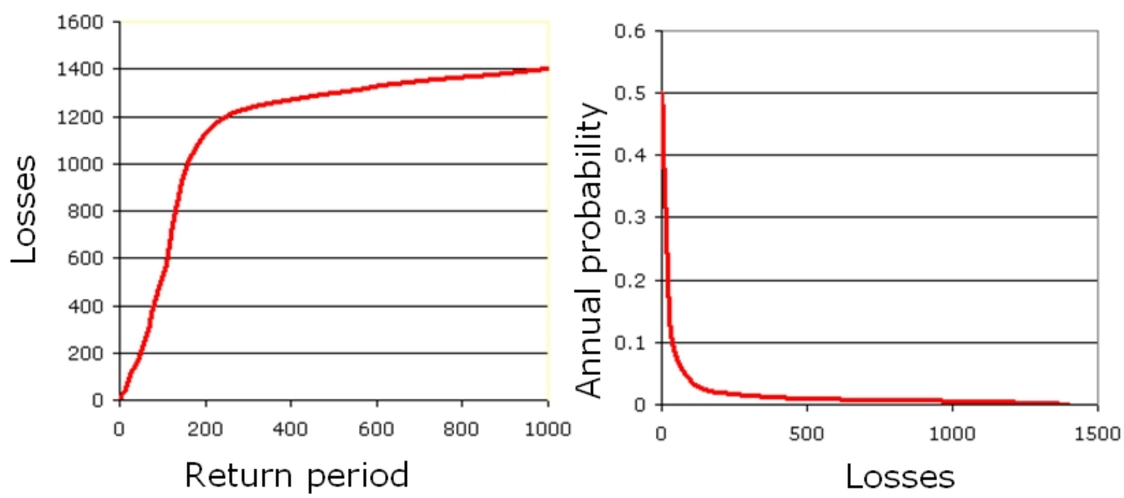


Figure 6.5: Two ways to represent a risk curve. Left: Plotting losses against return period. Right: plotting losses against annual probability. Losses are in 10^6

6.3 Qualitative risk assessment

The qualitative approach is based on the experience of the experts and the risk areas are categorized with terms as 'very high', 'high', 'moderate', 'low' and 'very low' risk. The number of qualitative classes varies but generally three or five classes are accepted which should have a direct line with practical indications (e.g. in very high risk areas: 'immediate physical and no-physical remedial measures are required and no more infrastructure development must be allowed in this area'). Fell (1994) proposed terminology definitions for qualitative risk assessment considering classes for magnitude, probability, hazard, vulnerability and specific risk. A terminology proposal guideline for assessing risk to property was developed by the Australian Geomechanics Society and the Sub-committee on Landslide Risk Management (AGS, 2000) considering a combination of likelihood and the possible consequences as shown in Table 6.5. This method is applicable for spatial analysis using GIS. These approaches are usually applied at national or regional levels as in these scales the quantitative variables are not available or they need to be generalized.

Table 6.5: Qualitative risk analysis matrix – level of risk to property (AGS, 2000). VH: Very High, H: High, M: Moderate, L: Low and VL: Very Low risk.

Likelihood	Consequences				
	Catastrophic	Major	Medium	Minor	Insignificant
Almost certain	VH	VH	H	H	M
Likely	VH	H	H	M	L-M
Possible	H	H	M	L-M	VL-L
Unlikely	M-H	M	L-M	VL-L	VL
Rare	M-L	L-M	VL-L	VL	VL
Not credible	VL	VL	VL	VL	VL

Such as method can be used for situations where an inexpensive and fast method is required for risk assessment. The methods use a scoring and weighting approach emphasising on quantifying the subjective components involved in the risk assessment procedure as much as possible, defining terms as precisely and clearly possible and development of categories of hazard, consequence and risk that may be presented in a quantitative format. Once the hazard has been qualitatively estimated, the consequence is assessed for different elements at risk like railway lines, roads, etc. For each type the consequences are rated into the levels (e.g. VH, H, M, L, VL). See for example table 6.6 from Ko Ko et al. (2004).

Table 6.6: Qualitative assessment (Ko Ko et al., 2004).

Score	Description	Annual probability	Hazard level
>100	The event is expected and may be triggered by conditions expected over a 5 year period	> 0.2 (within 5 years)	Very High (VH)
80 - <100	The event may be triggered by conditions expected over a 5-50 year period	0.2 – 0.02 (within 5 to 50 years)	High (H)
60 - <80	The event may be triggered by conditions expected over a 50-500 year period	0.02 - 0.002	Medium (M)
40 - <60	The event may be triggered by conditions expected over a 500-5000 year period	0.002 – 0.0002 (within 500 to 5000 years)	Low (L)
<40	The event is possible and may be triggered by exceptional circumstances over a period exceeding 5000 year	> 0.0002 (> 5000 years)	Very Low (VL)

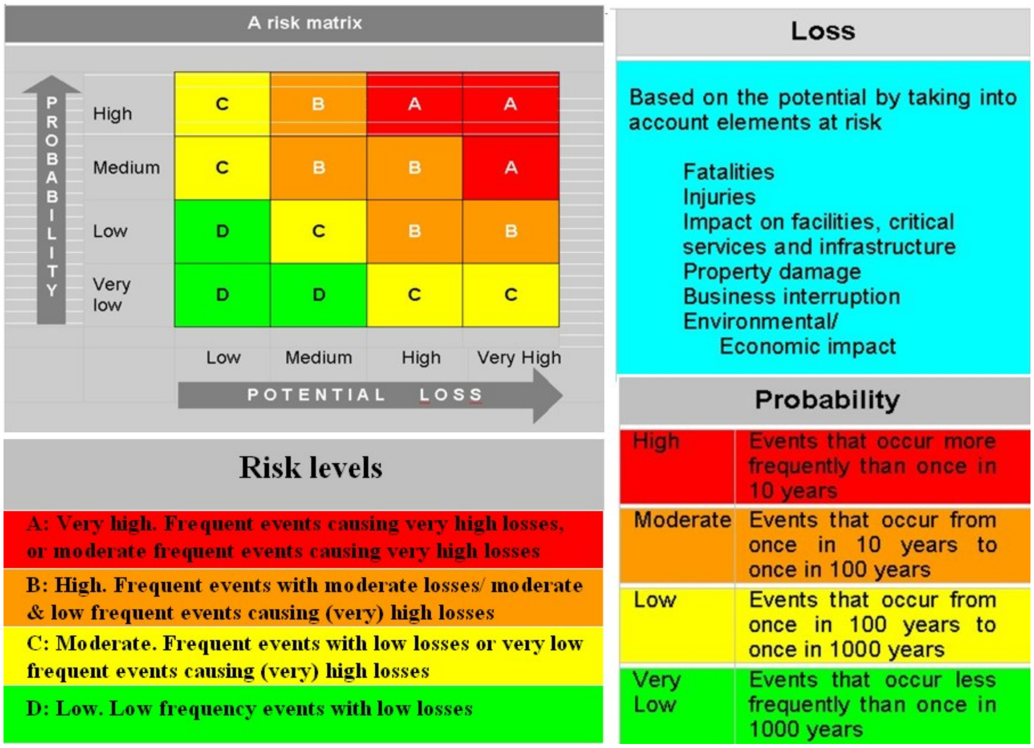


Figure 6.6: Example of a qualitative risk matrix, combining probability of the event with the potential losses.

Position of site (Distance from the phenomenon) (far) → (close)		Site: level of stake (-) → (+)			
		Null (0)	Low (10)	Moderate (30)	High (100)
	Far (0.2)	0	2	6	20
	Moderatly far (0.5)	0	5	15	50
	Close (0.9)	0	9	27	90
	Very close (1)	0	10	30	100

Final stake

- Null
- Low
- Moderate
- High

Figure 6.7: Example of a qualitative risk matrix relating the distance of the stake (=element at risk) and the importance level of the stake to risk classes, as used in France.

Task 6.6: RiskCity exercise for qualitative risk assessment (duration 1 hour)

Go to the RiskCity exercise 6 dealing with qualitative landslide risk assessment, which is an example of the use of a risk matrix, combining qualitatively vulnerability with hazards.

6.4 Semi quantitative landslide risk assessment

The main difference between qualitative and semi-quantitative approaches is the assignment of weights under certain criteria which provide numbers as outcome instead of qualitative classes. The semi quantitative estimation for risk assessment is found useful in the following situations i) as an initial screening process to identify hazards and risks; ii) when the level of risk (pre-assumed) does not justify the time and effort and iii) where the possibility of obtaining numerical data is limited. Semi-quantitative approaches consider a number of factors that have an influence on the risk. A range of scores and settings for each factor may be used to assess the extent to which that factor is favourable or unfavourable to the occurrence of instability (hazard) and the occurrence of loss or damage (consequence). The matrix of hazards and consequences is used to obtain a ranked risk value. This is made by combining a set of hazard categories with a set of consequence categories. The final risk values can also be categorised and ranked with qualitative implications. The risk estimation can be done separately for loss of life and economic loss.

The semi-quantitative approach could be adapted to cover larger areas (spatial or GIS-based). In any case, there will always be the dilemma of adapting the scoring system to each particular region. This approach may be applicable at any scale or level of analysis, but more reasonably used in medium scales. Nowadays, such a semi-quantitative approach can efficiently use spatial multi-criteria techniques implemented in GIS that facilitate standardization, weighting and data integration in a single set of tools. In this section on semi-quantitative methods we will look at two different approaches:

- Risk indices
- Spatial Multi Criteria Evaluation

6.4.1 Spatial Multi-Criteria Evaluation

In session 5 the concept of Spatial Multi Criteria Evaluation (SMCE) was presented. SMCE is a very important tool for both vulnerability as well as hazard assessment. Figure 6.8 gives an example of the use of SMCE for the generation of a risk index for landslides for the country of Cuba (Castellanos and Van Westen, 2007). In this example a risk index is generated by combining a hazard index and a vulnerability index. The hazard index is made using indicator maps related to triggering factors (earthquakes and rainfall) and environmental factors. The vulnerability index is made using four groups of indicators. Initially a total of 43 vulnerability indicators were considered to be used in this study at the national level, and the Cuban National Statistical Office was asked to provide information on these. However, due to the fact that not all information could be obtained, and the high correlation between several of the initially selected indicators, the total number was reduced to five key indicators: housing condition and transportation (physical

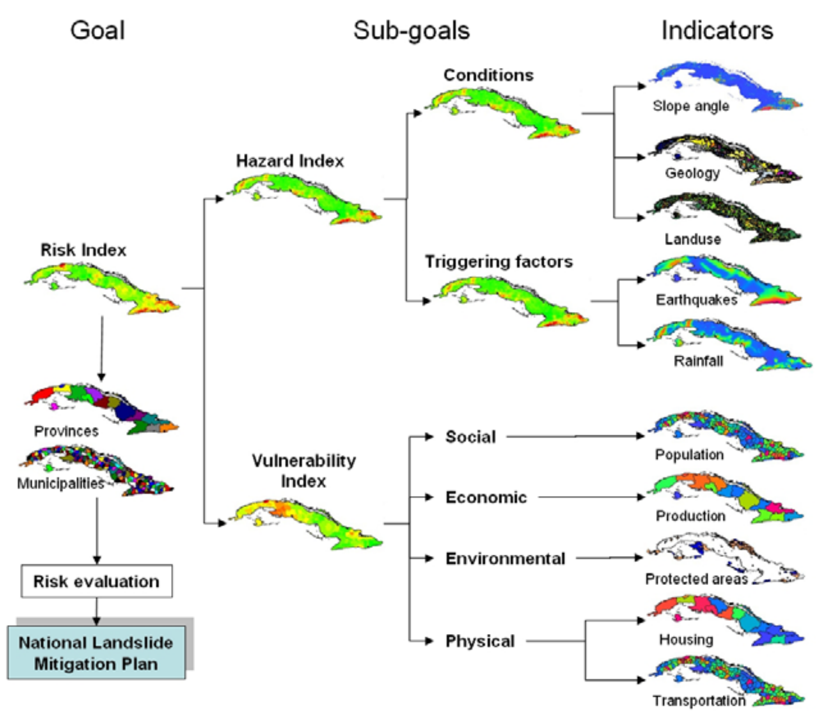


Figure 6.8: Schematic flowchart for the assessment of a national risk index for landslides in Cuba, using spatial multi criteria evaluation (source: Castellanos and Van Westen, 2007)

vulnerability indicators), population (social vulnerability indicator), production (economic vulnerability indicator) and protected areas (environmental vulnerability indicator). The indicators are based on polygons related to political-administrative areas, which are mostly at municipal level. Each indicator was processed, analysed and standardized according to its contribution to hazard and vulnerability. The indicators were weighted using direct, pairwise comparison and rank ordering weighting methods and weights were combined to obtain the final landslide risk index map. The results were analysed per physiographic region and administrative units at provincial and municipal levels. The final risk map is presented in Figure 6.9.

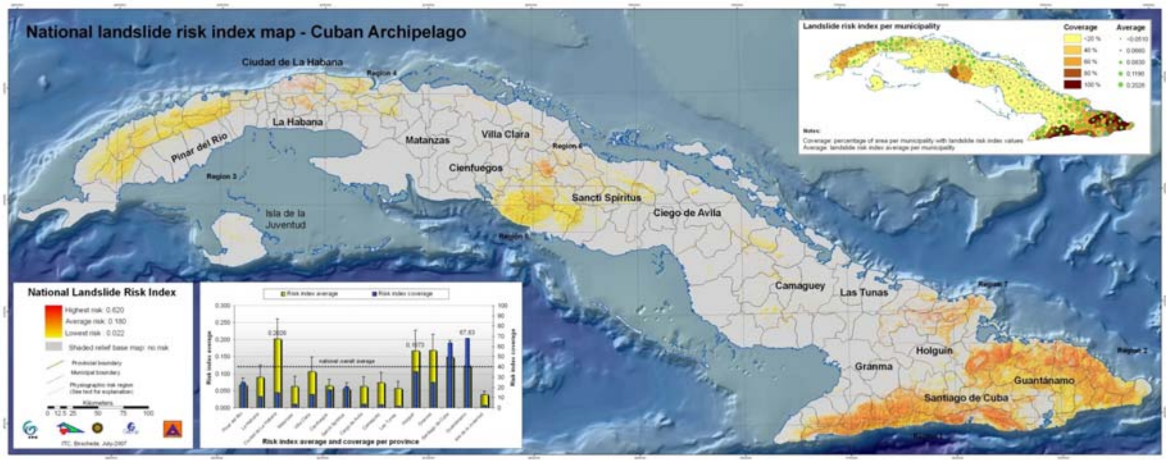


Figure 6.9: Final landslide risk index map for Cuba made using spatial multi criteria evaluation.

6.4.2 Risk indices

There are many methods in which such risk indices have been used in combination with SMCE. This section will present some examples.

Disaster Risk Index (DRI):
This measures the physical exposure and relative vulnerability of a country. The DRI enables the calculation of the average risk of death per country in large- and medium-scale disasters associated with earthquakes, tropical cyclones, and floods based on data from 1980 to 2000. It also enables the identification of a number of socio-economic and environmental variables that are correlated with risk of death and which may point to causal processes of disaster risk. In the DRI, countries are indexed for each hazard type according to their degree of physical exposure, their degree of relative vulnerability, and their degree of risk (UNDP, 2004a; UNDP, 2004b).

Task 6.7: DRI index (duration 15 minutes)
The DRI index can also be consulted as an interactive tool on internet
Go to the following website: http://gridca.grid.unep.ch/undp/
Select your own country and view the risk profile. Compare your country with another one.

IDB Indicator System: this method uses a set of indicators for benchmarking countries in different periods (e.g. from 1980 to 2000) to make cross-national comparisons in a systematic and quantitative fashion. Each index has a number of variables that are associated with it and empirically measured. The choice of variables is driven by a consideration of a number of factors including: country coverage, the soundness of the data, direct relevance to the phenomenon that the indicators are intended to measure, and quality. Four components or composite indicators reflect the principal elements that represent vulnerability and show the advances of different countries in risk management: Disaster Deficit Index, Local Disaster Index, Prevalent Vulnerability Index and Risk Management Index. See also: http://idea.unalmzl.edu.co . The following boxes explain the four indicators that are used.

The following description of the IDB system of indicators developed by A.D. Cardona can be found in: http://www.unisdr.org/HFdialogue/download/tp3-paper-system-indicators.pdf

The **Disaster Deficit Index** measures country risk from a macroeconomic and financial perspective according to possible catastrophic events. It requires the estimation of critical impacts during a given period of exposure, as well as the country's financial ability to cope with the situation.

$$DDI = \frac{MCE\ loss}{Economic\ Resilience}$$

The losses occurring in a Maximum Considered Event (MCE) represent the maximum direct economic impact in probabilistic terms on public and private stocks that are governments' responsibility. This is a fraction of the total loss LR which is estimated as :

$$L_R = E\,V(I_R F_S)\,K$$

where, E is the economic value of all the property exposed; V( ) is the vulnerability function, which relates the intensity of the event with the fraction of the value that is lost if an event of such intensity takes place; I_R is the intensity of the event associated to the selected return period; F_S is a factor that corrects intensities to account for local site effects; and K is a factor that corrects for uncertainty in the vulnerability function.

Economic resilience is a composite index which is made by combining 5 indicators:

- Insurance and reassurance payments (F1p)
- Reserve funds for disasters (F2p)
- Aid and donations (F3p)
- New taxes (F4p)
- Budgetary reallocations (F5p)
- External credit (F6p)
- Internal credit (F7p)

A DDI greater than 1.0 reflects the country's inability to cope with extreme disasters even by going into as much debt as possible. The greater the DDI, the greater the gap between losses and the country's ability to face them.

The **Local Disaster Index** identifies the social and environmental risks resulting from more recurrent lower level events (which are often chronic at the local and subnational levels). These events have a disproportionate impact on more socially and economically vulnerable populations, and have highly damaging impacts on national development. The LDI is equal to the sum of three local disaster subindices that are calculated based on data from the DesInventar database (made by the Network of Social Studies in Disaster Prevention of Latin America, La RED in Spanish) for number of deaths K, number of people affected A, and losses L in each municipality, taking into account four wide groups of events: landslides and debris flows, seismo-tectonic, floods and storms, and other events.

$$LDI = LDI_K + LDI_A + LDI_L$$

The LDI captures simultaneously the incidence and uniformity of the distribution of local effects. That is, it accounts for the relative weight and persistence of the effects attributable to phenomena that give risk to municipal scale disasters. The higher the relative value of the index, the more uniform the magnitude and distribution of the effects of various hazards among municipalities. A low LDI value means low spatial distribution of the effects among the municipalities where events have occurred.

The **Prevalent Vulnerability Index** is made up of a series of indicators that characterize prevalent vulnerability conditions reflected in exposure in prone areas, socioeconomic weaknesses and lack of social resilience in general.

$$PVI = PVI_{ES} + PVI_{SF} + PVI_{LR}$$

The weighting technique used to obtain the PVI was the Analytic Hierarchy Process (AHP); a widely used technique for multi attribute decision making proposed by Saaty (1980, 1987). This is also further explained in the next section.

An overview of indicators to determine PVI is shown below.

Description	Indicator	Weight		
Population growth, average annual rate (%)	ES1	w1	PVI_{ES}	PVI
Urban growth, avg. annual rate (%)	ES2	w2	PVI_{ES}	PVI
Population density, people/5 Km²	ES3	w3	PVI_{ES}	PVI
Poverty-population below US$ 1 per day PPP	ES4	w4	PVI_{ES}	PVI
Capital stock, million US$ dollar/1000 km²	ES5	w5	PVI_{ES}	PVI
Imports and exports of goods and services, % GDP	ES6	w6	PVI_{ES}	PVI
Gross domestic fixed investment, % of GDP	ES7	w7	PVI_{ES}	PVI
Arable land and permanent crops, % land area	ES8	w8	PVI_{ES}	PVI
Human Poverty Index, HPI-1	SF1	w1	PVI_{SF}	PVI
Dependents as proportion of working age population	SF2	w2	PVI_{SF}	PVI
Social disparity, concentration of income measured using Gini index	SF3	w3	PVI_{SF}	PVI
Unemployment, as % of total labor force	SF4	w4	PVI_{SF}	PVI
Inflation, food prices, annual %	SF5	w5	PVI_{SF}	PVI
Dependency of GDP growth of agriculture, annual %	SF6	w6	PVI_{SF}	PVI
Debt servicing, % of GDP	SF7	w7	PVI_{SF}	PVI
Human-induced Soil Degradation (GLASOD)	SF8	w8	PVI_{SF}	PVI
Human Development Index, HDI [Inv]	LR1	w1	PVI_{LR}	PVI
Gender-related Development Index, GDI [Inv]	LR2	w2	PVI_{LR}	PVI
Social expenditure; on pensions, health, and education, % of GDP [Inv]	LR3	w3	PVI_{LR}	PVI
Governance Index (Kaufmann) [Inv]	LR4	w4	PVI_{LR}	PVI
Insurance of infrastructure and housing, % of GD [Inv]	LR5	w5	PVI_{LR}	PVI
Television sets per 1000 people [Inv]	LR6	w6	PVI_{LR}	PVI
Hospital beds per 1000 people [Inv]	LR7	w7	PVI_{LR}	PVI
Environmental Sustainability Index, ESI [Inv]	LR8	w8	PVI_{LR}	PVI

The **Risk Management Index** brings together a group of indicators that measure a country's risk management performance. These indicators reflect the organizational, development, capacity and institutional actions taken to reduce vulnerability and losses, to prepare for crisis and to recover efficiently from disasters.

The RMI was constructed by quantifying four public policies, each of which has six indicators. The policies include the identification of risk, risk reduction, disaster management, and governance and financial protection. Risk identification (RI) is a measure of individual perceptions, how those perceptions are understood by society as a whole, and the objective assessment of risk. Risk reduction (RR) involves prevention and mitigation measures. Disaster management (DM) involves measures of response and recovery. And, finally, governance and financial protection (FP) measures the degree of institutionalization and risk transfer.

$$RMI = (RMI_{RI} + RMI_{RR} + RMI_{DM} + RMI_{FP}) / 4$$

Also this index is made using a set of indicators:

Indicator	Description	Weight		
RI1	Systematic disaster and loss inventory	w_{RI1}	RMI_{RI}	RMI
RI2	Hazard monitoring and forecasting	w_{RI2}	RMI_{RI}	RMI
RI3	Hazard evaluation and mapping	w_{RI3}	RMI_{RI}	RMI
RI4	Vulnerability and risk assessment	w_{RI4}	RMI_{RI}	RMI
RI5	Public information and community participation	w_{RI5}	RMI_{RI}	RMI
RI6	Training and education on risk management	w_{RI6}	RMI_{RI}	RMI
RR1	Risk consideration in land use and urban planning	w_{RR1}	RMI_{RR}	RMI
RR2	Hydrographical basin intervention and environmental protection	w_{RR2}	RMI_{RR}	RMI
RR3	Implementation of hazard-event control and protection techniques	w_{RR3}	RMI_{RR}	RMI
RR4	Housing improvement and human settlement relocation from prone-areas	w_{RR4}	RMI_{RR}	RMI
RR5	Updating and enforcement of safety standards and construction codes	w_{RR5}	RMI_{RR}	RMI
RR6	Reinforcement and retrofitting of public and private assets	w_{RR6}	RMI_{RR}	RMI

Indicator	Description	Weight		
DM1	Organization and coordination of emergency operations	w_{DM1}	RMI_{DM}	RMI
DM2	Emergency response planning and implementation of warning systems	w_{DM2}	RMI_{DM}	RMI
DM3	Endowment of equipments, tools and infrastructure	w_{DM3}	RMI_{DM}	RMI
DM4	Simulation, updating and test of inter institutional response	w_{DM4}	RMI_{DM}	RMI
DM5	Community preparedness and training	w_{DM5}	RMI_{DM}	RMI
DM6	Rehabilitation and reconstruction planning	w_{DM6}	RMI_{DM}	RMI
FP1	Interinstitutional, multisectoral and decentralizing organization	w_{FP1}	RMI_{FP}	RMI
FP2	Reserve funds for institutional strengthening	w_{FP2}	RMI_{FP}	RMI
FP3	Budget allocation and mobilization	w_{FP3}	RMI_{FP}	RMI
FP4	Implementation of social safety nets and funds response	w_{FP4}	RMI_{FP}	RMI
FP5	Insurance coverage and loss transfer strategies of public assets	w_{FP5}	RMI_{FP}	RMI
FP6	Housing and private sector insurance and reinsurance coverage	w_{FP6}	RMI_{FP}	RMI

The IDB indicator system was designed to measure indicators at national level using existing information from existing national and international databases. Although it can be used at local level, it was primarily designed for national and sub-national comparisons. It gives a complete idea of how vulnerable a country is, according to the hazards that affect it.

Seismic Risk Index (SRI): Is a composite index that measures risk to earthquakes within cities. First, the model defines the physical seismic risk index (also called hard) based on descriptors obtained from estimating potential urban losses due to future earthquakes. Second, it defines the context seismic risk index (also called soft) obtained as the scaled product of the seismic hazard and context vulnerability descriptors. Both the physical seismic risk index and the context seismic risk index are combined using weights (Cardona, 2001a).
The DRI measures risks for country indexation purposes; therefore, it uses national indicators such as GDP (Gross Domestic Product) or HDI (Human Development Index). On the other hand, the EDRI measures risk at city level, but as a general index for comparison with other cities worldwide. None of the results of these indices can be used at the local level for risk reduction practices. In the case of the SRI, the measurement of risk can be performed within cities, allowing for comparison at different aggregation levels. No matter how the different authors group the vulnerability factors in all three indices, the information used for the assessment is basically the same, except when the SRI is used to assess risk within a city, where more detailed information is needed

Global Hotspots Project
The Hotspots project generated a global disaster risk assessment and a set of more localized or hazard-specific case studies. The method is based on the EM-DAT database (see session 1). (http://www.cred.be). The study assessed the global risk for mortality and economic losses, by combining hazard exposure with historical vulnerability for two indicators of elements at risk—gridded population and Gross Domestic Product (GDP) per unit area and for six major natural hazards: earthquakes, volcanoes, landslides, floods, drought, and cyclones. By calculating qualitative risks for each grid cell rather than for countries as a whole, we are able to estimate risk levels at sub-national scales.

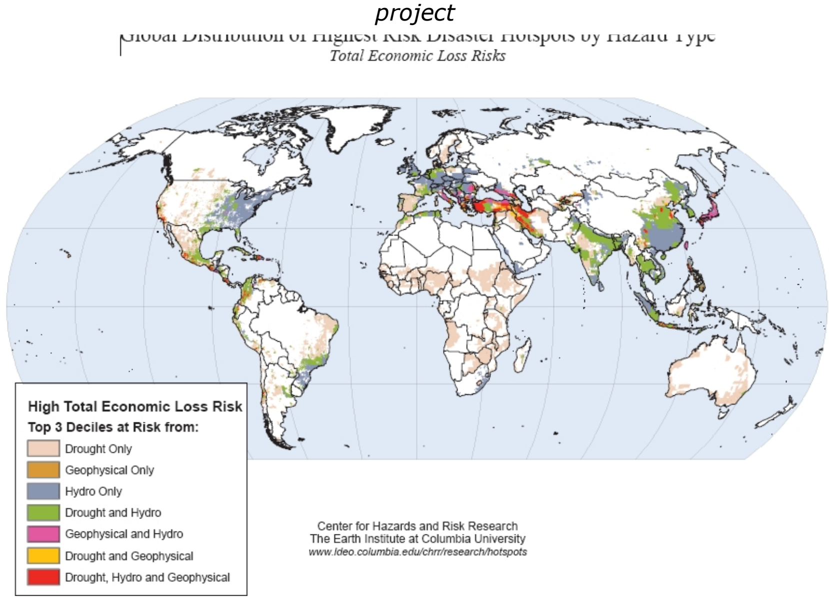


Figure 6.10: Example of a map of the Global Disaster Hotspots project

Task 6.8: Evaluating Global hotspots data with GIS (duration 30 minutes)

The data for the Global hotspots project can be downloaded from the following website:
http://www.ldeo.columbia.edu/chrr/research/hotspots/
We have downloaded a few of the data layers for you, and have also converted them into ILWIS, and added a vector map of the world: global multi-hazard economic risk and global multi-hazard mortality.
Open the maps with ILWIS and add the vector map of the world to it. Evaluate how the risk information is for your own country.
You can also download and import more specific information from the website. Make sure to import the .ASC files into ILWIS.

6.5 Quantitative risk assessment

Quantitative risk assessment aims at quantifying the risk according to equation 6.3. In this method the combined effects in terms of losses for all possible scenarios that might occur are calculated. There are several approaches. Although there are certain similarities, some differences appear between the approaches. They include either the way to calculate the hazard or to calculate vulnerability and consequence. Commonly agreement was found among the methods in combining hazard as probability of the hazard and vulnerability as consequences. For a number of different hazard scenarios the consequences are plotted against the temporal probability of occurrence of the hazard events in a graph. Through these points a curve is fitted, the so-called risk curve, and the area below the curve presents the total risk. In a multi-hazard risk assessment this procedure is carried out for all individual hazard types, and care should be taken to evaluate also interrelations between hazards (e.g. domino effects, such as a landslide damming a river and causing a flood). Since the risk is normalized into annual risk, it is then possible to evaluate the multi-hazard risk, and use the risk curves as the basis for disaster risk reduction.

6.5.1 Flood risk

In this section examples are given of the use of probabilistic risk assessment for flooding, landslides and earthquakes.

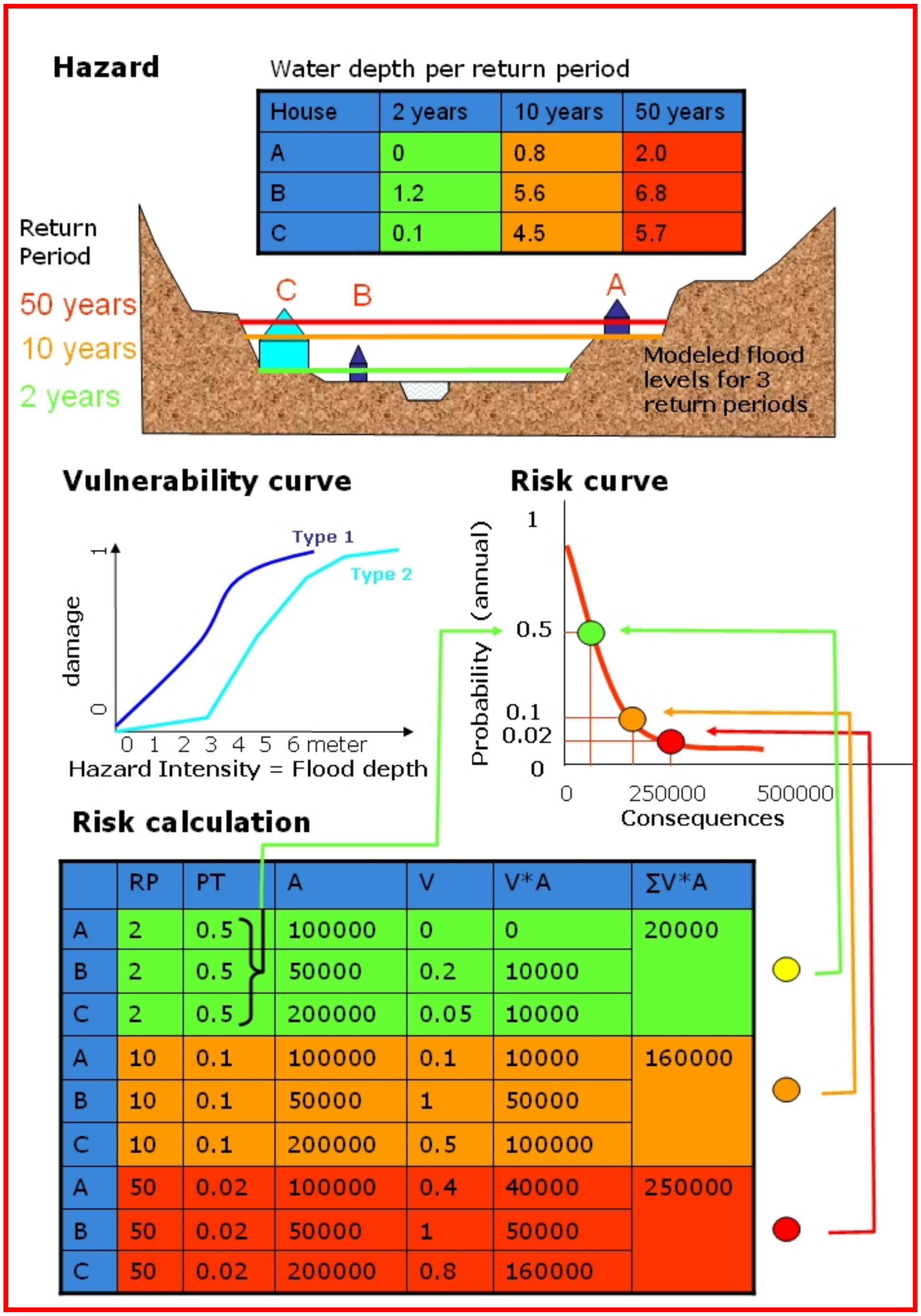
Figure 6.11 gives an example of a probabilistic risk assessment for building that are threatened to flooding. Whereas is figure 6.2 only one flooding scenario was given, we now have three different scenarios, each with a different probability of occurrence (2 years, 10 years and 50 years). These scenarios are derived from the hazard modeling approaches presented in session 3. In this simple example there are 3 elements at risk only (buildings) that are of two types. Type-1 buildings are weaker in construction than type-2 buildings. Based on past occurrences of flooding a relation has been made between the water depth and the degree of damage using vulnerability curves (explained in chapter 5). This means that with the same water depth type-1 buildings will suffer more damage than type-2 buildings. The vulnerability curves presented in figure 6.11 are hypothetical ones, but are the crucial component in the risk assessment. The three hazard scenarios will affect the three buildings in a different way. The small table in figure 6.11 indicates the water depth that can be expected for the three houses related to the three scenarios.
In the risk calculation presented in the lower table of figure 6.11, the following types of information are determined for each element at risk:

- PT = annual probability of occurrence of the scenarios (this was treated in session 3.1). The annual probability is calculated as the reciprocal of the return period.
- A = the quantification of the elements at risk. In this case the quantification is done in monetary values, including both the structure and the contents of the buildings.
- V = the vulnerability of the building for the specific flood scenario. This is done by relating the flood depth with the damage amount according to the vulnerability curve.
- V * A = the consequences. The expected losses per building for a given flood scenario is calculated by multiplying the vulnerability with the amount of elements at risk.
- ∑ V * A = the total consequences of a flood scenario for all elements at risk exposed to the scenario.

The values of the total consequences per scenario(∑ V * A) are plotted against the temporal probability (PT) in a graph. Each scenario represents on point, and the location depends on the probability of occurrence and the total consequences. If you have at least three scenarios it is possible to plot a curve through the points, which is called the risk curve, or the Loss Exceedance Curve (LEC).

The total area under the curve represents the total annual risk for flooding.

The definition of an accurate Loss Exceedance Curve requires information on many hazard scenarios.



House	2 years	10 years	50 years
A	0	0.8	2.0
B	1.2	5.6	6.8
C	0.1	4.5	5.7

	RP	PT	A	V	V*A	ΣV*A
A	2	0.5	100000	0	0	20000
B	2	0.5	50000	0.2	10000	
C	2	0.5	200000	0.05	10000	
A	10	0.1	100000	0.1	10000	160000
B	10	0.1	50000	1	50000	
C	10	0.1	200000	0.5	100000	
A	50	0.02	100000	0.4	40000	250000
B	50	0.02	50000	1	50000	
C	50	0.02	200000	0.8	160000	

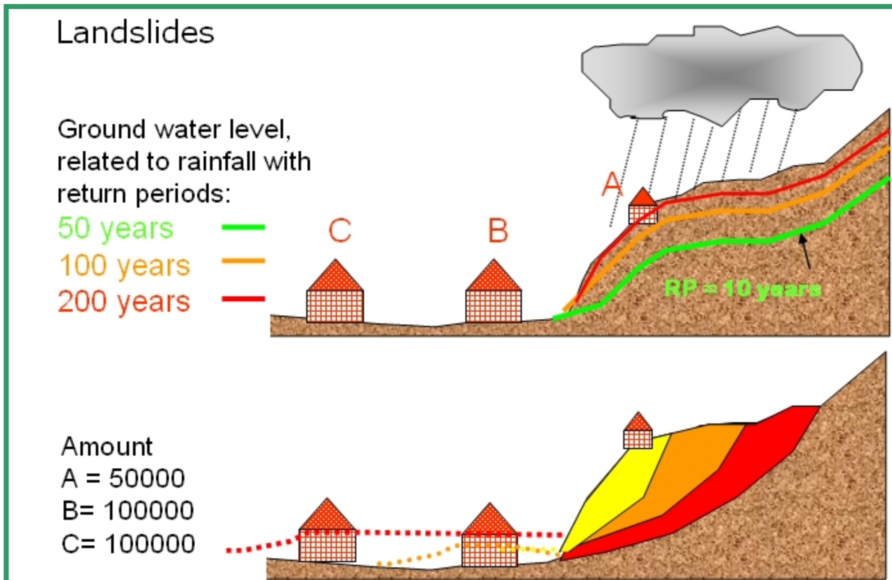
Figure 6.11: Simple example of a probabilistic risk assessment, resulting in the calculation of a risk curve, or loss exceedance curve (LEC).

For each scenario we need to know: the probability of occurrence, the spatial extent, and the magnitude of the event that varies spatially. We also need to know the distribution of the elements at risk, their classification and characterisation in aspects that are relevant for estimating the degree of damage. And we need to know the relation between the magnitude and the expected damage in the form of vulnerability curves.

6.5.2 Landslide risk

Figure 6.12 presents the same concept but now for landslides. The hazard assessment starts with the modelling of groundwater depths, based on a slope hydrology model, where daily rainfall and the soil characteristics form the main sources of input. Based on the rainfall records and the modelling it is theoretically possible to estimate groundwater levels related to a particular return period.

Based on the groundwater modelling a second analysis is carried out using a physically based slope stability model to calculate the factor of safety for each particular return period. This results in three landslide scenarios, in which different volumes of landslides can be identified. The next step would be to carry out a run out analysis, to estimate the length of runout, the velocity and the depth of the landslide materials. These parameters would form the input in a vulnerability assessment.



Risk calculation

	RP	PT	A	V	V*A	ΣV*A
A	50					
B	50					
C	50					
A	100					
B	100					
C	100					
A	200					
B	200					
C	200					

Risk curve

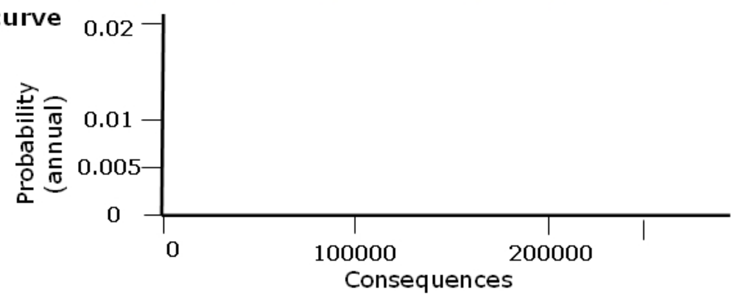
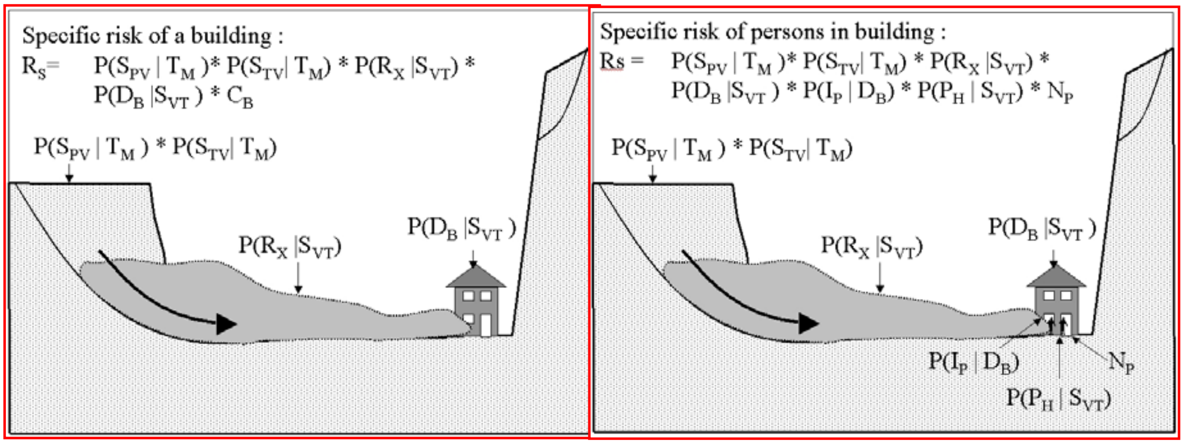


Figure 6.12: Example of quantitative landslide risk assessment, similar to the approach presented in figure 6.11

Task 6.9: Calculation of a risk curve (duration 30 minutes)
*Calculate the specific risks for the individual risk scenarios for 50, 100 and 200 years, using the temporal probability (PT), the amount (A), and the vulnerability (V). In this case make an estimate of the expected degree of loss given the particular scenario. Calculate the consequences (V*A) and the sum of the consequences (ΣV*A). Plot the Temporal probability against the total consequences and create the risk curve.*

Figure 6.13 gives another example of calculation risk for a landslide situation, in which the specific risk is consisting of a number of individual probabilities (see also section 3.3.L).



In which:

$P(S_{PV} \| T_M)$	= **Spatial probability**. This is the conditional probability of initiating a landslide with a specific volume and type at a specific location, given a certain triggering event (e.g. rainfall, earthquake) with a certain magnitude/intensity.
$P(S_{VT} \| T_M)$	= **Temporal probability**. Conditional probability of initiating a landslide with a specific volume and type , given a certain triggering event (e.g. rainfall, earthquake) with a certain magnitude/intensity, within a certain time period.
$P(R_X \| S_{VT})$	= **Conditional probability of runout**. The chance that a run out zone with distance X to the building will be covered, given the occurrence of the landslide with a particular volume and type.
$P(D_B \| S_{VT})$	= **Conditional probability of damage to the building** of a particular construction type, given the occurrence of the landslide with a particular volume and type.
C_B	= **Replacement costs** of the particular building.
$P(I_P \| D_B)$	= **Conditional probability of injuries or death** for a person present in the house, given the degree of damage to the building by a landslide of a given volume and type
$P(P_H \| S_{VT})$	= Conditional probability of persons being present in the building, given then time of the day that the landslide might occur (or percentage of persons in the building given time of the day)
N_P	= **Number of persons** in the building

Figure 6.13: Example of landslide risk estimation for a building (upper left) and people in a building (upper right).

The estimation of landslide risk as indicated above is conceptual. In practice there are a number of aspects that make landslide risk assessment a particularly difficult procedure. Figure 6.14 illustrates some of these difficulties involved in calculating landslide risk. In this figure, the two schematically represented buildings (elements at risk) present different vulnerabilities as they are geographical located in diverse positions, and might be affected by different types of landslides and in different ways (undercutting

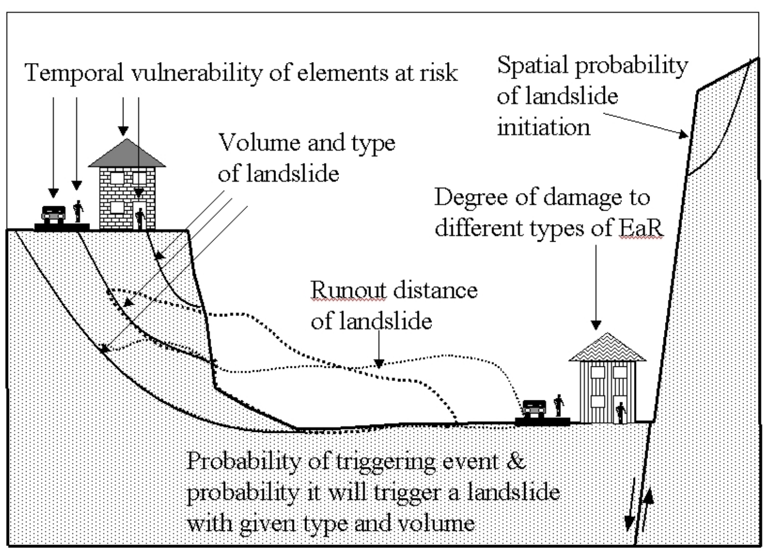


Figure 6.14: Illustration of some of the most problematic aspects of landslide risk assessment

/ impact). Vulnerability is also determined by construction types, (e.g. building materials, foundation types) which determine the strength of the building to withstand impact/erosion. Besides, due to the use, structure and size, the value or cost of these buildings will also be different. In the consequence calculation each building will get a different value and for the same hazard (e.g. a 10 years return period landslide) the risk will be also different. Furthermore, when calculating risk to persons the temporal changes in vulnerability also play a major role, both for persons that are in buildings, or that or in risky locations outside (e.g. in traffic). Although the determination of the (temporal) vulnerability of the elements at risk might be problematic, the elements at risk themselves can be mapped and classified without many conceptual problems, although the process may be quite time consuming. Out of the three risk determining factors as indicated in equation 1, the hazard component is by far the most complex to establish for landslides. Figure 6.14 illustrates several of the problems associated with determining the temporal and spatial probability of occurrence, the volume of the expected landslide, and the extent to where the landslide might be moving (run-out zone).

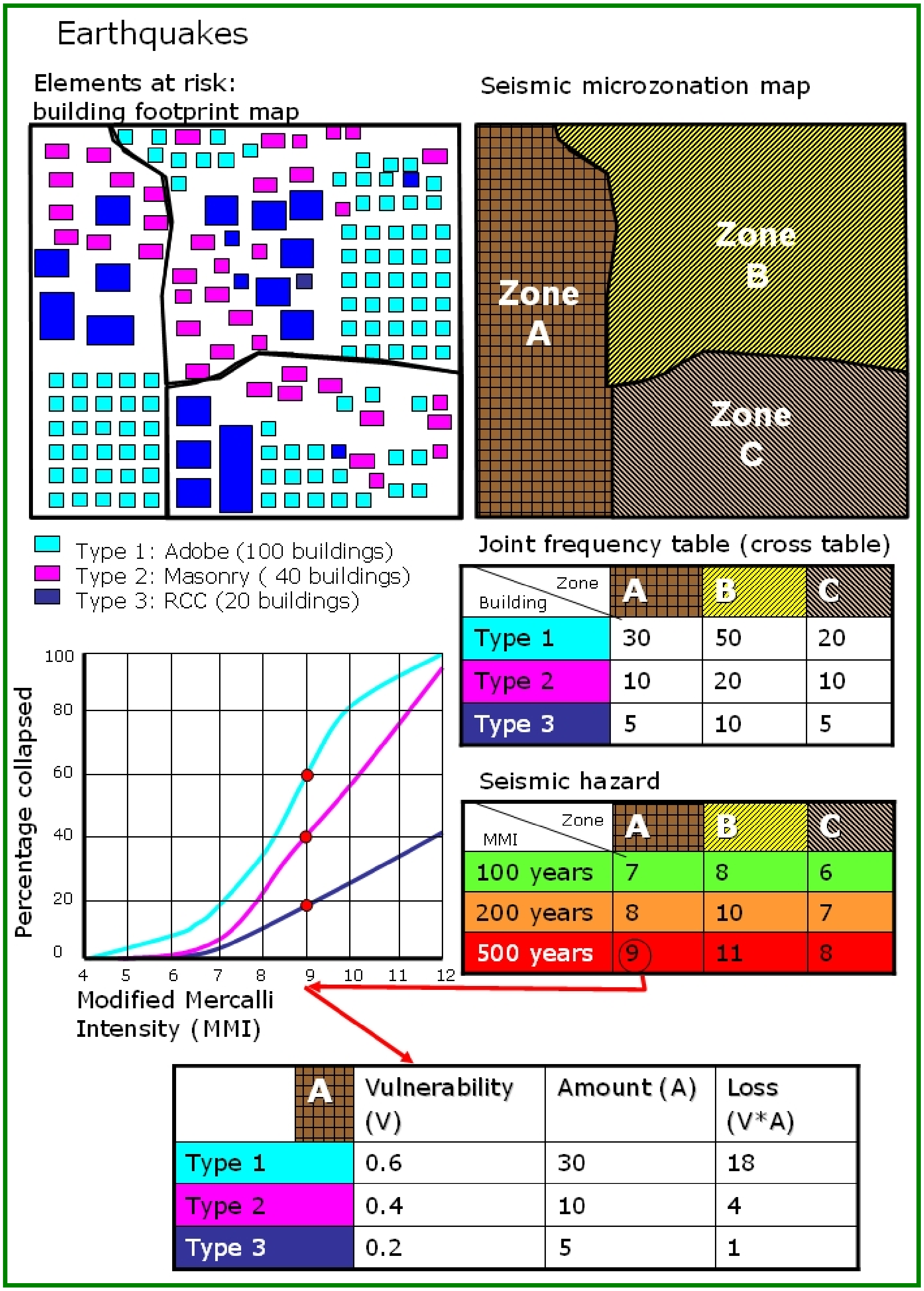
Therefore, quantitative risk assessment for landslides can be done in different ways:

- Using **physically based models**. In a large scale analysis, or at site investigation scale, based on physical modelling and/or expert opinion. The stability of the slope is calculated as well as the runout and the variability of the input factors is combined with the probability of occurrence of the triggering factors into a probabilistic analysis.
- In the case of a **complete landslide inventory**: this is for instance possible along a transportation route. Landslide probability and vulnerability can be obtained from the historical landslide records.
- **Event-based landslide maps**. In a medium scale analysis event-based landslide inventory maps can be made, displaying landslides that have been triggered by the same event for which the temporal probability is known. They are used in a statistical analysis which results in a landslide susceptibility map, that can be classified in classes (e.g. high, moderate and low). For each return period and each class the following aspects are calculated (See also equation 6.3):
    - o P_T = temporal probability, which is related to the return period of the triggering event responsible for the event-based landslide inventory;
    - o P_L = locational or spatial probability that a certain area will be impacted by a landslide. This is calculated as the landslide density (of the particular event-based landslide inventory) within the susceptibility class.
    - o V is the physical vulnerability,for landslides this is very often taken as 1.
    - o A is the quantification of the specific type of element at risk evaluated.

6.5.3 Earthquake risk

The examples given in figure 6.11 and 6.12 refer to simple examples based on profiles. However, in practice risk assessment is done for an entire area, and the input data is spatial. Figure 6.15 gives an example of a spatial risk assessment, in this case for earthquakes. The upper right part of the figure shows the seismic microzonation map, resulting from the hazard assessment as described in session 3). There are three zones, each characterized by a different ground acceleration, and seismic intensity (in Modified Mercalli Intensity), indicated in the table on seismic hazard. The upper left map shows the buildings (elements at risk) classified into 3 building types. For each of the building types a vulnerability curve is available. The figure also shows the joint frequency table (cross table) resulting from the overlaying of the seismic microzonation map with the elements at risk map. Based on the joint frequency table, the hazard table and the vulnerability curve it is possible to calculate the vulnerability, amount (this time expressed as the number of buildings) and the loss/consequence (V*A) for each combination of the zone, building type, and earthquake scenario. Then the losses can be summed up by zone and scenario, and eventually by scenario for the whole map. The losses per scenario are plotted against the annual probability and a risk curve can be constructed.

In the case of earthquake hazard assessment, there may by many different scenarios to consider, as there are many different potential earthquake locations that would lead to a different degree of ground shaking for the same area. Therefore a probabilistic risk assessment for earthquakes required the incorporation of many individual scenarios



Building \ Zone	A	B	C
Type 1	30	50	20
Type 2	10	20	10
Type 3	5	10	5

MMI \ Zone	A	B	C
100 years	7	8	6
200 years	8	10	7
500 years	9	11	8

A	Vulnerability (V)	Amount (A)	Loss (V*A)
Type 1	0.6	30	18
Type 2	0.4	10	4
Type 3	0.2	5	1

Figure 6.15: Schematic representation of spatial earthquake loss estimation. See text for explanation.

Task 6.10: Calculate seismic risk (duration 30 minutes)
*From the figure above calculate the specific risks for the individual risk scenarios for 100, 200 and 500 years, using the temporal probability (PT), the amount (A), and the vulnerability (V). In this case make an estimate of the expected degree of loss given the particular scenario. Calculate the consequences (V*A) and the sum of the consequences (∑V*A). Plot the Temporal probability against the total consequences and create the risk curve. Do the calculation in an Excel file.*

A complete risk assessment also includes many more aspects than the direct physical damage to the building stock. Figure 6.16 shows an example of the earthquake loss estimation modules of the HAZUS method, used in the US.

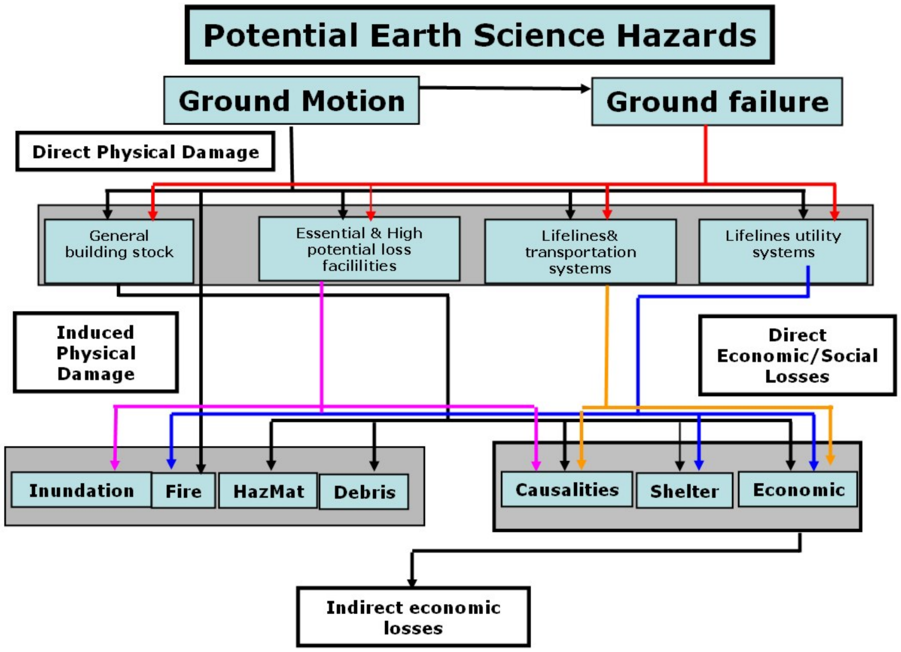


Figure 6.16: Overview of the various modules of the HAZUS method for earthquake loss estimation (Source: www.fema.gov/plan/prevent/hazus)

The generation of a complete earthquake risk assessment is very challenging. Even a methodology like HAZUS is often not complete, as it is difficult to incorporate all secondary effects and domino effects due to earthquakes. Figure 6.17 gives an example of that, showing some of the many hazard types that might be related to a tsunami, which is caused by an earthquake. In such cases the calculation of the return period, and the inundation depth is very difficult to carry out probabilistically.

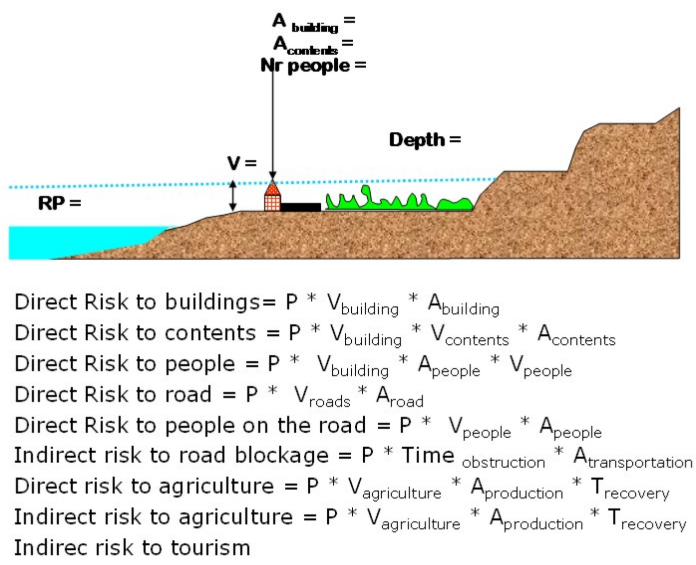


Figure 6.17: Example of the complexity of risk assessment when taking into account direct and indirect losses and different types of elements at risk. The example is for tsunami.

Task 6.11: RiskCity exercise on quantitative risk assessment (duration 3 hours)

*Now you can select here if you want to do one of the following topics: **Flood risk assessment, landslide risk assessment, earthquake risk assessment, Technological risk assessment**. Each has its own exercise description. Go to the exercise book and make your selection. Then follow the instruction there.*

6.5.4 Technological risk

Technological risk assessment is rather different from the risk assessment related to geological or hydro meteorological hazards, discussed before. Technological hazards such as accidents in industrial facilities, or accidents involving hazardous materials depend on the occurrence of failure in a system. There are a range of techniques developed to analyze the risk of such events, which could sometimes also be used to analyze natural events. Some of these techniques are mentioned below.

Use of historical information. This is based on an evaluation of the probability of an accident in a given industrial site, based on statistical information from comparable installations elsewhere. There should be enough historical information in order to be able to make such an analysis. For very rare events it will not be possible to make such a probability estimate (e.g. in the case of a major industrial accident). In other situations it might be more easier to use (e.g. the frequency of road accidents involving vehicles with explosive or flammable substances).

Success path analysis

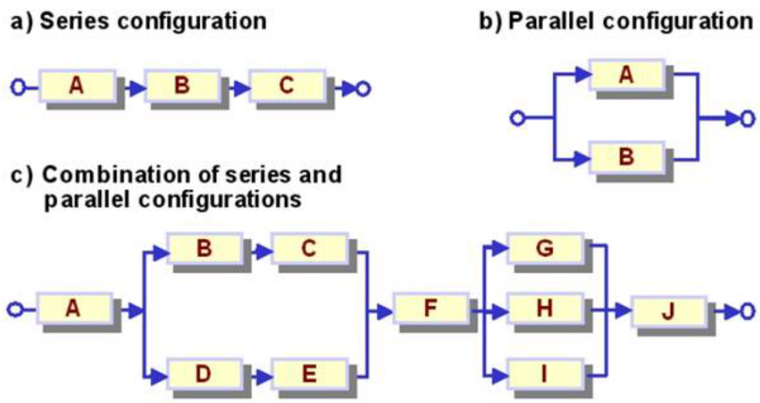


Figure 6.18: Example of configurations that can be used in a Success Path Analysis (SPA). Source: Nahris

The success path method is a drawing and calculation tool used to model relatively complex systems. In this method, the different components of a system are symbolized as individual graphic and functional elements, called "reliability blocks" (for this reason, in its industrial applications this method is also known under the name of "Reliability Block Diagram", or RBD, method). These blocks are reliability-wise arranged and related, often, but not necessarily, in the same way that the corresponding components are physically connected. Once the blocks are properly configured, and reliability data for these blocks is provided, calculations can be performed in order to calculate the failure rate, the "mean time between failure" (MTBF), reliability and availability of the system. The simplest and most elementary types of reliability blocks configurations are the series and active-parallel configurations. Items connected in series must all work for the system to fulfill its function ("success path"). In the example of figure 6.18 a, the system will fail if either A, B or C fails. Items placed in parallel are considered to be redundant, because the good working of only one of them is enough for the system to function. In the example of figure 6.18 b, either A or B (but not A and B simultaneously) can fail and the system will continue to function.

The reliability of a system of N independent components, all in series or all in active-parallel, can respectively be calculated from the following mathematical expressions (Ri: reliability of component i, assumed to be known) [McCormick, 1981]:

$$R_{sys}(t) = \prod_{i=1}^{N} R_i(t) \qquad \text{(series)}$$

$$1 - R_{sys}(t) = \prod_{i=1}^{N} [1 - R_i(t)] \quad \text{(active-parallel)}$$

These two elementary configurations form the basis of the reliability block diagram construct and success path analysis. The above construction and calculation scheme can be expanded further, as shown in figure 6.18 c, with various combinations of series and parallel configurations in the same diagram.

Event tree analysis.

Event tree analysis is based on binary logic, in which there are always two options: an event happens or does not happen, or a component of a technical system either works or fails. In a fault tree analysis each of the possibilities has a certain probability. An event tree starts with an initiating event, such as a fire or a failure of a component of a system. The consequence of the event is followed through a series of possible paths. Each path is assigned a probability of occurrence and the probability of the various possible outcomes can be calculated.

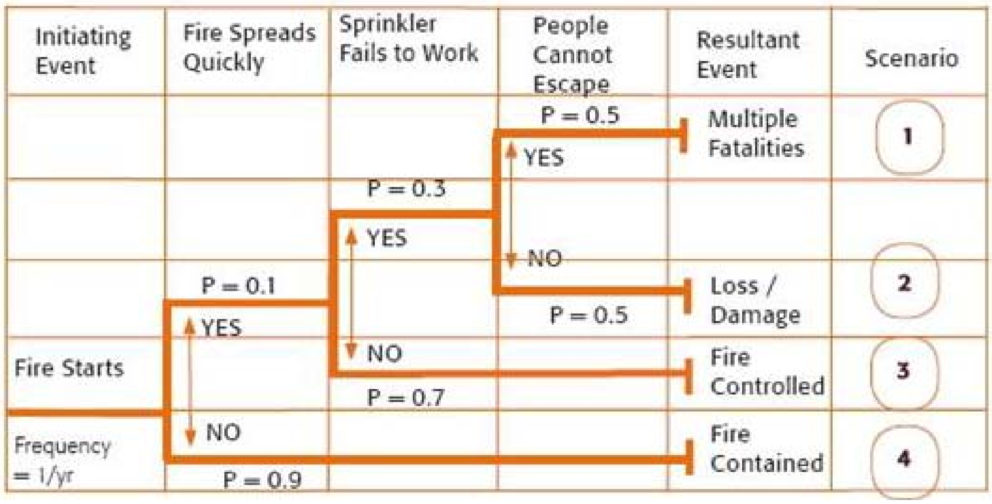


Figure 6.19: Simple example of an event tree analysis for a case of fire. Source: http://www.theiet.org/factfiles/health/index.cfm

Fault-tree analysis

A fault tree is a graphical representation that provides a systematic description of possible occurrences in a system, which can result in an undesirable outcome. The most serious outcome such as a landslide, explosion etc. is selected as the Top Event. A fault tree is then constructed by relating the sequence of events, which individually or in combination, could lead to the Top Event. This may be illustrated by considering the probability of a crash at a road junction and constructing a tree with AND or OR logical operators. The tree is constructed by deducing in turn the preconditions for the top event and then successively for the next levels of events, until the basic causes are identified.

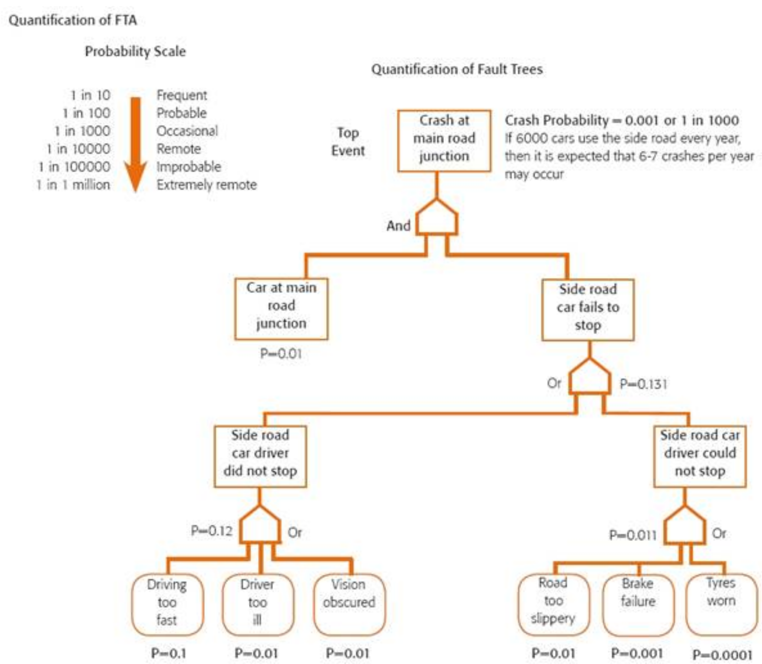


Figure 6.20: Example of a fault-tree analysis. Source: http://www.theiet.org/factfiles/health/index.cfm

6.5.5. Converting risk curves to annualized risk

Once we have calculated a risk curve for any of the hazard types discussed in the previous sections, it is important to convert the information into Averaged Annualized Loss (AAL), which is the Expected loss per year when averaged over a very long period (e.g., 1,000 years). Computationally, AAL is the summation of products of event losses and event occurrence probabilities for all stochastic events in a loss model.
The total annual risk is the total area under the risk curve, of which the X-axis display losses (in monetary values) and the Y-axis displays the annual probability of occurrence. The points in the curve represent the losses associated with the return periods for which an analysis was done (e.g. the return periods listed in the table above). There are two "graphical" methods to calculate the total area under the curve. We will first briefly look at those.

Method 1: Triangles and rectangles method
The area under the curve is divided into trangles, which connect the straight lines between two points in the curve and have X-axis difference as difference between the losses of the two scenarios. Y-axis of the triangles is the difference in probability between two scenarios. The remaining part under the curve is then filled up with rectangles, as illustrated in figure 6.21.

Method 2: Simplified rectangles method.
In this method we simplify the graph into a number of rectangles, which have as Y-axis the difference between two successive scenarios, and as X-axis the average losses between two successive loss events. See figure 6.21.

It is also possible to represent the graph as a function and use this in the calculation of the area under the curve.

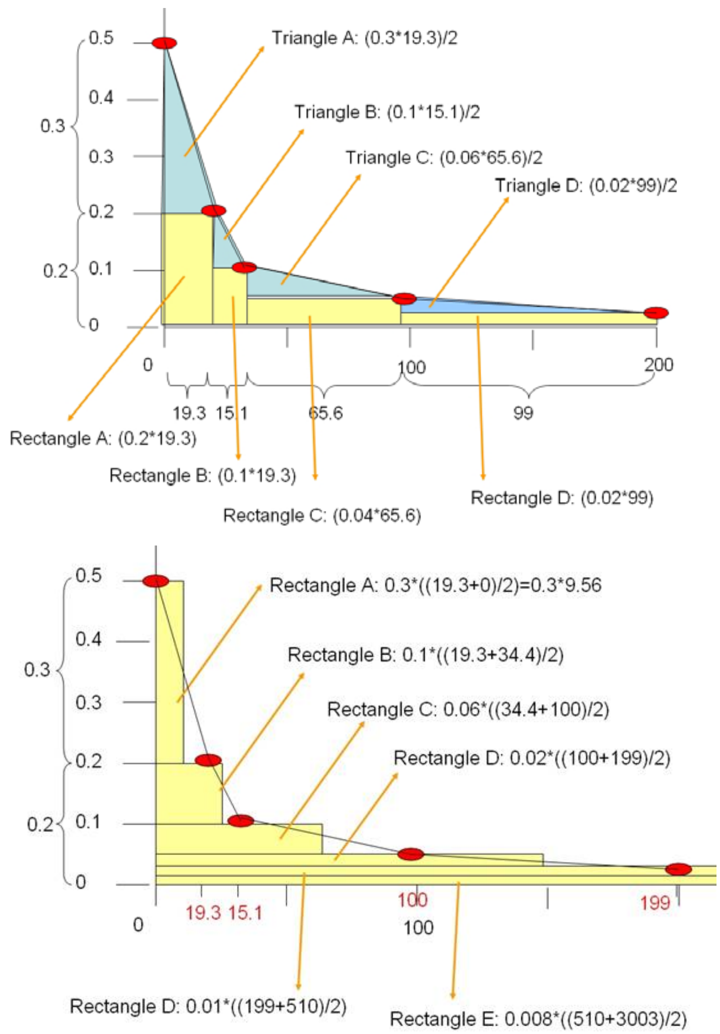


Figure 6.21: Two methods for calculating the area under the risk curve. Left: triangles method; right: simplified rectangles method.

Task 6.12: RiskCity exercise on Multi-hazard risk assessment (duration 3 hours)

In the RiskCity exercise on multi-hazard risk assessment we will evaluate the risk of the 4 hazard types (flooding, landslides, earthquakes and technological hazards, and we will compare the results). Please go to the exercise description and follow the instructions.

6.6 Multi-hazard risk assessment

The risk assessment procedures explained in the previous sections result in risk curves which can be compared, as they are all showing the annualized risk. In figure 6.22 a summary is given of the multihazard risk assessment as applied in the RiskCity case study, illustrated for two hazard types: flooding and landslides. Multi-hazard risk assessment was carried out in the RiskCity case study for buildings. First attribute maps were generated that contain the number of buildings affected for each hazard type and hazard class (A in equation 6.3) for each of the 1306 mapping units in the urban area. Then the values were multiplied with values for vulnerability (V) and with the temporal and spatial probability (P_T and P_L) to convert them into annual risk values. The consequences are plotted against the annual probability and risk curves were generated. For each hazard type, separate scenarios were made for each return period. In the case of flooding this was done for return periods of 5, 10, 25, 50 and 100 years, based on the results of the HEC-RAS and SOBEK modeling. For landslides scenarios were made with return periods of 50, 100, 200, 300 and 400 years, based on the landslide inventory which included a considerable subjective component in defining the age of many of the large landslides in the area. For flooding the spatial probability (P_L in equation 6.3) was taken as 1 since the individual hazard scenarios indicate the areas that will be flooded. For the landslide risk assessment the return period of the triggering event (P_T) was multiplied with the spatial probability of landslides occurring in the high, moderate, and low susceptibility classes (P_L in equation 6.3), the vulnerability per land use type and the number of buildings located in each of the three zones. The resulting risk curves were

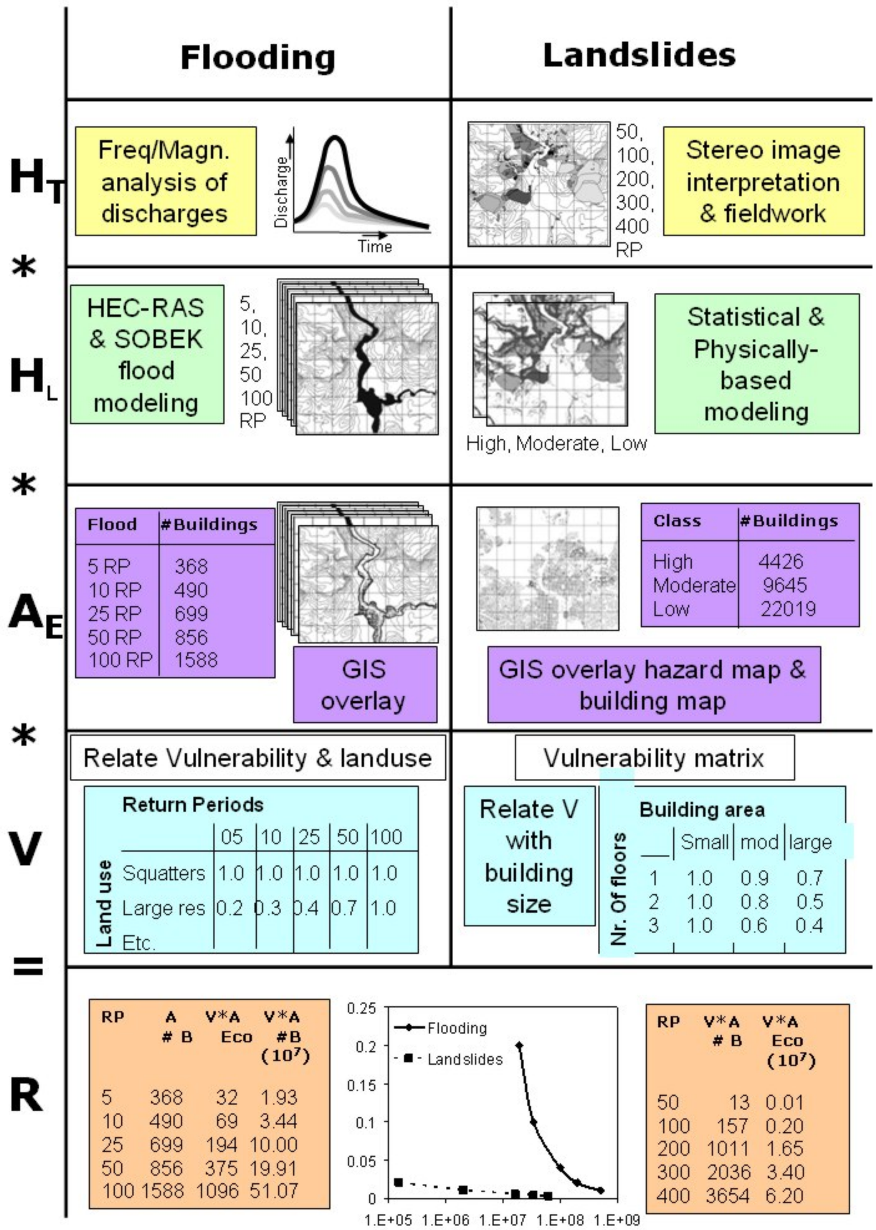


Figure 6.22: Procedure to produce the risk curves for flooding and landslide. The individual components of the risk equation are given on the left hand side. For each component some schematic analysis results are presented.

plotted and the annual risk was calculated by integrating the area under the curve, and by using a simply graphical area calculating in Excel.
Population losses were estimated on the basis of building losses, based on the population vulnerability estimates for different injury levels indicated by HAZUS (FEMA, 2008). HAZUS uses four severity levels ranging from minor injuries (level 1) to deaths (level 4). For each of these four injury levels a relation is made with the building damage level. In a table linked to the mapping units the percentage of the population with a particular severity level was calculated. This calculation was done for the three temporal population scenarios indicated before. The population values were plotted using F-N curves to serve as a basis for defining the risk acceptability levels.
The calculation of direct economic losses due to flooding and landslides was restricted to building losses. The degree of loss to buildings was taken as input for this assessment. In order to valuate the buildings in terms of unit replacement costs, standard values were linked to the urban land use types, and the floorspace for individual buildings. Unit costs (per square meter), based on literature review and evaluation of real estate values, were then applied per mapping unit for buildings and for contents of buildings. These were multiplied with the floorspace to obtain the total costs per mapping units. After this attribute maps were generated that contain the costs of buildings affected for each hazard type and hazard class, which were then used as the A_{ES} parameter in equation 2, and combined with the vulnerability and probability information to generate risk curves with economic losses

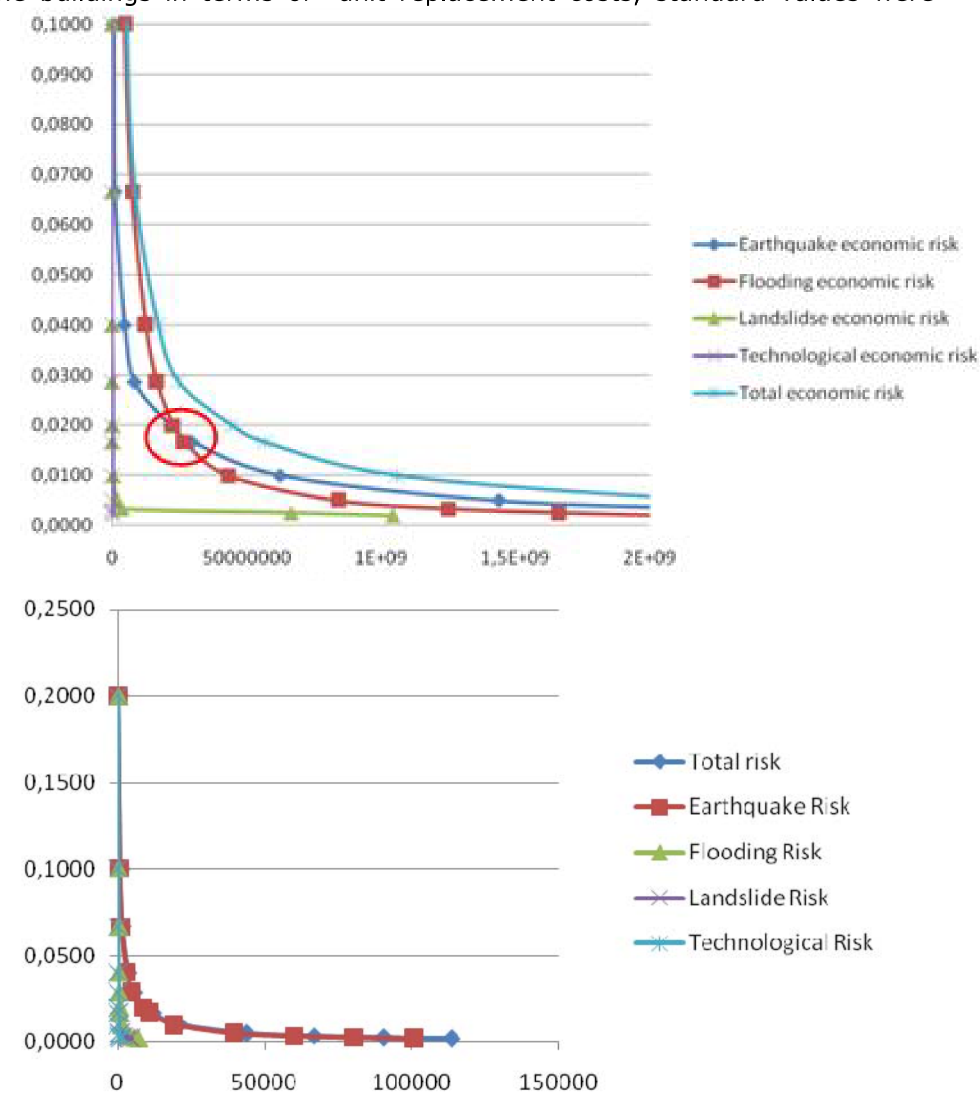


Figure 6.23: Risk Curves for the RiskCity case study for economic building losses (above) and number of buildings (below)

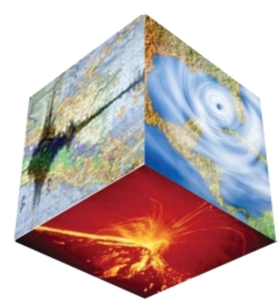
6.7 Loss estimation methods

Computer applications have been developed by different companies and institutions to perform loss estimations for different natural hazards. There are many commercial or non-free applications, such as NHEMATIS (Nobility-Environmental-Software-Systems-Inc., 1999), MRQuake, MRStorm and MRFlood (MunichRe, 2000), RiskLink-ALM, RiskLink-DLM, RiskBrowser and RMS-DataWizard (RMS, 2004), and CLASIC/2, CATRADER, CATMAP/2, AIRProfiler, ALERT (AIR, 2004). These will not be considered in the analysis due to their commercial nature, and that they are basically aimed at supporting insurance company's analyses.

RADIUS (Risk Assessment Tools for Diagnosis of Urban Areas against Seismic Disasters): The amount of information needed by RADIUS enables users to perform an aggregated loss estimation using a gridded mesh, that, depending on the information available, weights each mesh unit assigning it a degree of loss in terms of number of buildings damaged, length of lifelines damaged, and as a number of casualties and injured people. The accuracy of the estimation depends on the detail of the information provided; nevertheless, the algorithms are based on broad assumptions, for instance, soil characteristics and fragility curves (developed for settings different from the one where the methodology is applied). Radius provides a rapid assessment of possible damages according to the detail of the information provided. Although all the categories and weights can be changed, Radius only gives a rough estimate of damage due to the few categories considered and the "raster-like" unit distribution that doesn't account for the typical political administrative boundaries used for decision making and policies.

HAZUS-MH: allows a very detailed analysis of losses based on an enormous amount of information. The information collection can be especially difficult in developing countries due to the poor or inexistent databases and the costs and time needed to update the information necessary for this method. However, after a thorough campaign of information acquisition and preparation, information must be adapted to the requirements of HAZUS-MH. Special attention should be drawn to the issue of the classifications used by HAZUS; since they were designed for the United States of America; other classifications have to be adapted, introducing other sources of error and uncertainty in the loss estimation.
Although these loss estimation methods can give local authorities a loss scenario for a specific hazard, they provide limited insight on how to use that information for the relief and recovery process. They also lack information about the capacities of the community to withstand, cope, and recover from a disaster. Loss estimations can only be considered part of a vulnerability analysis when used as complete inventories of exposed infrastructure and population. In Annex II a summary of the factors considered to perform the loss estimation for the RADIUS and HAZUS initiatives are presented. More information on HAZUS can be obtained from: www.fema.gov/plan/prevent/hazus

CAPRA
CAPRA is an abbreviation for Central American Probabilistic Risk Assessment.
The objectives of CAPRA are: to develop a Disaster Risk Information Platform for decision making using a common methodology and tools for evaluating and expressing disaster risk, and to analyze a regional strategy, that is local, versatile and effective, to advance risk evaluation and risk management decision making. More information on CAPRA and the methods used can be obtained from: http://www.ecapra.org/es/



Selftest

In order to evaluate whether you have understood the concepts that were presented in this session. Please make the following test, and check the answers in Blackboard.

Question 6.1: risk curve

It is **impossible** to generate a risk curve in the following case:

A) When there is no information available on costs, but only on the number of elements at risk

B) When there is no information available on the vulnerability of the elements at risk, but only on the number of elements at risk affected

C) When there is no information available on hazard scenarios with different return periods

D) When there is no quantitative information available on the amount of all the individual elements at risk.

Question 6.2: Dynamic risk

Risk is not static but dynamic, because:

A) Vulnerability changes over time

B) The number of elements at risk changes over time

C) Hazard changes over time

D) All of the above

Question 6.3: Quantitative risk assessment

Which of the components of the "risk formula" can be evaluated based on historical events?

A) Probability of flooding

B) Vulnerability to flooding

C) Number of elements affected by flooding

D) All of the above

Question 6.4 Risk assessment

Consider an area where you have the following hazards and risk:

Flooding:

Return period	Buildings affected	Vulnerability
10	100	0.6
100	500	0.7
200	1000	0.8

Earthquakes

Return period	Buildings destroyed
10	500
100	1000
200	5000

The average building cost is considered to be 100.000 Euro

A) Calculate the contributions of flooding and earthquake to the annual risk.

B) Generate risk curves for the two events.

C) Which of the hazard types will give the highest risk.

D) What is the annual risk of flooding and earthquake combined

Question 6.5: Best methods for risk assessment

Which method for risk assessment would you recommend in the following situations (briefly explain why)

A) In case we would like to indicated the areas with the highest social vulnerability, using a hazard footprint map (without having information on return periods) and a database containing the characteristics of the population (age, gender, literacy rate etc.)

B) In case we would have three flood hazard footprints, each one with information on the return period and the water depth/flow velocity of the event, and an element at risk database with building information containing different building types.

Further reading

In order to know more about the approaches for quantitative loss estimation usnig the HAZUS methodology we refer you to three technical manuals that are included in the further reading part:

- Building loss estimation for earthquakes
- Building loss estimation for floods
- Builidng loss estimation for hurricanes

These manuals are available on the Further Reading directory of this session

ADPC 2005. Knowledge Development, education, public awareness training and information sharing. A Primer of Disaster Risk Management in Asia. Asian Disaster Preparedness Center. URL: http://www.adpc.net

AGS, 2000. Landslide risk management concepts and guidelines, Australian Geomechanics Society (AGS), Sub-committee on landslide risk management.

Alexander, D.E., 2002. Principles of emergency planning and management. Oxford University Press, New York, 340 pp.

Bell, R. and Glade, T., 2004. Quantitative risk analysis for landslides – Examples from Bíldudalur, NW-Iceland. Natural Hazards and Earth System Sciences, 4: 117-131.

Castellanos Abella, E.A., Multiscale landslide risk assessment in Cuba, Utrecht, Utrecht University, 2008. ITC Dissertation 154, 273 p. ISBN: 978-90-6164-268-8

Castellanos Abella, E.A. and Van Westen, C.J., 2007. Generation of a landslide risk index map for Cuba using spatial multi-criteria evaluation. Landslides, 4(4): 311-325.

Dao, H. and Peduzzi, P., 2003. Global risk and vulnerability index trends per year (GRAVITY) Phase IV: Annex to WVR and Multi Risk Integration, Geneva.

Davidson, R., 1997. A multidisciplinary urban earthquake disaster index. Earthquake Spectra, 13(2): 211-223.

Douglas, J., 2007. Physical vulnerability modelling in natural hazard risk assessment. Natural Hazards and Earth System Sciences, 7(2): 283-288.

DEBRIS 2006. Innovative education for risk management. Development of innovative forms of learning and teaching oriented towards building a family of new curricula in the field of natural risk EU Leonardo da Vinci programme. URL: http://www.e-debris.net

EMA, 2008. Disaster loss assessment guidelines. Emergency Management Australia. URL: http://www.ema.gov.au/agd/EMA/rwpattach.nsf/VAP/(383B7EDC29CDE21FBA276BBBCE12CDC0)~Manual+27A.pdf/$file/Manual+27A.pdf

Fell, R. and Hartford, D., 1997. Landslide risk management. In: D. Cruden and R. Fell (Editors), Landslide risk assessment. A.A. Balkema, Rotterdam, pp. 51-109.

FEMA, 2008a. Mitigation Planning :How To" Guides. Federal emergency Management Agency. URL: http://www.fema.gov/plan/mitplanning/planning_resources.shtm

FEMA, 2008b. Hazus, FEMA's software for estimating potential losses from disasters. Federal Emergency Management Agency URL: http://www.fema.gov/plan/prevent/hazus/

IADB, 2005. Indicators of disaster risk and risk management. Summary report for WCDR, Inter-American Development Bank (IADB), Manizales, Colombia.

Ko Ko, C., Flentje, P. and Chowdhury, R., 2004. Landslides qualitative hazard and risk assessment method and its reliability. Bulletin of Engineering Geology and Environment, 63(2): 149-165.

NAHRIS 2006. Dealing with NAtural Hazards and RISks. Swiss Virtual Campus Project. URL: http://www.nahris.ch/

Zillman, J., 1999. The physical impact of disaster. In: J. Ingleton (Editor), Natural disaster management. Tudor Rose Holdings Ltd., Leicester, pp. 320.

Guide Book
Session 7:
Disaster Risk Management

Cees van Westen & Nanette Kingma

Objectives

After this session you should be able to:

- Explain how risk analysis forms part of the overall risk management process
- Understand the factors involved in risk perception and evaluation
- Outline how spatial risk information plays a role in risk governance, risk communication and risk visualization
- Define which structural and non structural mitigation measures can be applied for different types of hazards.
- Carry out a cost benefit analysis to evaluate the most suitable risk reduction measures
- Understand how risk assessment forms part of a Strategic Environmental Assessment

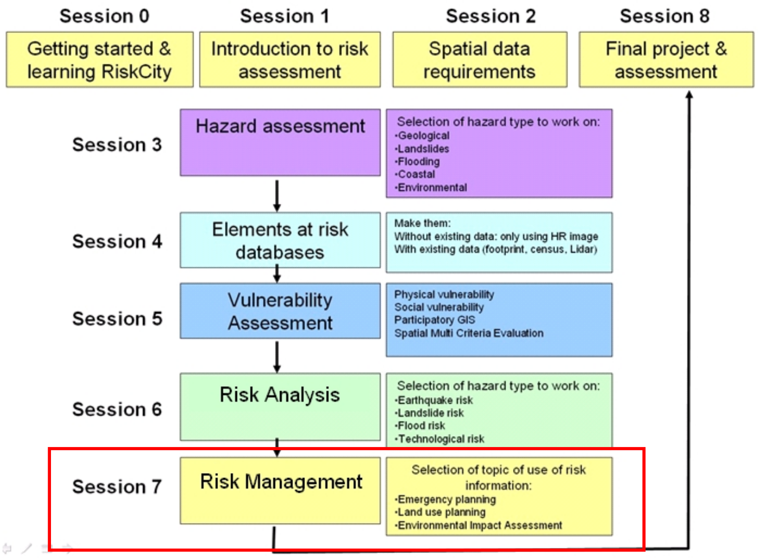
In this session you will see how risk information can be used in Disaster Risk Assessment. We will start by looking at the aspects of Risk Perception and Risk Evaluation. After looking at the framework of Disaster Risk Management we will concentrate on the aspect of Risk Governance, with stakeholder involvement as the main issue. We will then see how spatial information can be used in Risk Visualization as part of the Risk Communication process. We will look specifically to the use of WebGIS as a tool in communicating risk information to other stakeholders.

In the second part of the session we will then concentrate on the different structural and non-structural measures for risk reduction. Within that part we will do a simulation exercise where you are considered to be in the geoinformation department of the RiskCity municipality and you have to provide the right information to the emergency managers at the right time. The various risk reduction measure are evaluated and compared using a cost-benefit analysis. You will also do a Riskcity exercise on cost-benefit analysis. The last section deals with the use of risk information in Strategic Environmental Assessment (SEA).

The table below gives an overview of this session:

Section	Topic	Task	Time required		
7.1	Introduction to disaster risk management		Day 1	0.25 h	0.50 h
		Task 7.1: Key risk reduction elements and spatial data		0.25 h	
7.2	Risk perception and risk evaluation			0.25 h	0.50 h
		Task 7.2: Risk perception		0.25 h	
7.3	Risk governance			0.50 h	1.25 h
		Task 7.3: Risk governance		0.75 h	
7.4	Risk communication		Day 2	0.50 h	1.25 h
		Task 7.4: Risk communication		0.75 h	
7.5	Risk visualization			0.50 h	3.75 h
		Task 7.5: Risk visualization		0.75 h	
		Task 7.6: WebGIS exercise		2.00 h	
		Task 7.7: WebGIS and risk		0.50 h	
7.6	Risk reduction measures		Day 3	0.50 h	4.00 h
		Task 7.8: Risk reduction measures		0.50 h	
		Task 7.9: RiskCity exercise on disaster preparedness planning		3.00 h	
7.7	Cost benefit analysis		Day 4	1.00 h	4.00 h
		Task 7.10: riskcity exercise cost-benefit analysis		3.00 h	
7.8	SEA and risk assessment			0.25 h	0.25 h
				Total	**16 h**

7.1 Introduction to disaster risk management.



In this session we will concentrate on how you use risk information. In the last session we have been through the various steps to derive at risk maps. But once the risk maps have been generated, the question is: what for? How can we use these data in disaster risk management. And who will use this data? Which stakeholders require what type of information? How is the information shared? How is it visualized? Which role does it play in risk governance? Which risk level is acceptable? And what are the various risk reduction options? How much will they actually reduce the risk? These are the questions that will be addressed in this chapter. We start this chapter with a section on disaster risk management.

In section 1.2 an introduction was given to disaster risk management. Emphasis was given their also to the United Nations International Strategy for Disaster Reduction (ISDR). The ISDR Framework for Disaster Risk Reduction describes the general context and primary activities of disaster risk management, and elements regarded as necessary for any comprehensive disaster risk reduction strategy (see Figure 7.1). Some of the main points important for the use of spatial disaster risk information are:

- Effective disaster risk management depends on the informed participation of all stakeholders.
- The exchange of information and easily accessible communication practices play key roles.
- Data is crucial for ongoing research, national planning, monitoring hazards and assessing risks. The widespread and consistent availability of current and accurate (geo) data is fundamental to all aspects of disaster risk reduction. (UN-ISDR, 2004)

The ISDR conceptual framework for disaster risk reduction is placed in the broader context of sustainable development, where socio-cultural, environmental, economic and political factors/ goals need to be considered. In order to meet all these goals good governance is needed on all levels, from national to community level.

The UN-ISDR system:

The ISDR system supports nations and communities to implement the Hyogo Framework. ISDR is a system of partnerships including governments, inter-governmental and non-governmental organizations, international financial institutions, scientific and technical bodies and specialized networks as well as civil society and the private sector. The ISDR system's basic structure includes a Global Platform for Disaster Risk Reduction, a Management Oversight Board, an Inter-Agency Group that developed an ISDR System Joint Work-Programme, thematic and regional platforms and the UN/ISDR secretariat Conceptual framework for disaster risk reduction.
See: www.unisdr.org

Governments and communities have a shared responsibility to develop an integrated approach, in the context of sustainable development with the involvement of the different stakeholder groups. From the definitions on Disaster Risk Reduction (DRR) and Disaster Risk Management (DRM) of UN-ISDR (see section 1.2 for these) it is clear that disaster Risk Management is also very much focused on prevention. Studies have shown that for every Euro invested in risk management, broadly 2 to 4 Euros are returned in terms of avoided or reduced disaster impacts on life, property, the economy and the environment.

Despite the obvious benefits, disaster risk management (DRM) measures are often difficult to implement and there is still in many situations a reliance on reactive approaches after the disaster has happened. For example, bilateral and multilateral donors still allocate 90% of their disaster management funds for relief and reconstruction and only the remaining 10% for disaster risk management. One of the International NGO's (Tearfund) active in DRR, carried out a study showing that disaster risk reduction was given a relatively low priority within donors' relief and development plans, processes and practical implementation. Explanations for this low priority included:

- A lack of knowledge and understanding of the nature of risk reduction;
- The cultural divide between 'relief' and 'development' sectors, resulting in risk reduction not being fully 'owned' by either;
- Risk reduction 'competing' with other pressing development needs.
- A lack of concrete evidence regarding the types and extent of the cost and benefits of preventive disaster risk management measures.

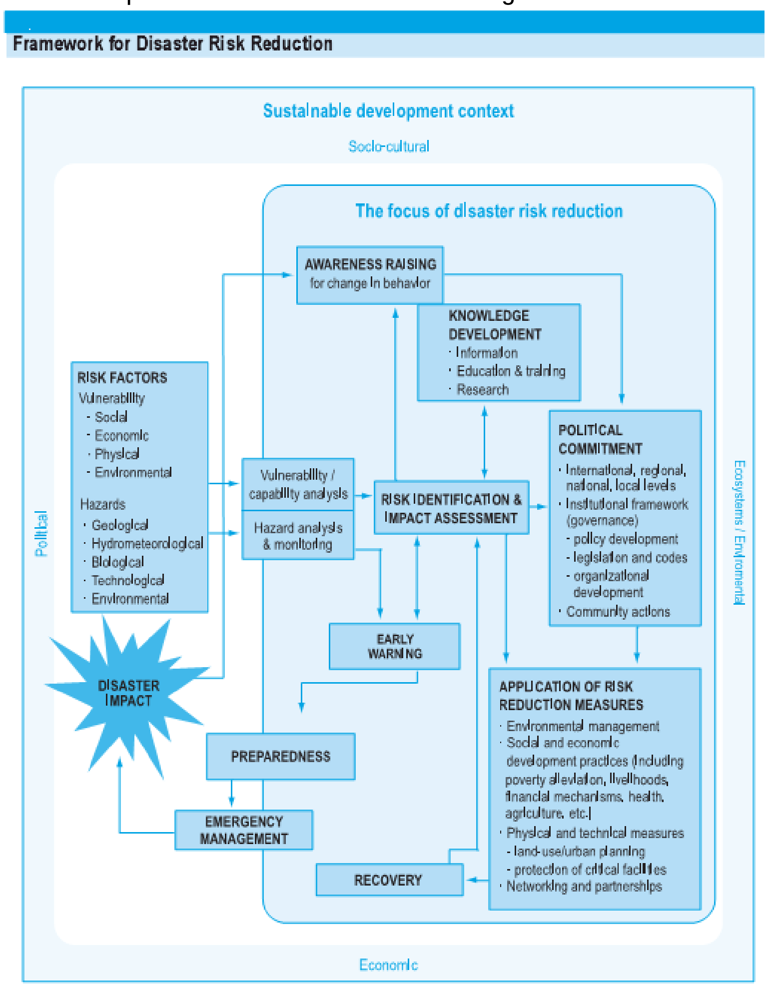


Figure 7.1: Framework for Disaster Risk Reduction(Source: "Living with Risk" (UN 2004))

The ISDR Framework for Disaster Risk Reduction (Figure 7.1) describes the general context and primary activities of disaster risk management, and elements regarded as necessary for any comprehensive disaster risk

The disaster risk reduction framework is composed of the following fields of action, as described in ISDR's publication 2004 "Living with Risk: a global review of disaster reduction initiatives (figure 7.1).

The Framework has the following main components:

Awareness raising to change the behavior in increasing vulnerability;

Knowledge development: information, education and research;

Political commitment and institutional development or **governance**;

Early warning, monitoring and forecasting

Risk management application & instruments : including environmental management, land-use and urban planning, protection of critical facilities, application of science and technology, partnership and networking, and financial instruments; physical and technical measures;

Disaster Preparedness, Contingency planning and emergency management. The risk reduction measures are both structural and non-structural and range from physical and technical planning, land use and urban planning and protection of critical facilities to social and economic development practices including poverty alleviation.

Central in the framework is the **Identification of risk and the impact assessment**. This multi-hazard risk assessment, including the analysis of hazards and the analysis of vulnerability and capacity, is a crucial prerequisite in order to be able to work on the other (above mentioned) building blocks of the Risk Reduction Strategy.

Apart from the UN-ISDR framework for disaster risk reduction many other frameworks have been presented, which often have a lot of common aspects, but have a difference in focus. Another framework we would like to present here, is the one from the Inter-American Development Bank. Table 7.1 lists the key elements of the proposed risk management strategies.

Table 7.1. Key elements for risk management strategies (IADB 2000a, 2004)

Pre-disaster activities				Post-disaster activities	
Risk identification	**Mitigation**	**Risk transfer**	**Preparedness**	**Emergency response**	**Rehabilitation-reconstruction**
Hazard assessment (frequency, magnitude, location)	Structural and non-structural works and actions	Insurance, reinsurance of public infrastructure and private assets	Warning systems, communication systems, protocols	Humanitarian assistance	Rehabilitation, reconstruction of damaged critical infrastructure
Vulnerability assessment (population and assets exposed)	Land-use planning and building codes	Financial market instruments (catastrophe bonds, weather-indexed hedge funds)	Contingency planning (utility companies, public services)	Clean-up, temporary repairs and restoration of services	Macroeconomic and budget management (stabilization, protection of social expenditures)
Risk assessment (function of hazards and vulnerability)	Financial incentives for preventive behavior	Public services with safety regulations (e.g. energy, water, transportation)	Networks of emergency responders (local, national)	Damage assessment and identification of priorities for recovery	Revitalization of affected sectors (e.g. exports, tourism, agriculture)
Hazard monitoring and forecasting (space-time modeling, scenario building)	Education, training and awareness about risks and prevention	Financial protection strategies	Shelter facilities, evacuation plans	Mobilization of recovery resources (public-multilateral, insurance)	Incorporation of risk management in reconstruction processes

Figure 7.3 shows the structure that will be followed in this chapter, and which focuses more on the use of (spatial) risk information, which is also the focus of this book.

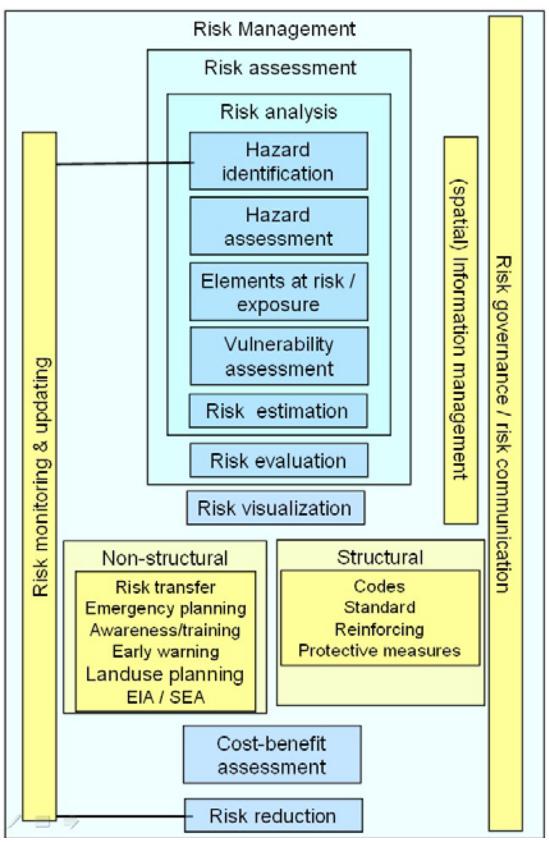


Figure 7.2: Framework on Risk Management, with indication of the various

Table 7.1 Definitions for risk management (IUGS, 1997).

Term	Definition
Risk analysis	the use of available information to estimate the risk to individuals or populations, property, or the environment, from hazards. Risk analysis generally contains the following steps: hazard identification, hazard assessment, elements at risk/exposure analysis, vulnerability assessment and risk estimation.
Risk evaluation	the stage at which values and judgements enter the decision process, explicitly or implicitly, by including consideration of the importance of the estimated risks and the associated social, environmental, and economic consequences, in order to identify a range of alternatives for managing the risks.
Risk assessment	the process of risk analysis and risks evaluation
Risk control or risk treatment	the process of decision making for managing risks, and the implementation, or enforcement of risk mitigation measures and the re-evaluation of its effectiveness from time to time, using the results of risk assessment as one input.
Risk management	the complete process of risk assessment and risk control (or risk treatment).

The process of risk estimation and risk analysis has been extensively treated in the previous sessions. Therefore no further emphasis will be given to that here. The process of risk assessment goes beyond the process of risk analysis and also looks if the outcome of the risk estimation is acceptable to the society or community given the existing economic, social, political, cultural, technical and environmental conditions. If the risk level is not acceptable, risk reduction measures have to be taken, which can be either structural measures or non-structural measures.

Task 7.1: Key risk reduction elements and spatial data (duration 15 minutes)

When you look at table 7.1 and the different activities required in the various pre- and post disaster phases; for which activities is the use of spatial data essential? Indicate the phases where spatial data is crucial and the ones for which it is of secondary importance.

Disaster risk management is the systematic process of using administrative decisions, organization, operational skills and capacities to implement policies, strategies and coping capacities of the society and communities to lessen the impacts of natural and related environmental and technological disasters.

Traditionally the process of Disaster Risk Management was presented as a cycle, in which the various phases would follow each other until the next disaster event would happen. It involves several phases: Prevention, Preparedness, Relief / Response, Recovery and Reconstruction. This cyclic way of presenting Disaster Risk Management has been debated. Others mentioned that all phases receive more or less attention depending on the situation. In a disaster event obviously relief and response would get more attention, and later on prevention would become more dominant (Expand-Contract Model). However, in our opinion the ideal way of representing Disaster Risk Management is in the form of a circle that becomes larger each time due to improvements in the process. Small hazard event will not turn into disaster events, and don't need to be followed-up with relief/response. It takes more time before a larger hazardous event still would become a disaster event, and relief response would be needed. Eventually the aim is to break the circle. Due to good performance of the pre-disaster phases, a hazard event doesn't turn into a disaster event anymore. Of course there will always be hazard events, like earthquakes or floods, but the losses and damage of these would be reduced each time more. The various phases are explained below. Disaster prevention includes:

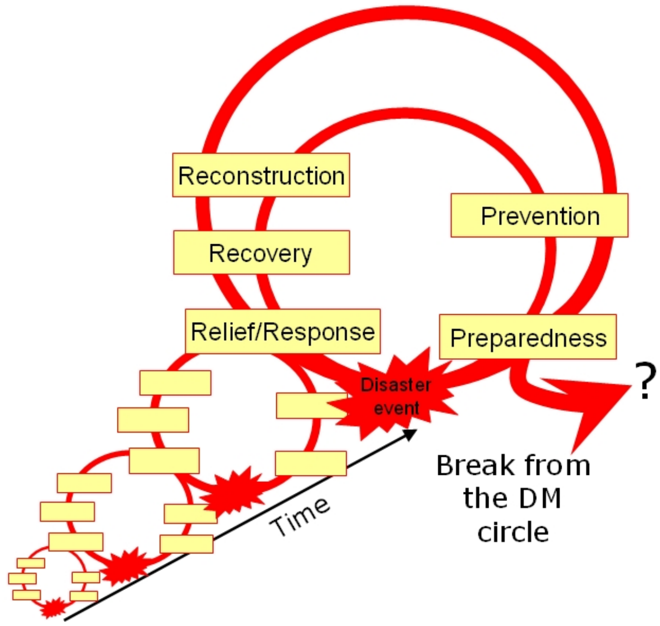


Figure 7.3: Traditional view of the disaster management cycle, and the view of the cycle as an expanding one with increasing success of disaster risk management until it will not lead to a new disaster event.

- Risk analysis, risk evaluation and effective risk reduction.
- The formulation and implementation of long-range policies and programmes to prevent or eliminate the occurrence of disasters or more frequently, to reduce the severe effects of disasters (mitigation strategies);
- Establishment of legislation and regulatory measures, principally in the field of physical and urban planning, public works and

Prevention:
Activities to provide outright avoidance of the adverse impact of hazards and means to minimize related environmental, technological and biological disasters.
Depending on social and technical feasibility and cost/benefit considerations, investing in preventive measures is justified in areas frequently affected by disasters. In the context of public awareness and education, related to disaster risk reduction changing attitudes and behavior contribute to promoting a "culture of prevention".

building e.g. rules on land use planning, rules on building codes, building of special constructions, etc.

In essence, disaster prevention consists of the acquisition of basic geographically-registered information on hazards, the vulnerability of the elements at risk and consequent risks analysis and, on the basis of that information, the planning of human activities such as land-use, construction and public/engineering works so as to reduce or eliminate the possibility of damage and destruction.

Preparedness is supported by the necessary legislation and means a readiness to cope with disasters or similar emergencies which cannot be avoided. It includes:

- forecasting and warning / monitoring
- education and training of the population
- organization for and management of disasters situations,
- preparation of operational plans, training of relief groups,
- stock piling of supplies
- earmarking of necessary funds

> **Preparedness:**
> Activities and measures taken in advance to ensure effective response to the impact of hazards, including the issuance of timely and effective early warnings and the temporary evacuation of people and property from threatened locations (UN-ISDR, 2004).

As distinct from disaster prevention, which seeks to mitigate the severity of, or to totally avoid, disasters, preparedness presumes the inevitability of some disasters and prepares for the actions required when they occur. Major components of disaster preparedness are: organization, emergency operations, communications, evacuations, disaster warnings.

The concept of "mitigation" spans the broad spectrum of disaster prevention and preparedness activities. Mitigation is a management strategy that balances current actions and expenditures with potential losses from future hazard occurrences. It means reducing the actual or probable effects of an extreme hazard on man and his environment. Perhaps the most fundamental point to be made about a disaster is that the situation - both in reality as well as perception - changes with time and, especially with a fast-breaking disaster, it is necessary to maintain awareness of current status. In many emergencies the first aid comes from the family or neighbours, then the community, then perhaps provincial or regional sources, and only after that, is aid received from national and international sources.

> **Relief / Response:**
> The provision of assistance or intervention during or immediately after a disaster to meet the life preservation and basic subsistence needs of those people affected. It can be of an immediate, short term, or protracted duration.

The effective delivery of relief from the community level upwards, depends strongly on the adequacy of public awareness and disaster preparedness plans and the effectiveness with which they are carried out. Major components of disaster relief are: assessment of the situation (both the assessment of the extent of the damage as well as that of relief requirements), rescue operation, relief supplies and handling of strategic problems.

> **Recovery / Reconstruction:**
> Decisions and actions taken after a disaster with a view to restoring or improving the pre-disaster living conditions of the stricken community, while encouraging and facilitating necessary adjustments to reduce disaster risk.

After the relief phase recovery activities start until all systems return to acceptable, normal or better levels.

- Short term recovery activities return vital life-support systems to minimize operation standards;
- Long term recovery activities may continue for years until acceptable performance levels are achieved.

Recovery (rehabilitation and reconstruction) affords an opportunity to develop and apply disaster risk reduction measures (UN-ISDR, 2004).

7.2 Risk perception and risk evaluation

Risk can be divided into two distinct dimensions:

- The "factual" dimension, which indicates the actual measured level of risk, and which can be expressed in probability of losses (e.g. number of people, building, monetary values)
- The "socio-cultural" dimension, which includes how a particular risk is viewed when values and emotions come into play.

Risk evaluation is a component of risk assessment in which judgments are made about the significance and acceptability of risk. This can be for society as a whole or for certain groups or individuals. Risk evaluation is done by comparing the level of risk against predetermined standards, target risk levels or other criteria

Risk evaluation is the stage at which values and judgment enter the decision process, explicitly or implicitly, by including consideration of the importance of the estimated risks and the associated social, environmental, and economic consequences, in order to identify a range of alternatives for managing the risks.

Risk perception is about how individuals, communities, or governments perceive/judge/evaluate/rank the level of risk, in relation to:

- **Their personal situation.** For instance a teenager would perceive the risk of hang gliding much lower than a middle aged person.
- **Cultural and religious background**: the cultural background plays an important role, as it will define the way in which people see hazardous events as "Act of God", or not.
- **Social background**: people living in squatter areas may perceive the same objective level of risk as being much lower than people living in more developed areas.
- **Economic level**: the lower the economic background, generally the lower the perception of the risk to (natural) events will be, as it is rated against other socio-economic problems.
- **Political background**: the political background of people also plays an important role. For instance in countries with a centralistic political system, the risk is perceived as a risk that the government should deal with more easily than in a country where individual actions and decisions are rated more important.
- **Level of awareness**: in order to perceive risk it is necessary that people are aware of the risk. Therefore the awareness level is very important.
- **Media exposure**: related to that is the media exposure. If a particular threat is getting a lot of media exposure, the risk is also perceived higher.
- **Other risks**: when perceiving risks people will always relate risk to each other. Risk that are related to more frequently occurring events, for instance flooding, generally are perceived as more problematic then risk from very infrequent events such as earthquakes.
- **Risk reduction situation**: a person living in a country where much emphasis is given to risk reduction will perceive

Risk perception is analyzed by interviewing people and asking them to rank the dangers they foresee in their own situation, or ask them to indicate the way in which they worry about certain aspects.

Figure 7.4: Risk perception.

Task 7.2: Risk perception (duration 15 minutes)
Suppose you would have to make interviews of people living in flood prone areas in:
***A**. The parts of the Netherlands that are below sea level, which are protected by dikes. In the Netherlands all flood control is the task of the local authorities (waterboards) and central government.*
***B**. In the squatter areas of RiskCity that have experienced a massive flood event in 1998. After the flood event many people came from the rural parts of the country and settled in the flood prone areas.*
***C**. In a city on an alluvial fan downstream of a mountainous area, where there is a possibility that a future earthquake would trigger landslides damming a river and causing a lake-break out flood.*

- *Which questions would you ask them?*
- *What do you think would be the outcomes in the different cases?*

In the risk evaluation a number of key aspects play a role (see table 7.3).

Table 7.3 Factors that affect the level of acceptability of risk. Partly from: Sandman, P. M. 1993. Responding to community outrage: Strategies for effective risk communication

Factor	Explanation
Unfamiliarity	When people are familiar with risk involved in an activity they are more willing to accept it. Societies experiencing frequent landslides may have different level of landslide risk acceptance that that experiencing rare landslide situations.
Involuntary	Voluntary risks are risk for which one can choose to take them (e.g. driving a motorcycle), whereas involuntary risks are those for which one cannot choose, but is exposed to. People are more obviously willing to accept voluntary risks (as it is their own choice) rather than involuntary risks (e.g. the construction of a hazardous chemical industry nearby your house)
Incontrollable	The inability to control a risk decreases its acceptability. Once the risk is under personal control (e.g. driving a car) it is more acceptable than the risk controlled by other parties (e.g. travelling as a passenger).
Dreaded	A risk that is highly feared (e.g. airplane crash) is considered less acceptable than one that is not (e.g. car accident)
Memorable	A risk that is embedded in a remarkable event (e.g. Indian ocean tsunami) is judged as being less acceptable.
Catastrophic	An event that is catastrophic is judged less accepted than many small events having the same impact
Uninformed	Risk of which people are not properly informed are judge to be more acceptable
Long term	Long term risk, with a small probability of occurrence or that impact over a larger period of time are judge to be more acceptable than short term ones.
Unbeneficial	Risk that do not have any additional benefits are judged to be less acceptable than those that do have added benefits
Untrustworthy	If the source of the risk or method of analysis is not trustworthy, the risk will be judged to be less acceptable
Uncertain	A risk that is very uncertain and where we know little about is judged to be less acceptable.

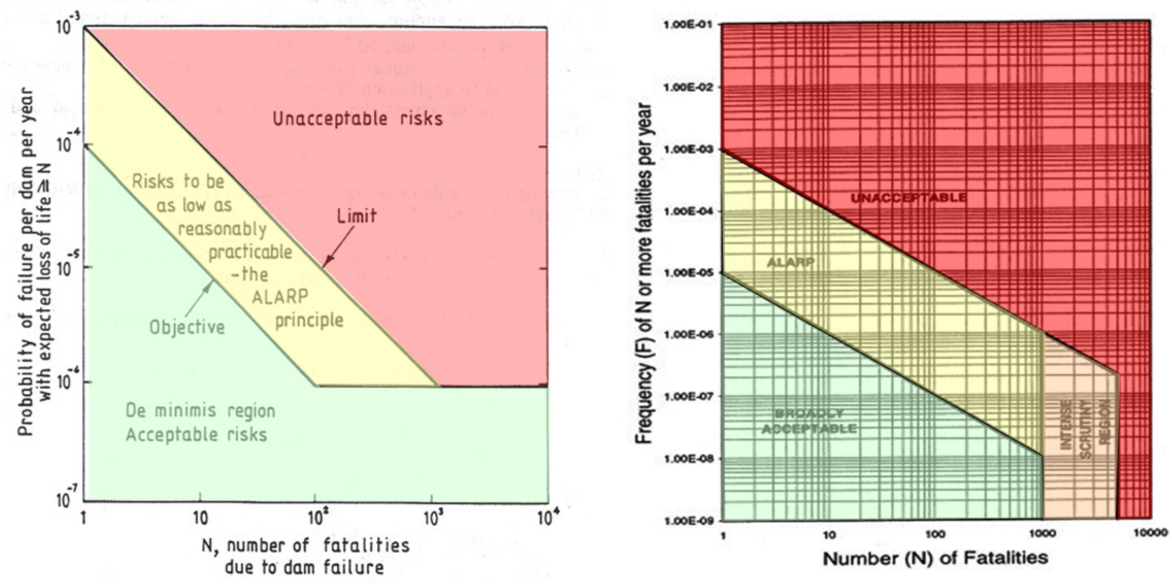
These aspects define the levels at which risk is considered to be acceptable or not acceptable.

Acceptable risk: a risk which the society or impacted individuals are prepared to accept. Actions to further reduce such risk are usually not required unless reasonably practicable measures are available at low cost in terms of money, time and effort.
Tolerable risk: a risk within a range that society can live with so as to secure certain net benefits. It is a range of risk regarded as non-negligible and needing to be kept under review and reduced further if possible.
ALARP (As Low As Reasonably Practicable) principle: Principle which states that risks, lower than the limit of tolerability, are tolerable only if risk reduction is impracticable or if its cost is grossly in disproportion (depending on the level of risk) to the improvement gained.

Figure 7.5: Risk perception?

Risk acceptability is mostly done on the basis of F-N curves (see also section 6.2.1). F-N curves display the probability per year of causing N or more fatalities (F) to N. Such curves may be used to express societal risk criteria and to describe the safety levels of particular facilities. Generally the incremental risk from a hazard to an individual should not be greater than the level to which someone is already exposed to in everyday life. This defines therefore the starting line with N=1.

Figure 7.6: Use of F-N curves to define risk acceptability criteria. Left: the general principle of dividing the F-N curve into regions of acceptable, ALARP (tolerable), and unacceptable risk levels. Right: example of risk acceptability levels for Hongkong.

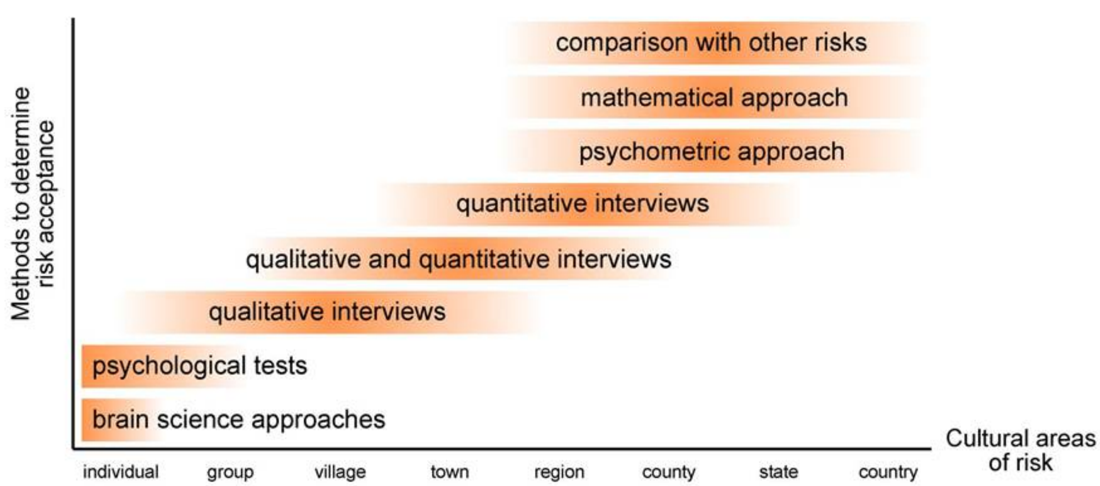


The definition of acceptability levels is a responsibility of the national or local government in a country. Risk acceptability depends on many factors, and differs from country to country. Therefore it is also not possible to simply export them to other countries. Figure 7.7 shows a series of methods that can be used to define acceptability levels. Table 7.4 shows some examples of individual acceptable risk thresholds from different countries and the box on the next page gives an example of societal risk thresholds for the Netherlands.

Table 7.4: Examples of individual acceptable risk thresholds for natural hazards in different countries.

	Individual acceptable risk level
UK Health and Safety Executive Board	< 10-4 /year
Iceland, Ministry for the Environment	> 3 x 10-4 / year
Switserland (BUWAL, Swiss agency for the Environment, Forests and Landscape)	< 0.3x10-4 / year
Hongkong (Geotechnical Engineering Office)	Existing developments: <10 –4 / year New developments: <10-5 /year
Netherlands	< 1.4 × 10-5/year

Figure 7.7: Methods that can be used to define risk acceptability levels, depending on the level of analysis.



Example: Acceptable risk levels in the Netherlands.

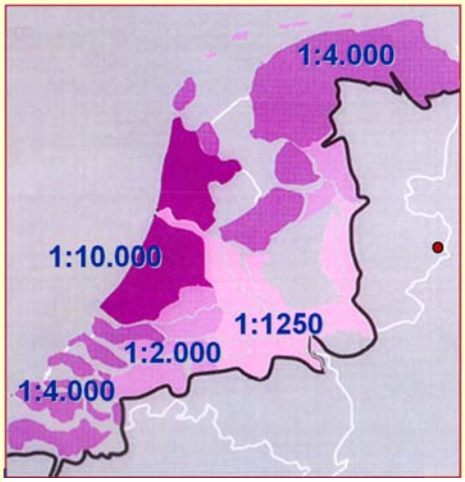


Figure 7.8: Safety standards with respect to flooding in the Netherlands

The Netherlands is a country subjected to severe risk to flooding, both from the sea as well as from the main rivers (Rhine, Meuse). The country has been severely affected by flooding in many occasions. In fact flooding has been intricately connected to the development of the Netherlands. The last major flood disaster happened in 1953, when of the southwestern part of the Netherlands was flooded due to a severe northwestern storm and over 1800 people lost their lives. To protect the country from flooding, so-called "dyke rings" have been constructed, which protect the low lying areas that they surround. A National Commission has set the acceptable risk for complete failure of every "dyke ring" in the country at 1 in 125,000 years. However the cost of building this level of protection was deemed too high, so the acceptable risk was set according to region as follows:

- North and South Holland (the area with the highest concentration of population) 1 per 10,000 years
- Rest of the country at risk from sea flooding 1 per 4,000 years
- Transition areas between high land and low land 1 per 2,000 years

River flooding causes less damage than salt water flooding so areas at risk from river flooding have a higher acceptable risk. Also river flooding has a longer warning time, making for a lower estimated death toll.

- South Holland at risk from river flooding 1 per 1,250 years
- Rest of the country at risk from river flooding 1 per 250 years.

These acceptable risks were put down in the Delta law, requiring government to keep risks of catastrophic flooding within these limits and upgrade defenses should new insights into risks require this.

The current Dutch policy on risk acceptance looks at two levels of risk: Individual and societal risk. The individual risk for a point location around a hazardous activity is defined as the probability that an average unprotected person (hypothetically) permanently present at that point location, would get killed due to an accident at the hazardous activity. The individual risk depends on the geographic location and is represented as lines with equal amount of risk (iso-risk lines). The societal risk for a hazardous activity is defined as the probability that a group of more than N persons would get killed due to an accident at the hazardous activity area. The societal risk limit is set at $F=10^{-3}/N^2$, which serves as a guideline (F = annual frequency, N = number of fatalities)

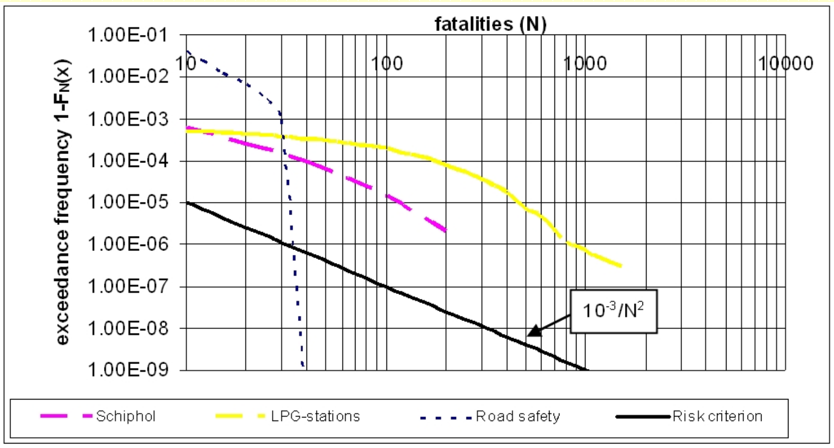


Figure 7.9: FN-curves with the national risk acceptability criterion (adapted from: National Institute for Public Health and the Environment, 2004, and Vrijling, van Gelder and Ouwerkerk (2008))

7.3 Risk Governance.

In the last decades the word governance has become very popular, and is being used in many different settings, including the risk management field.

> The term "governance" refers to the capacity of actors, social groups and institutions to build an **organizational consensus**, to agree on the contribution of each partner and on a common vision. Governance describes structures and processes for collective decision making involving governmental and non-governmental actors.
> **Risk governance** includes the totality of actors, rules, conventions, processes, and mechanisms concerned with how relevant risk information is collected, analysed and communicated and management decisions are taken (IRGC)

Risk management cannot take place without proper risk governance. Risk governance has been integrated in the ISDR, Hyogo framework for action: "Promote and improve dialogue and cooperation among scientific communities and practitioners working on disaster risk reduction, and encourage partnerships among stakeholders, including those working on the socio-economic dimensions of disaster risk reduction".

Governance depends on the level of political commitment (on international, national, regional and local levels) and strong institutions. Good governance is identified in the ISDR Framework for disaster reduction as a key area for the success of effective and sustained disaster risk reduction. Good governance will:

- Elevate disaster risk reduction as a policy priority;
- Allocate the necessary resources for disaster risk reduction;
- Enforce implementation of disaster risk reduction measures and assign accountability for failures; and
- Facilitate participation from civil private society.

The major components for successful governance for disaster risk reduction are (table 7.4)

- Policy and planning;
- Legal and regulatory frameworks;
- Resources;
- Organisation and structures.

> Governance: the institutional and policy framework for disaster risk reduction
> http://www.preventionweb.net/files/4080_governacedevelopment.pdf

Governance has different dimensions:

- **Economic governance** includes the decision-making processes that affect a country's economic activities and its relationship with other economies. This has major implications for equity, poverty and quality of life.
- **Political governance** is the process of decision making to formulate policies, including national disaster reduction and planning. The nature of this process and the way it brings together the state, non-state and private sector actors determines the quality of the policy outcomes.
- **Administrative governance** is the system of policy implementation and requires the existence of well-functioning organizations at the central and local levels. In the case of disaster risk reduction, it requires functioning enforcement of building codes, land-use planning, environmental risk and human vulnerability monitoring and safety standards.

Policy can be enacted at a variety of levels and in a number of different ways, exerting different degrees of control varying from very binding legislation to vague guidelines and incentives for certain practices to be adopted. Three policy mechanisms can be identified:

- Direct (legal) regulation,
- Economic incentives
- Moral persuasion.

The national context generally provides the overall framework in which general aims of the policy are identified and the instruments of implementation are articulated. Some fulfilment of the policies is overseen by government ministries but many of the policies are actually carried out by other government agencies and by local authorities.

The International Risk Governance Council (IRGC) developed a framework for risk governance integrating scientific-, economic-, social- and cultural aspects and includes the effective engagement of stakeholders (see figure 7.3.). It relates Pre-Assesment conditions, Risk Appraisal, Tolerability & Acceptability Judgement of Risk and Management of Risk. There are two different spheres:

- The technical sphere focusing on the generation of knowledge and information on risk;
- The management sphere, focusing on decision making and implementation of actions.

The risk process has 'communication' as a companion to all phases of addressing and handling risk and is itself of a cyclical nature. However, the clear sequence of phases and steps offered by this process is primarily a logical and functional one and will not always correspond to reality (IRGC).

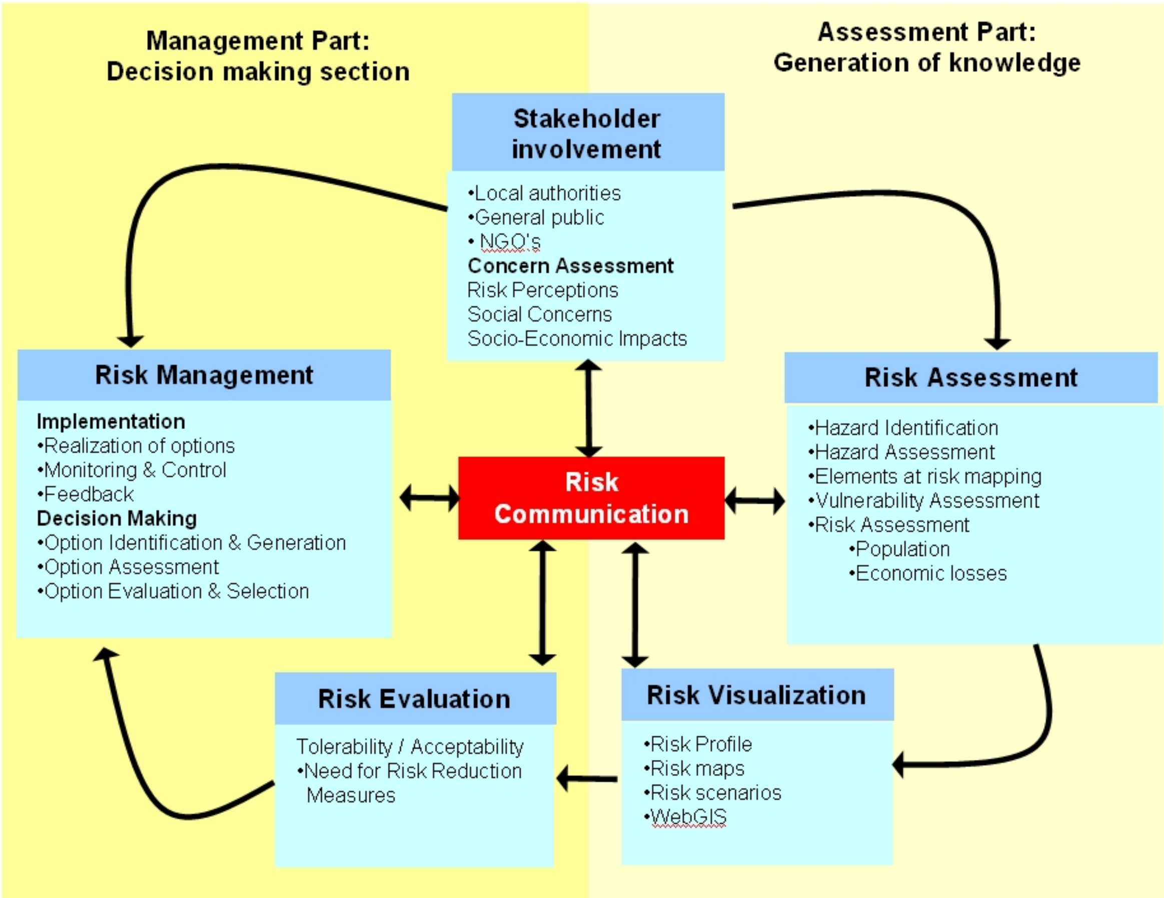


Figure 7.10: The International Risk Governance Council Risk Governance Framework (modified fromr IRGC, 2006)

Task 7.3: Risk Governance (duration 45 minutes)
Download the document:
Introduction to the IGRC Risk Governance Framework, from the following website:
http://www.irgc.org/IMG/pdf/An_introduction_to_the_IRGC_Risk_Governance_Framework.pdf

Read the document. What are your main findings after reading the document?

The aim of Risk governance is to involve the various stakeholders within all aspects of risk management. The involvement of local people is in the process is a very important component. There are many aspects that are relevant for stakeholder involvement in the process of risk governance. Table 7.5 gives a list of the main aspects together with the main questions related to them.

Table 7.5: Important aspects in stakeholder involvement (source: Glade, 2008)

Aspect	**Question**
Identification	Are stakeholders identified (through a proper process - including prioritisation)?
Representation	Are all relevant social groups represented?
Engagement	Are all relevant social groups motivated to engagement?
Access to Information	Share of stakeholders that regularly take part in information meetings
Interest	Are the stakeholders interested in having information, in the outcome?
Trust	Do the stakeholders trust the decision makers, institutions and information available?
Acceptance - Process	Do the stakeholders accept the process?
Acceptance - Outcome	Do the stakeholders accept the outcome?
Dialogue	Are stakeholders engaged in dialogue with listening and mutual understanding?
Financial	Do the financial resources available meet the needs of the governance process defined?
Personnel	Do the personnel resources available in expertise and capacity meet the needs of the governance process defined?
Time	Is there calendar time to meet the governance process defined?

There are many stakeholders involved in the risk management framework. The most important ones are the general public, decision makers and technical staff. However, there are many more, each with its own role. Table 7.6 gives an overview of stakeholders with their interests.

Table 7.6: Overview of stakeholders in risk management and their main interests

Interested in risk information	Stakeholder	Main interests
Limited	Political representatives	Get (re)elected, and earn the favor of the public
	Business sectors	Making profits, with less restrictions as possible
	General public	Live safely where they want without restrictions
	Decision makers of (local) authorities	Taking decisions on optimal development of the area under their jurisdiction and optimizing safety of the population.
	Technical staff of local authorities	Carry out regulations without problems
	Media	Discover and present remarkable/shocking information
	NGO's	Promote environmental and sustainable development
	Pressure groups	Bring their point of view under the attention of the media and influence public opinion
	Disaster management authorities	Make adequate disaster preparedness measures
	Insurance industry	Make optimal insurance policy for making profits
Very much	Scientific / technical staff of professional organizations	Collect and present realistic information on hazards and risks, and get enough funds from national government for their work.

The information presented in table 7.6 is a generalization. In reality these stakeholders might have quite a different range of interests, in particular the political representatives, the general public and the decision makers of (local) authorities. Once they become sufficiently aware of the risk situation their main interests might change quite drastically, from a "don't want to know" position, to a very active position, in which for example the public will be closely related to political pressure groups. Quite often the interests of stakeholders are different, even opposite, which makes the stakeholder communication a very important component in the risk governance framework.

7.4 Risk Communication

One of the most essential parts of risk governance is risk communication.

Risk communication is the interactive exchange of information about risks among risk assessors, managers, news media, interested groups and the general public.

Risk communication focusing on the imminent threat of an extreme event is referred to as a warning and is meant to produce an appropriate emergency response. On the other hand a risk communication program can also focus on the long-term potential for such events to happen, and is then called a hazard awareness program, intended to produce long-term hazard adjustments.
Communication should be analyzed in terms of **who** (Source) says **what** (Message), via **what medium** (Channel), to **whom** (Receiver), and directed at what kind of **change** (Effect). One of the models used of the factors that influence individual's adoption of protective actions against natural and technological hazards and disasters is called the Protective Action Decision Model (PADM) (See figure 7.11).

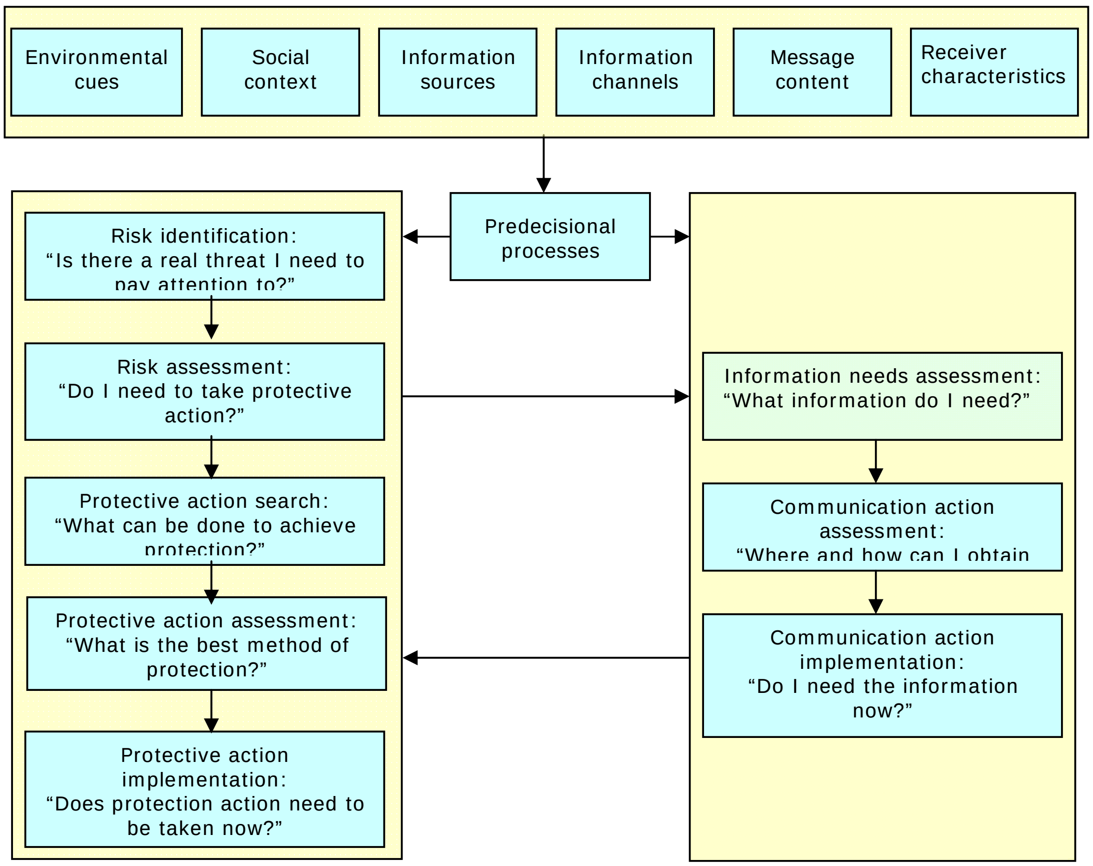


Figure 7.11: The PADM model for risk communication (Source: Lindell and Perry, 2004)

The process of decision making begins with environmental cues or risk communication messages that initiate a series of predecisional processes. In turn, these predecisional processes stimulate either a protective action decision making process or an information seeking process. To proceed through the successive stages of either process, the individual must arrive at an affirmative answer to the questions posed. The dominant tendency is for environmental cues and risk communication messages to prompt protective action decisionmaking, but information seeking occurs when there is uncertainty about the answer to the critical question at a given stage in the protective action decisionmaking process. Once the question is resolved, processing proceeds to the next stage in the protective action decisionmaking process.

Risk communication can be done in a variety of manners and at different levels. The main differentiation is between risk communication at the national level, using mass media campaigns, and risk communication at the local level, where more focused measures can be used.

Risk communication at the national level is aimed at:

- making people aware of the risk in their neighborhood,
- improving their knowledge on possible disasters and how they could be prepared,'
- changing their attitude towards disaster preparation, and
- changing eventually their behavior.

National authorities can make use of a variety of tools to communicate the risk to the population. In these cases the information is normally not site specific and is directed to all people in the country.

- **Mass media**: television, radio, newspaper; this is the standard way of communicating to large audiences. Several countries have launched national campaigns to increase the awareness of the general public to disasters and make them prepared. These campaigns are not always equally successful. For instance, the disaster prevention campaign in the Netherlands up to some years ago focused on the the following rules: when a disaster strikes, go indoors, close the doors and windows and switch on the radio or tv. Later on the government changed the campaign, and focused on a variety of disaster types, each with a different way to react. Figure 7.12 shows a photograph of the media campaign, and figure 7.13 shows the communication leaflet distributed to the public. Through a website the public is able to get a personalized leaflet with the hazard relevant for the postal code in which they live. Innovative ways have been used to communicate disaster awareness, for instance using movies or soaps with disaster related issues. An example of this is the tv-soap broadcasted on Sri-Lankan national tv dealing with a crisis situation for landslides.

Figure 7.12: Example of the Netherlands media campaign "Think Ahead", which stressed that a disaster cannot be planned.

- **Electronic media**: website, email, email discussion lists, electronic conferencing, distance learning platform, SMS and MMS. Nowadays there many possibilities to use new media for risk communication, for instance the use of SMS messages to people located in an area that is likely to be affected by a disaster. Also for instance the use of twitter (http://twitter.com/) is a new approach to send very short messages
- **Audio-visual**: video, audio, multi-media, artwork, photographs, slide show, model, map.
- **Postal:** direct mailing.
- **Stand-alone print**: billboard, poster, banner, warning sign, flood water level. For instance one of the best ways of promoting earthquake safe constructions in the Kathmandu valley was to support advertisements of a local steel company in defining that by using their iron bars the houses would become earthquake safe.

At a local level the risk communication can be much more focused on the stakeholders involved in a risk assessment, and can consists of :

- **Face-to-face**: meeting, seminar, workshop, conference, march, exhibition, demonstration, training, exchange visit, planning.
- **Distributor print**: leaflet, pamphlet, brochure, booklet, guideline, case study, newsletter, journal, research paper, report.
- **Folk media**: story, drama, dance, song, puppet, music, street entertainment.
- **People**: community leader, volunteer, project worker, head of women's group.

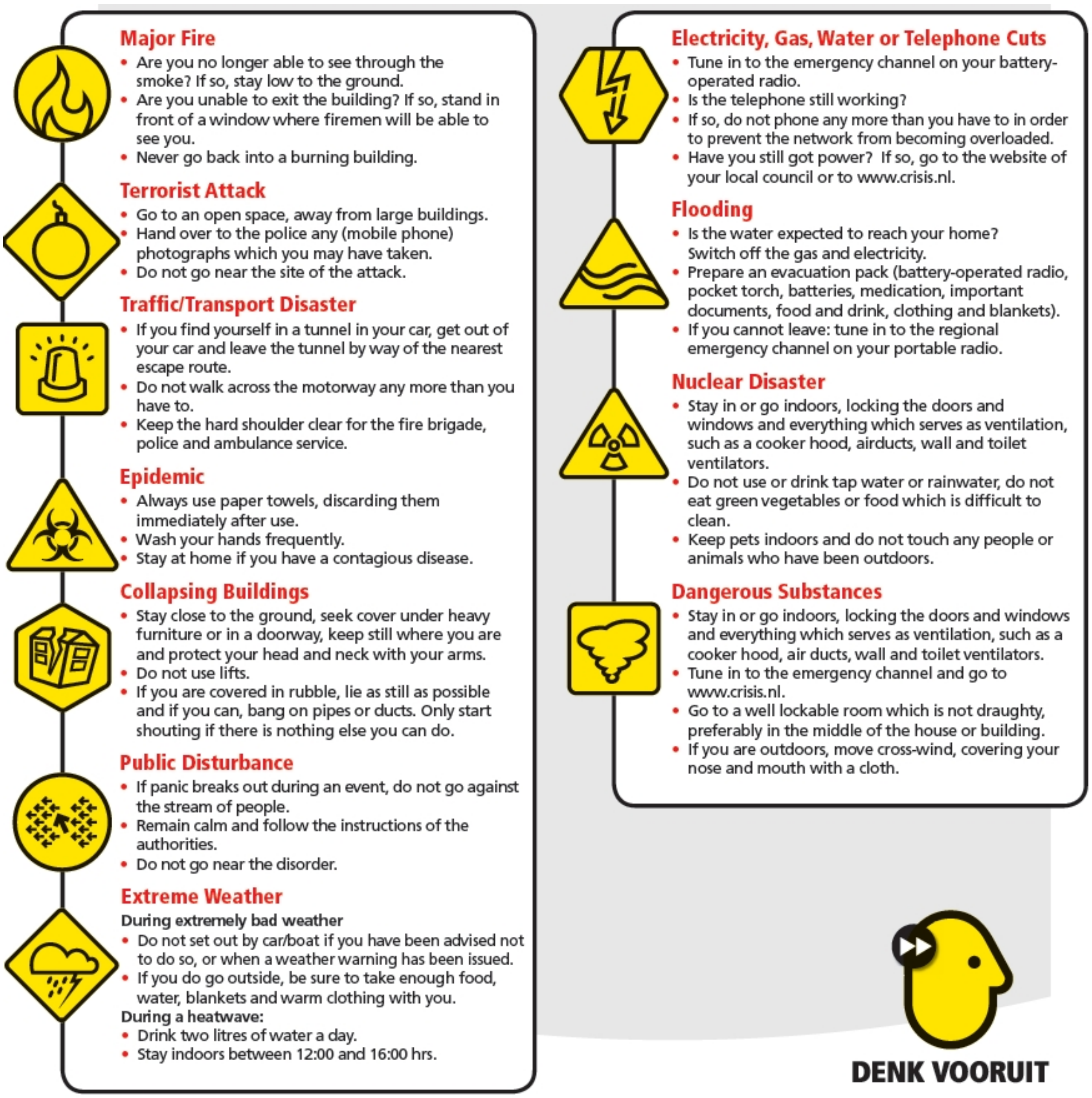


Figure 7.13: Example of the risk communication leaflet used by the Netherlands government (see also : http://denkvooruit.nl/english/).

Task 7.4: Risk Communication (duration 45 minutes)

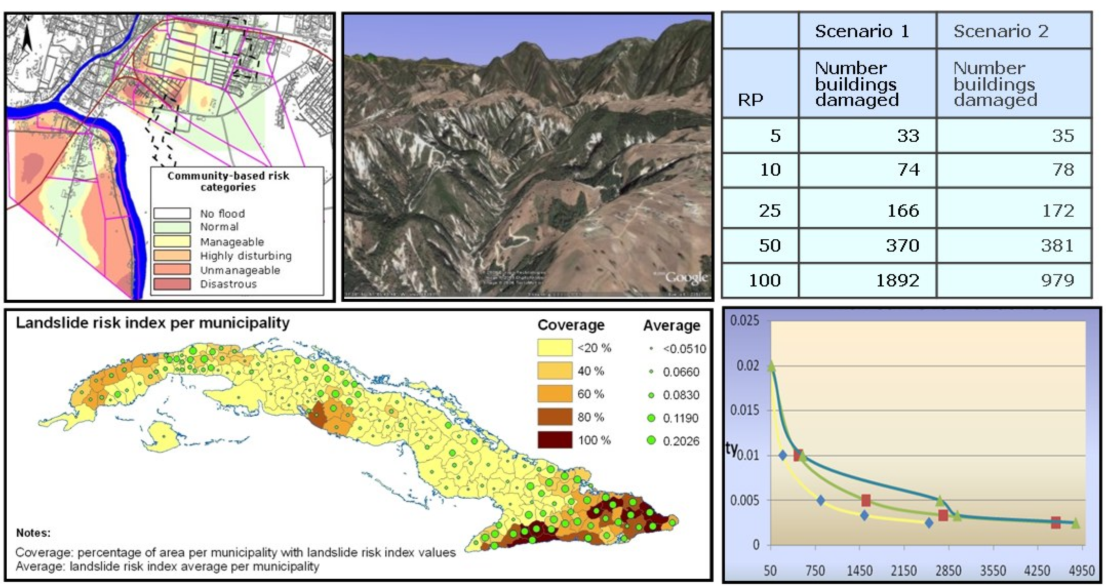
Have a look at the "failed" Netherlands campaign "Think Ahead" on the following site:
http://www.youtube.com/watch?v=EQInZRK8Tbs&feature=related
Why do you think this campaign was not successful?
Check some of the disaster preparedness videos from the US on disaster preparedness:
http://www.youtube.com/watch?v=M1uM9LY80LU&feature=PlayList&p=9D2D73485E97A3AB&playnext=1&playnext_from=PL&index=22
Earthquake drill at school:
http://www.youtube.com/watch?v=bAHNhtRT50A&feature=related
Evacuation planning:
http://www.youtube.com/watch?v=CcRWwcu0O6Y&feature=related
And if you want to see how they thought of informing the public in the seventies in a "moviestyle" manner , watch:
http://www.youtube.com/watch?v=mlcswmcDmCs&feature=related

7.4 Risk visualization

One of the important processes in risk governance is the visualization of risk. Since risk is a spatially varying phenomenon, Geographic Information Systems (GIS) technology is now the standard tool for the production and presentation of risk information as we have seen in the previous sessions. Risk can be presented in the form of:

- **Statistical information per administrative unit** (country, province, municipality, or neighborhood), such as:
    - A Risk Index value resulting from qualitative risk assessment (e.g. Spatial Multi Criteria Evaluation);
    - The Probable Maximum Loss (PML) or Average Annual Loss (See table 6.2);
- **Risk curves**, such as:
    - Loss Exceedance curve for economic risk, or;
    - F-N curves for societal population risk;
- **Maps** which shows the spatial variation of risk over an area:
    - A hazard map with an overlay of the elements at risk;
    - Qualitative classification of risk classes in high, moderate and low;
    - Quantitative estimations of building-, economic or population losses per unit;
- **WebGIS applications** that allow the user to combine different types of information, and display information such as:
    - Hazard maps of individual hazard types;
    - Elements at risk information;
    - Maps of individual risk types, for instance for different return periods;
    - Multi-hazard risk;
- **Spatial Data Infrastructure / Clearinghouses**, where through internet basic GIS data can be shared among different technical and scientific organizations involved in hazard and risk assessment.
- **Animations** showing the spatial and temporal distribution of hazards and risk, such as:
    - Flood animations showing the development of a flood over time, where the flood height, and water velocity are shown per time step as a movie file, overlain with elements at risk information;
    - Fly-throughs, three dimensional displays of risk information over a high resolution satellite image. For instance, Google Earth now offers great opportunities to make such animations, as one can export the risk maps from GIS and KML files that can be directly overlain in Google Earth.

The type of Risk visualization depends very much on the stakeholder to which the risk information is presented. Table 7.7 gives and overview of the relation between stakeholders and the type of risk visualization.



RP	Scenario 1 Number buildings damaged	Scenario 2 Number buildings damaged
5	33	35
10	74	78
25	166	172
50	370	381
100	1892	979

Figure 7.14: Examples of visualization techniques that can be used for communicating risk information. Above: Maps, 3-D animations and statistical information; below: per administrative unit and loss exceedance curve.

Table 7.7: Relationship between stakeholders in risk management and risk visualization options.

Stakeholder	Purpose	Type of risk visualization
General public	General information on risks over large areas	Basic WebGIS applications in which they can overlay the location of major hazard types with high resolution imagery or topographic maps.
	Awareness raising	Animations (what if scenarios)
	Community-based DRR projects	Simple maps of the neighborhood with risk class, buildings and other features
Businesses	Investment policies, and location planning	General information about hazards and risks in both graphical and map format.
Technical staff of (local) authorities	Land use regulation / zoning	Map with simple legend in three classes: construction restricted, construction allowed, further investigation required.
	Building codes	Maps indicating the types of building allowed (building type, number of floors)
	Spatial planning	Hazard maps, with simple legends related to probabilities and possible consequences
	Environmental Impact Assessment	Maps and possible loss figures for future scenarios
	Disaster preparedness	Real time simple and concise Web-based information in both map and graphical forms
Decision makers / local authorities	Decision making on risk reduction measures	Statistical information, loss exceedance curves, F-N curves, maps.
	Investments	Economic losses, projected economic losses for future scenarios.
	Strategic Environmental Assessment	General statistical information for administrative units.
NGO's	Influence political decisions in favor of environment and sustainable development	This can vary from simple maps to Web-based applications, depending on the objectives of the NGO
Scientists / technical staff of hazard data producers	Hazard information exchange to public and other agencies	WebGIS applications where they can access the basic information
	Exchange of basic information for hazard and risk assessment	Spatial Data Infrastructure / Clearinghouse for exchanging information
Insurance industry	Development of insurance policy	Loss Exceedance Curves of economic losses, F-N curves
Media	Risk communication to public,	Animations of hazard phenomena that clearly illustrate the problems.

As there are no international standards for risk mapping yet, risk visualization needs to receive more attention and needs to be focused on the stakeholder or end user. A risk assessment is done by a group of thematic experts. The risk map is produced based on the interpretation and cartographic skills of these experts. However, the risk evaluation is carried out by stakeholders (mentioned above) also with their interpretation and cartographic knowledge. If either the researchers, as risk information providers; or the stakeholders, as risk information receivers; perform erroneously, the risk reduction actions taken in the study area may have mistakes, which may lead to serious consequences.

Cartographic aspects of spatial risk information

The fact that risk maps represent 'areas at risk' is the main reason why most maps employ intensity scales in classes for one colour or traffic-light colours, in continuous ramps or in coloured patterns. The proper definition and representation of risk classes is an important issue. For example, when using gray tones for risk classes, the colour white should represent areas with no risk at all. Similarly, with traffic-light colours the colour green should represent safe areas with a negligible or zero risk. When colour ramps are utilized at least the minimum and maximum values of risk should be in the legends. While at national and provincial level risk maps could be presented by continuous values or classes, at municipal and local level the risk of individual objects is required to be visualized.

When the risk has been estimated quantitatively or semi-quantitatively and it is represented by a continuous ramp there are three main options by which these risk values could fit between the minimum and maximum intensity colour: by the standard deviation, by the histogram and by the minimum and maximum values. Figure 7.15 shows the visual effects of some of these options for the same area of a risk index map with the traffic-light representation (i.e. green-yellow-red). The differences in visualization for the same risk values are quite remarkable. In risk maps with classes, similar problems arise since the number of classes and the break values between them should be decided by the researcher.

The use of simple classifications with three classes is preferred for end users such as local authorities. However, for physical planners or other researchers a higher number of classes could be required. For selecting the break values among classes, current GIS systems (the map maker) can select from many methods (e.g. equal intervals, defined intervals, standard deviation and natural breaks).

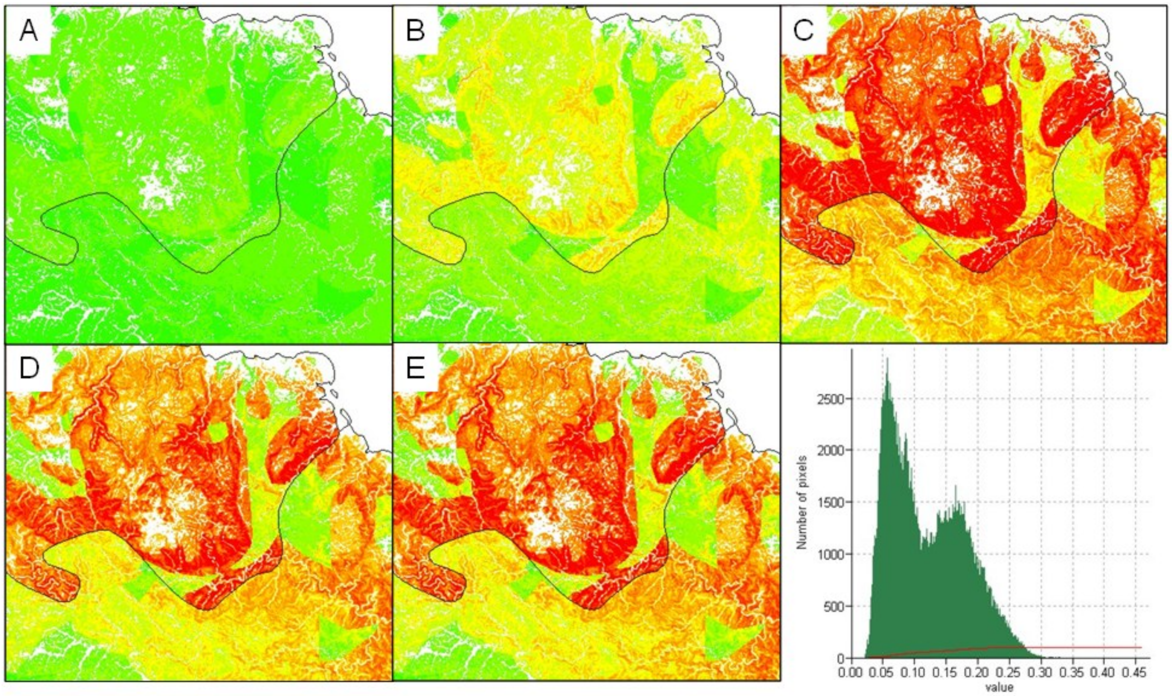


Figure 7.15: Risk representation of the same area with some stretch options and map histogram. A: risk values stretched between 0-1, B: between minimum and maximum risk values, C: between 2 times standard deviation, D: between 0.5 percentage of the histogram and D: between 1 percentage of the histogram (Source: Castellanos, 2008).

Task 7.5: Risk visualization (duration 45 minutes)

The aim of this task is that you use see a number of good examples of visualizations of hazard and risk information. Some examples are:

- http://apps.arcwebservices.com/sc/hurricane_viewer/index.html
  This is the Hurricane Disaster Viewer. You can see current Hurricanes, weather, flood risk maps and many more in this WebGIS application.
- http://www.nola.com/katrina/graphics/flashflood.swf
- This is a so-called Shockwave animation of the events that lead to flooding in New Orleand during Hurricane Katrina.
- http://earthquake.usgs.gov/eqcenter/catalogs/
- http://earthquake.usgs.gov/research/data/google_earth.php
- http://earthquake.usgs.gov/regional/nca/virtualtour/modern.php
  Here you can find a number of examples of Google Earth visualization for earthquakes, and seismic hazard and risk maps for the San Francisco Bay area

WebGIS

Conventional GIS systems include all components of a GIS, such as data management, data analysis or application and data presentation in one single platform, or tier. They have a non-distributable software design, meaning that all components are done on the same system (See Figure 7.16). This makes it difficult to share the results with other users that are located in different places. Therefore in order to be able to visualize and analyze data that are located somewhere else physically, and do that with many different clients, another design is needed. In an Internet based GIS all the individual layers are separated (mulit-tier approach) thus allowing many clients to access and visualize the geo-data at the same time.

The Client is separated from the presentation logic. It offers the possibility to connect different client platforms (PCs,PDAs, mobiles) to the same information system.

A **WebGIS** is a special GIS tool that uses the Internet as a means to access and transmit remote data, conduct analysis, and present GIS results.

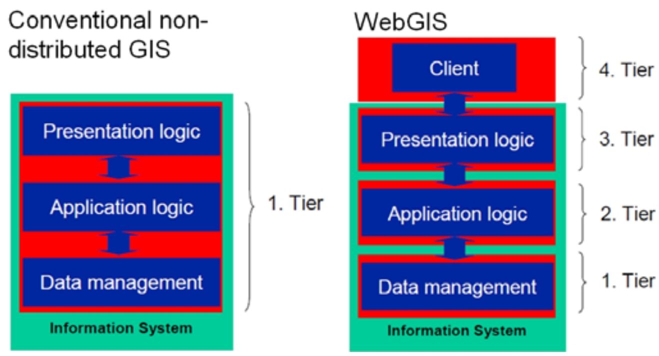


Figure 7.16: A conventional GIS contains all components inside the same system. A WebGIS separates the management, application and presentation part, and makes it accessible to a client. (Source: B. Köbben, ITC).

Several terms are also use: Internet GIs, Distributed GIS, Online GIS, or Networked GIS.
In a WebGIS there is a client – server approach with clients requesting information and servers responding to individual requests.
In a simple case a client (browser) requests a simple HTML document from a Web-Sever (HTML-server). However in a WebGIS the transferred document is not a simple copy of a previously stored HTML document. Based on the request parameters the output will be dynamically generated as a map. Therefore these systems use other languages , referred to as XML, such as Geographical Markup Language (GML) for geographical data and Scalable Vector Graphics (SVG). The systems should be **interoperable**, meaning that they should be able to transfer data and metadata seamlessly and access functions seamlessly. This requires interfaces and standardization. For WebGIS applications the standardization is done by the Open GeoSpatial Consortium (OGC), a non-profit organization with the aim to deliver spatial interface specifications that are openly available for global use. There are several OGC Webservice specifications such as Web Coverage Service (WCS) focusing on raster data and satellite imagery, and Web Feature Service (WFS) focusing on vector data.

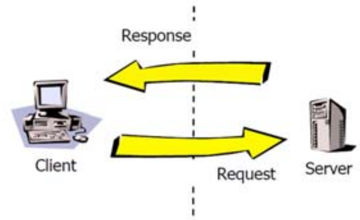


Figure 7.17: Client-Server approach in WebGIS.

WebGIS has been applied successfully in many countries for the visualization of risk information. Some of the best examples of these are:\

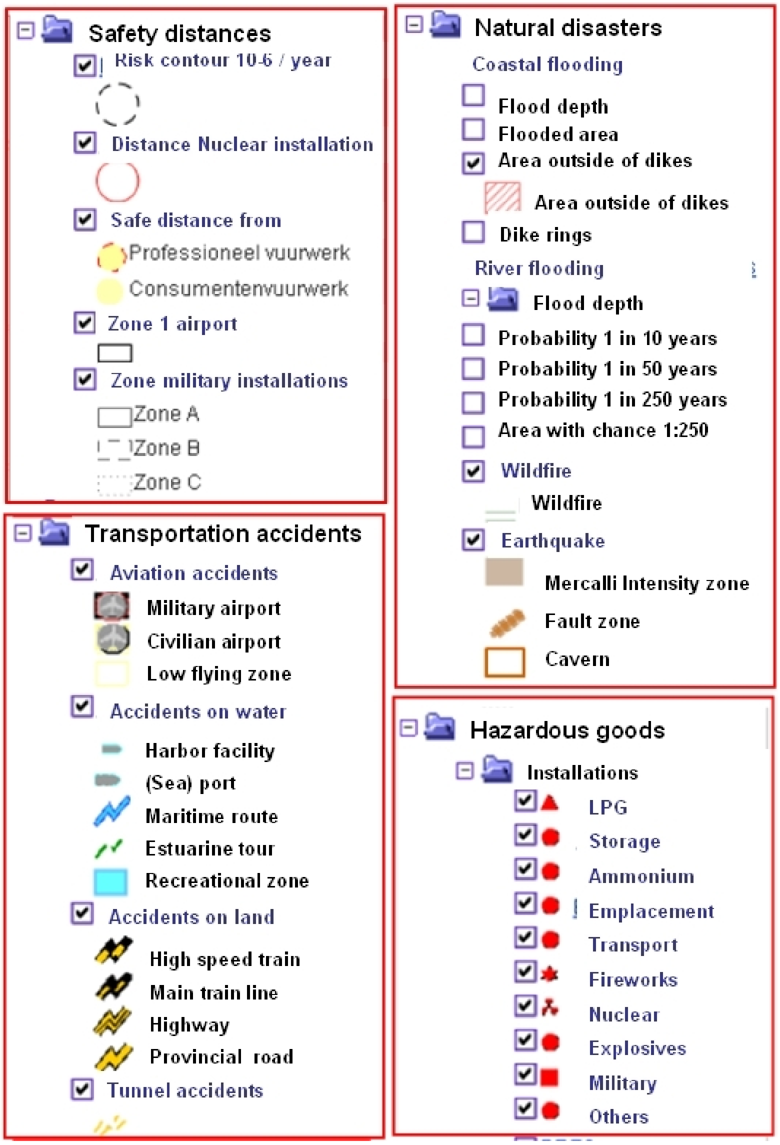
- The Dutch risk map that allows to query multi-hazard risks for the whole of the Netherlands (See also task 7.7)
- The flood risk webGIS application from the UK.

Task 7.6: WebGIS exercise RiskCity (duration 2 hours)

For RiskCity we have also developed a WebGIS application, as mentioned in session 1.3. In this exercise we will use the WebGIS application for a disaster preparedness exercise.

A simplified version of RiskCity dataset is offered. Spatial data are available for different interactions: the user can personally evaluate the type and the resolution of result data archived for every exercise session, compare different kinds of information in a multi hazard-risk assessment, prepare queries according to exercise aims, download information tables for outside elaboration, create his personal layout with new shapes and labels directly drawn on map. WebRiskCity allows the users to learn different levels of risk assessment without actually executing all steps by themselves.

For the exercise descriptions please consult the separate handouts or the blackboard.



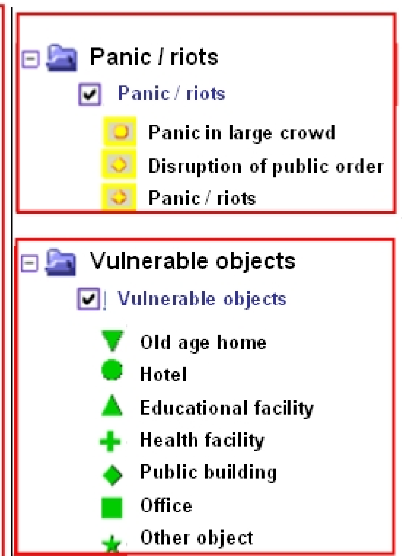


Figure 7.18: Legend of the Dutch national WebGIS risk atlas. [*www.risicokaart.nl*](http://www.risicokaart.nl)

Task 7.7: WebGIS and risk (duration 30 minutes)

The aim of this task is that you use WebGIS for visualizing risks spatially. We are using the national risk atlas from the Netherlands, which can be accessed through: www.risicokaart.nl

- Click on the Province: **Zuid Holland**. Now the webGIS application will start. Depending on your internet speed this might take some time.
- Select the button for **English** in the upper left corner. Now you can use the legend on the right hand side of your screen to select the items you would like to see.
- Expand the part on **Natural hazards**. Zoom in on the harbour area of Rotterdam.
- Use the information tool to get information on the hazard areas.
- Zoom in further until you are able to expand the **Vulnerable objects**.
- Compare the area with what you can see on Google Earth / Google Maps (e.g. http://maps.google.com/
- What can you conclude on the identification of vulnerable objects on this map?

The Netherlands also has a WebGIS for all areas that are planned to be constructed in the coming decade. This map is accessible through the website: www. www.nieuwekaart.nl

- Click on the map on the left hand side. The interactive map will start.
- Zoom in on the same area that you selected for the risk atlas. You can now check if there are planned developments in high risk zones, by comparing the results of both atlases.

Spatial data infrastructure (SDI)

In session 2 we have discussed how different data types are useful for different disaster types, and at different stages in the disaster management (DM) cycle. From the previous session it has become clear that risk assessment requires a multitude of data, coming from different data sources. In practice it can be a problem to get the appropriate data when needed. Therefore it is important to have a strategy on how to make data available for risk management. Since data is coming from different organizations we have to look at aspects such as data quality, metadata, multi-user databases, etc. Many (supposedly) project-specific data sets can be used for various purposes (e.g. for resource management was well as risk assessment). This requires that the potential users know what data exist, and have ready access to them.

A **spatial data infrastructure** is the foundation or basic framework (e.g. of a system or organization) with policies, resources and structures to make spatial information available to decision makers and the community when they need it, where they need it and in a form where they can use it (almost) immediately.

The SDI has the following characteristics: widely available, standardized delivery, easy to use, flexible, multipurpose, taken for granted, public good. An SDI is a system to promote access to and sharing of geodata. It includes the actual Geodata, but also **metadata**, which is a description of the data in terms of producer, contents, scale, quality, format and time of production. The use of data standards is important, in order to be able to share it. But even more so, it is required to have data sharing policies and partnerships to promote and improve the sharing of such data. This in practice is often the largest bottleneck in developing countries where national organizations are often not willing to easily exchange data. SDIs can be implemented at different levels: regional, national and global levels. They support multiple simultaneous users, while allowing limited access to source data (copyright protection). The website where the data is actually exchange is called a **clearinghouse**. In many cases, unfortunately, such data clearinghouses are only established after an disaster event (e.g. following the Indian ocean tsunami or Hurricane Mitch).

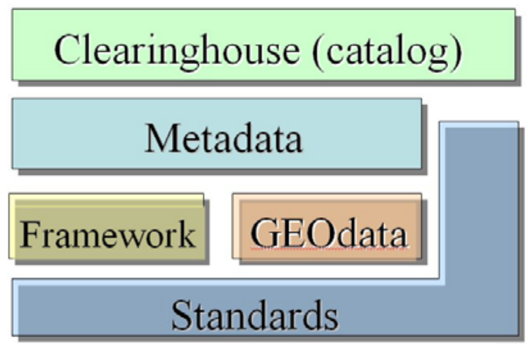


Figure 7.19: Spatial Data Infrastructure

Individual SDIs can be linked into a Global Spatial Data Infrastructure (GSDI: http://www.gsdi.org/). You can find examples of SDI's in many different countries. Figure 7.14 shows the clearinghouse of ITC from where images, airphotos and maps can be obtained from all over the world.

Some relevant sites for finding recent disaster data are:

Reliefweb: www.reliefweb.int
Alernet: www.alertnet.org
HEWSweb: www.hewsweb.org
UNOSAT: unosat.web.cern.ch
Intern. Disaster Charter: www.disastercharter.org
Respond: www.respond-int.org
GDACS: www.gdacs.org

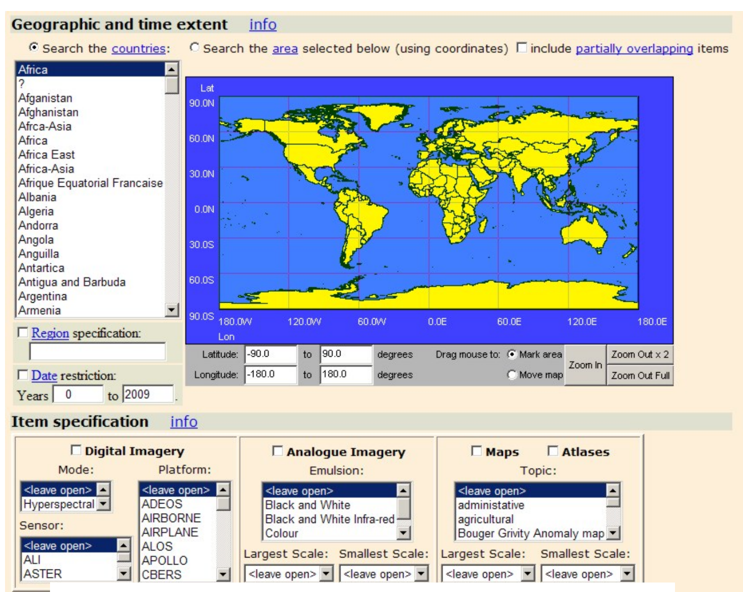


Figure 7.20: ITC's geodata warehouse search page.

7.5 Risk Reduction (or Mitigation) Options

Risk reduction can be done using different strategies:

- **Risk avoidance**: the aim is to eliminate the risk by modifying the hazard
- **Risk reduction**: to mitigate the risk by modifying the vulnerability to damage and disruption.
- **Risk transfer**: to outsource or insure and modify the financial impact of hazards on individuals and the community.
- **Risk retention**: to accept the risk and budget / save for the expected damages.

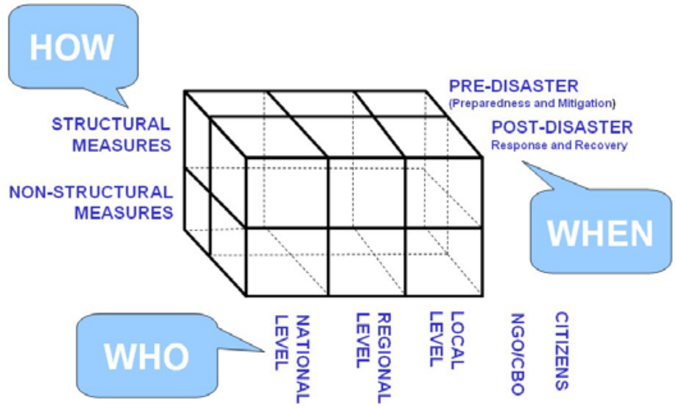


Figure 7.21: Important aspects of disaster risk reduction: how, who and when.

It is important to realize that disaster risk has three main components namely hazards, vulnerability, and amount of elements at risk.

Risk = Hazard * Vulnerability * Amount of elements-at-risk [8.1]

This means that risk reduction can be achieved by reduced the hazard, the vulnerability and/or the amount of exposed elements at risk. Risk reduction measures can be grouped in:

Structural measures refer to any physical construction to reduce or avoid possible impacts of hazards, which include engineering measures and construction of hazard-resistant and protective structures and infrastructure. The strategy is to modify or reduce the hazard.

Non-structural measures refer to policies, awareness, knowledge development, public commitment, and methods and operating practices, including participatory mechanisms and the provision of information, which can reduce risk and related impacts. With the aim of modifying the susceptibility of hazard damage and disruption and/or modifying the impact of hazards on individuals and the community.

7.5.1 Structural Measures.

Engineering work can be viewed as either protective or corrective in nature. Of course a cost/benefit analysis has to be done for the engineering works. Often structural measures give a false sense of security, they have a certain design level based on cost benefit analysis or other criteria. If these levels are surpassed there is a residual risk.

A few examples are given here of structural measures for flood hazard reduction (see also Figure 7.19):

- Construction of dams and reservoirs: the return period of the flood in the area downstream of the dam and reservoir are reduced, since the reservoir can accommodate the peak flows.
- Development of controlled /temporary storage of flood water, so-called flood retention basins, which are used to manage storm runoff and to prevent floods and erosion in downstream areas.
- Construction of artificial levees to protect the land at the non-river side from flooding.
- Flood walls (barrier constructed of materials such as masonry block and reinforced concrete). Some designs have openings for access to buildings so they need closures and human presence.
- Channel improvements/ modifications;
- Flood proofing of buildings.

Figure 7.22: Examples of structural mitigation measures. Above: Raised community centre (tsunami hazard), and school retrofitting (earthquake hazard). Middle: raised electrical connection, gabions with vegetation for flood control and floating houses (flood hazard). Below: Retaining walls, slope drainage and biological engineering (landslide hazards)

Some examples of structural measures for landslide risk reduction are:

- Retaining walls that put a load against the toe of the slope to prevent movement
- Anchoring, rock bolting and soil nailing to add strength to rock or soil.
- Galleries to protect transportation lines from rockfall or avalanches.
- Drainage in the slope
- Terracing of slopes

Task 7.8: Structural and non structural mitigation measures (duration 30 minutes)

The aim of this task is that for one type of hazard and consider which structural and non-structural mitigation measures would be suitable.
The assignment has the following steps:

- First make a selection of a type of hazard relevant for your own country. Think about a particular area that has its own type of problems. For instance tsunami risk reduction on the southern coast of Sri Lanka, or volcanic risk reduction around the Merapi volcano in Indonesia. Think about an example yourself.
- Consider different risk reduction options that look at Risk Avoidance, Risk Reduction, and Risk Transfer (see beginning of the section)
- Read also the second part of this section on non-structural mitigation measures
- Make a list of the possible mitigation measures.
- Make a ranking of the mitigation options in terms of feasibility in the area that you consider;
- Explain the ranking and the advantages and disadvantages of the different mitigation options.
- Submit the result of the assignment through blackboard or e-mail.

7.5.2 Non structural Measures

Table 7.6 gives an overview of the main types of non-structural measures.

Table 7.6: Examples of non-structural risk reduction measures(Source: Living with Risk, UN 2004)

Non_structural Measures	Main characteristics / actions
Policy and Planning	Prioritize risk reduction; Incorporation of risk reduction policies into post disaster reconstruction; Integration of risk reduction in development planning and sectorial policies in order to reach the goals of sustainable development, poverty eradication etc.
Legal and regulatory framework	Establishment of legislation and regulatory measures, principally in the field of physical and urban planning, public works rules on land use planning, rules on building codes buildings of special constructions etc.
Organizational structures	Implementation and coordinating bodies; Local Institutions for DRR; Participation of Civil Society, NGO's, private sector, community participation
Resources	Resources mobilization and allocation; Staff allocation; Public Private partnerships
Research	Research programmes into the different aspect of risk and risk reduction; National, regional and international cooperation in research, science and technology development.
Environmental and natural resource management	Combine goals of risk reduction in the management of coastal zones, wetlands, watershed management etc.
Preparedness and contingency planning	The planning of emergency & relief operations. Preparation of operational plans, training of relief groups
Early warning	Monitoring and forecasting; Warning and Dissemination
Emergency management	Management of the disaster situation (effective response); Organizations involved: Civil protection and defence organizations, volunteer networks, NGO.s
Social and economic development practices	Social protection and safety nets; Financial instruments in DRR Sustainable livelihood strategies
Information and communication	Information and dissemination progammes & channels; Public and private information systems ; Networks for DRM
Education and training	Educational policies to include disaster reduction on all educational levels; Vocational training; Dissemination and use of traditional knowledge
Public Awareness	Public Awareness policies and programmes Media involvement in communication risk and awarneness

Legal and regulatory measures

Zoning is used to regulate the activities of the private sector by placing locational restrictions and minimum standards on specific types of land uses and activities.

- **Macro-zoning** is the establishment of land-use planning zones at the national and regional levels. Such zones generally establish agricultural, urban, industrial and recreational uses incorporating existing and future patterns; Specific uses are allowed in designated areas. Macro-zoning has a broad function in risk reduction, since hazardous areas can be zoned permanently for agriculture or recreational uses, minimizing as much as possible urban or semi-urban concentrations of population.
- **Micro-zoning** is the detailed preparation of land use maps by public authorities, fixing specific land uses for each site. Micro zoning is a basic tool which relates natural hazard assessment to land use planning.

Figure 7.23 gives an example of the use of natural hazard maps used in spatial planning in Switzerland, and figure 7.24 an example of the legend used in local zoning maps.

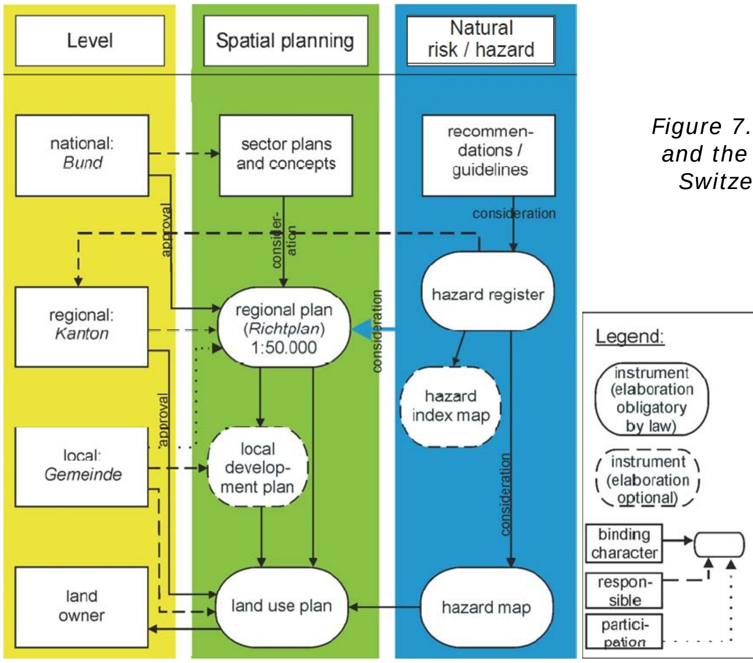


Figure 7.23: Spatial planning system and the integration natural Risks in Switzerland (Source: Darmstadt University 2001)

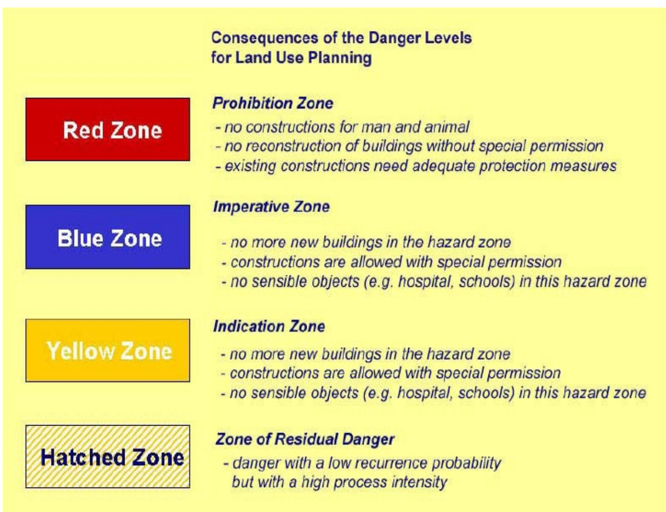


Figure 7.24: Legend of Swiss hazard planning map.

Building codes.

Building codes establish minimum standards of design, construction and materials in order to avoid structural collapse under conditions of severe physical stress caused by extreme natural phenomena. Building codes are used for earthquake, flood, wind, and landslide hazard reduction. The co-ordination of land-use controls and building codes is one of the most effective local level devices for disaster prevention and mitigation;

Standards for the repair or rehabilitation of older structures could serve as a supplementary means of improving the safety of existing structures.

Retrofitting:

Retrofitting is the modification of existing buildings to protect them (or their content) from damaging events, such as earthquakes.

Development and redevelopment policies

These include:

- Design & location of services and utilities;
- Redevelopment and renewal;
- Land-right acquisition:

- Permanent evacuation; e.g. Public land acquisition to withhold land for development for prevention measures.
- Open-space use / control: agricultural lands, parks and other types of open spaces can play an important role in helping mitigate the effect of natural disasters. Open spaces may serve to prevent or mitigate disasters while providing some economic return.

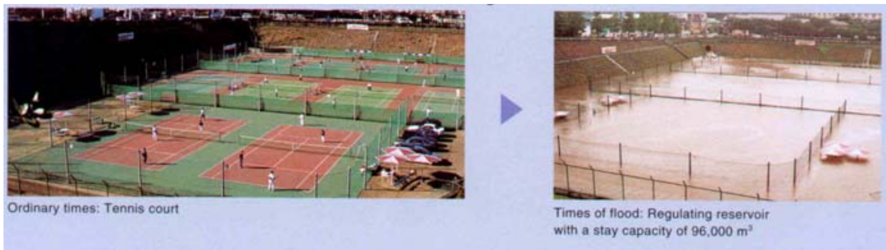


Figure 7.25: Use of the same area for two purposes during normal and flood periods (Source: Rivers and Japan no15/2000)

Construction or location permits

A construction permit can be used not only to regulate the type of land-use activity and the structure it occupies but also to enable the authorities to control employment opportunities thereby influencing patterns of development.

Organizational structures e.g Community-Based DRR.

Recognizing that disasters happen at the local level, risk reduction strategies must be built on sustainable community-based development plans. This allows reducing vulnerabilities and strengthens people's capacity to cope with hazards. In the text box below Community based disaster risk management is explained.

Preparedness and contingency planning

Actions designed to minimize loss of life and damage, and to organize and facilitate timely and effective rescue, relief and rehabilitation in cases of disaster. (i.e. the planning of emergency / relief operations).

It includes:

- Forecasting and warning / monitoring
- Education and training of the population
- Organization for and management of disasters situations,
- Preparation of operational plans, training of relief groups,
- Stock piling of supplies
- Earmarking of necessary funds

Major components of disaster preparedness are: organization, emergency operations, communications, evacuations, disaster warnings.

Task 7.9: RiskCity exercise: disaster preparedness planning (duration 3 hours)

The aim of this exercise is that you use the risk information that you have generated in the previous exercises for emergency preparedness. We will make a simulation of an emergency that might take place in RiskCity. You work in a team as the geo-information department of the local authority and you have to provide the local authority with the required information to respond to the emergency.

This exercise is done in real time, so you have to indicate to the course coordinator when you want to start with the exercise. You will then receive e-mails from technical institutions and from the RiskCity Emergency Preparedness Center, requesting for information. In a period of 3 hours you have to provide the correct answers to their requests and mail them back to the course coordinators.

'**Community-based disaster risk management (CBDRM)**

Community-based disaster risk management (CBDRM) is a process in which at-risk communities are actively engaged in assessment of the community's hazard exposure and analysis of their vulnerabilities as well as capacities and this forms the basis for activities, projects and programs to reduce disaster risks. The community should be involved in the process of assessment, planning and implementation.
(http://www.adpc.net/PDR-SEA/publications/12Handbk.pdf)

This means that people are at the heart of decision making and implementation of disaster risk management activities. The involvement of most vulnerable social groups is considered as paramount in this process, while the support of the least vulnerable groups to them is necessary for successful implementation.
CBDRM emerged as an alternative during the 1980s and 1990s. Over the past two decades it has become apparent that top-down approaches fail to address the needs of vulnerable communities, often ignoring local capacities and resources.
The top-down approach can increase vulnerabilities and undermine the quality of life, security and resiliency. The CBDRM approach emphasizes the active involvement of communities in al phases of risk management.

CBDRM is built upon the following principles (Source: Kafle) :

- CBDRM contributes to addressing the root causes of vulnerabilities and transforming the structures that generate inequality and underdevelopment;
- CBDRM is a development approach. Recognizing the need for community action for disaster risk reduction in all development practice;
- Any efforts to reduce disaster risks should build upon a community's knowledge and experience about hazards, vulnerabilities and disaster risk reduction. It will also be essential to recognize the importance of local customs, culture and materials while developing and implementing risk reduction programs.
- CBDRM requires a high level of coordination and cooperation amongst stakeholders e.g. among Government departments, NGOs, donors, vulnerable groups;
- CBDRM advocates and workers believe that they are accountable to the people first and foremost;
- There is a need to maintain efforts to enhance inclusiveness, decentralization and empowerment.

Processes of CBDRM

The main goal of CBDRM is to transform at-risk communities to disaster resilient communities. The general process of CBDRM is as follows (Victoria 2002 in Kafle, ADPC):

- Rapport building with community;
- Community profiling;
- Community risk assessment;
- Formulation of initial disaster risk reduction plan;
- Formation of community disaster response organization;
- Community-managed Implementation of reduction measures;
- Participatory Monitoring and evaluation.

CBDRM aims at achieving disaster risk reduction, sustainable development and poverty reduction, people empowerment and equity. CBDRM is envisioned as an integral component of sustainable development, since it helps in avoiding the negative impacts of disasters on development (ADPC 2004).

Key Actors

In the CBDRM processes the following stakeholders are considered as a key to make it effective and sustainable:

- Vulnerable groups and persons;
- Multiple social groups in a community;
- Outside agencies- Government Departments including local governments, NGOs, civil society groups, Media, donors and UN.

Early warning

Early warning systems are intended for the provision of timely and effective information, through identified institutions, that allows individuals exposed to a hazards to take action to avoid or reduce their risk and prepare for effective response.
Early warning systems include the following components:

- Understanding, and mapping the hazard;
- Monitoring and forecasting impending events ;
- Processing and disseminating understandable warnings to political authorities and the population, and
- Undertaking appropriate and timely actions in response to the warnings

Remote Sensing can offer very good possibilities in monitoring hazard events. Different satellite systems are available with different spectral (both optical and microwave), spatial and temporal resolutions. Monitoring is centered on the collection of diagnostic parameters of the hazard and tries to detect the onset of the hazard event. Different hazards need different monitoring systems. Besides there is the scale of monitoring and constraints can technological, economic, financial, social or environmental. In figure 7.26 an example is given of monitoring of floods in the Camarque using ERS_SAR (radar) imagery.

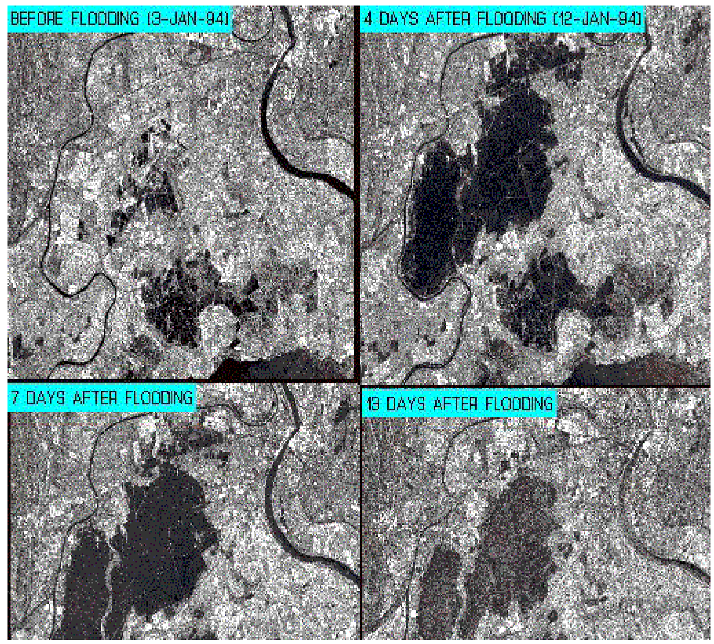


Figure 7.26: Monitoring flooding using radar imagery.

Forecasting relates to a scientific evaluation of an real time hazard event, leading to a general alert about hazardous conditions, and a warning contains additional information, including recommendations for action.
Technological developments have increased the availability, reliability and accuracy of short-term disaster warnings, particularly in cases of tropical storms, wild fires, high rainfall, floods, volcanic eruptions, tsunamis and crop damage (e.g., frost, locust plague, and drought). Ideally, warnings should be given sufficiently far in advance of the event to enable protection of both life and property. But the scale of the effort and time required to protect property is such that, in the present state of knowledge, warnings of (some) impending disasters can in most cases only be given in time to permit saving of life and perhaps the most valuable (or cherished) property. To be effective, warnings must have a very low false alarm rate. However, in slow-breaking disasters such as drought where assessment of the developing situation may be possible, food stockpiles and transportation infrastructure can (in theory, at least) be built up and/or steps can be taken to encourage people and animals to move to areas where more reliable water supplies may be found.
Five stages of forecasting /prediction and warning can be differentiated:

- Technological forecasting (by the scientific community)
- Scientific evaluation;
- Decision-making (to warn or not warn);
- Communications; (e.g. by radio/visual signals/sound signals)
- Public response.

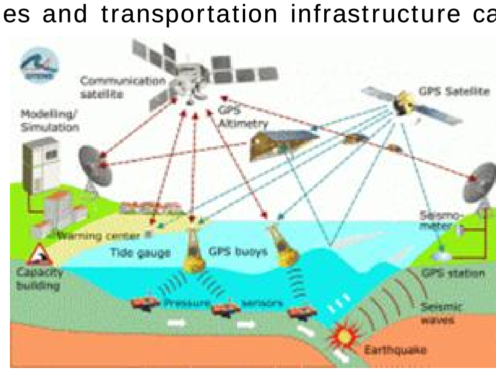


Figure 7.27: Set-up of the tsunami early warning system

For fast-breaking phenomena, there may be little time for the message to get out to the population; the delivery system, therefore, must be fast and reliable. It must permit the message to reach people directly and in such a manner that it is <u>convincing</u> because of a tendency to discount the validity of a warning or reluctance to part from home or other psychological factors. In order to improve the level and effectiveness of response to such warnings, education programmes including material on the warning systems themselves, should be carried out among the vulnerable population and their active participation should be sought.

Emergency management

This refers to the organization and management of resources and responsibilities for dealing with all aspects of emergencies, in particularly preparedness, response and rehabilitation. Emergency Management relates to short term measures to be taken to respond to particular disaster situations. It involves plans, structures and arrangements established to engage the normal endeavors of government, voluntary and private agencies in a comprehensive and coordinated way to respond to the whole spectrum of emergency needs.

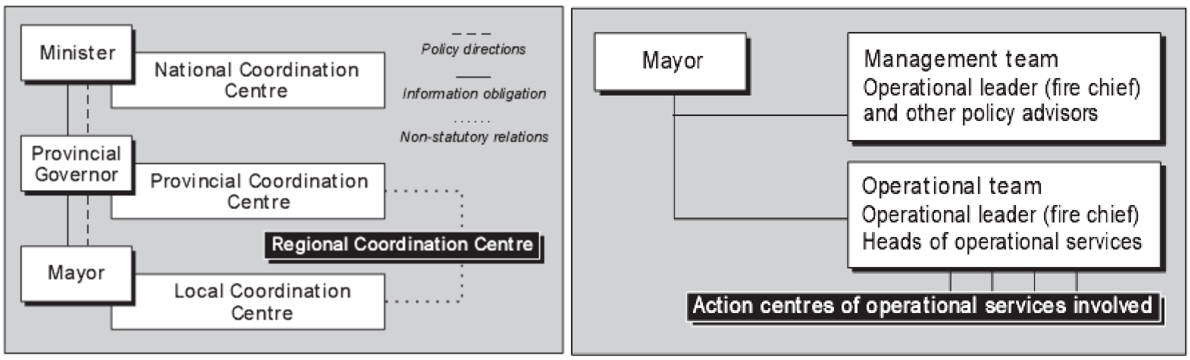


Figure 7.28: Structure of the Dutch Disaster Management organization. The Mayor plays a central role at the local level (Source: Bezuyen et al., 1997).

Social and economic development practices

In order to encourage the proper, rational development of land, governments may wish to provide fiscal and financial incentives, including subsidies and loans to land owners who comply with urban and land-use regulations designed to reduce disaster risks.
In addition to obtaining desirable development patterns, tax measures may be used to discourage development in areas where open spaces are needed for both low density uses and/or hazard mitigating measures. Governments may settle for higher tax yields rather than prevent settlement on disaster risk land.
Negative land taxation:

- Land taxation can have more than one purpose and more than one effect.
- Reduce land speculation,;
- Increase the rate of development on unimproved land,
- Land taxes designed to discourage development on high risk land may simply encourage more intensive development;

Positive land taxation:

- Various kinds of grants or low interest loans for building, or for the purchase of building materials in order to avoid building in high risk zones.
- The subsidies would have to be sufficient initially to outweigh other economic incentives or benefits of living in high risk zones.

Both insurance and mortgage policies can be used to encourage the public to adhere to zoning regulations and building codes specifically designed for disaster prevention and mitigation purposes.
Insurance is a key loss-sharing strategy. Through the payment of an annual premium , the policy holder is able to spread the costs of the disaster over a number of years. Insurance can be either commercial or state insurance. Not in every country it is possible for people to insure for natural hazards. Insurance companies may be persuaded to offer reduced premiums for buildings that incorporate hazard resistant structures. Other risk spreading instruments are: calamity funds, catastrophe bonds, micro-credit and finance.

Education, training and public awareness

Educational policy can be used to create awareness of hazards and the risks caused by the hazards, what can be done both by the public and the emergency authorities to prepare for the impact and reduce its effects; and what can be done after a disaster.

Education on disaster risk and risk reduction can be given at all levels of education. It is a long term goal. Community training programmes can be developed and carried out. It is also of importance in education and training to ensure that the public will, in time of need, react intelligently and promptly to warnings, and comply with them and with instructions issued by the emergency authorities. Education for disaster reduction is a transdisciplinary exercise aimed at developing knowledge, skills and values which will empower people of all ages, at all levels, to assume responsibility for building a safer and sustainable future (UNESCO). Activities can be training for disaster preparedness, earthquake drills, flood evacuation, participation in community based hazard mapping vulnerability mapping etc.

Figure 7.29: Example of awareness raising: Earthquake safety day in Kathmandu, Nepal (Source: NSET, Nepal)

Public Awareness relates to the processes of informing the general population, increasing levels of consciousness about risks and how people can act to reduce their exposure to hazards. Awareness campaigns try to educate the population a try bring about a change in behaviour leading towards a culture of risk reduction. This can be done by broadcasts on radio and television, items in the newspapers, organizing counseling/ meetings and the establishment of information centers and networks, and community and participation actions (after UNISDR, 2004)

Criteria for evaluating mitigation strategies.

Strategies and measures for risk reduction must be evaluated against a series of criteria (economic, technical, social, financial and environmental criteria) to allow the selection of the most desirable. The **final choice of strategies is political** and will eventually depend on the weight placed on safety by elected officials as **compared with** the emphasis given to **other goals** that the society is also attempting to achieve, such as **economic growth, improved health etc.**

Table 7.7: Criteria for evaluating mitigation options.

Criteria	Strategy-Related Questions
Equity	Do those responsible for creating the hazard pay for its reduction? Where there is no man-made cause, is the cost of response fairly distributed?
Sustainable	Does the risk reduction measure contribute to sustainable development?
Poverty reduction	Does the risk reduction measure contribute to poverty alleviation?
Timing	Will the beneficial effects of this strategy be quickly realized?
Leverage	Will the application of this strategy lead to further risk reducing actions by others?
Cost to government	Is this strategy the most cost-effective or could the same result be achieved more cheaply by others?
Administrative efficiency	Can it be easily administered or will its application be neglected because of difficulty of administration or lack or expertise?
Continuity of effects	Will the effects of the application of this strategy be continuous or merely short term?
Compatibility	How compatible is this strategy with others that may be adopted?
Jurisdictional Authority	Does this level of government have the legislated authority to apply this strategy?
Effect on economy	What will be the economic impact of this strategy?
Effects on environment	What will be the environmental impacts of this strategy?
Hazard creation	Will this strategy itself introduce new risks?
Hazard reduction potential	What proportion of the losses due to this hazard will this strategy prevent? Will it allow the safety goal to be reached?
Public and pressure group reaction	Are there likely to be adverse reactions to implementation?
Individual freedom	Does the strategy deny basic rights?

7.6 Cost-benefit analysis for disaster reduction measures

There are a number of tools that can be used in evaluating the best scenarios for disaster risk reduction:

- **Cost Benefit Analysis** is used to compare costs and benefits of a project over a period of time in monetary terms;
- **Cost Effectiveness Analysis**: (CEA) has most of the features of CBA, but does not require the monetization of either the benefits or the costs (usually the benefits). CEA does not show whether the benefits outweigh the costs, but shows which alternative has the lowest costs (with the same level of benefits).
- **Multi Criteria Analysis** (MCE) is a tool that, in contrast to CBA, allows the treatment of more than one criterion and does not require the monetization of all the impacts. MCE results in a ranking of alternatives.
- The growing importance of environmental and social issues has led to the emergence of instruments such as **Environmental Impact Assessment** (EIA) and Social Impact Assessment (SIA). The output of these instruments could be presented separately or linked to the outcome of a CBA.

According to the ISDR conceptual framework, disaster risk reduction must be placed in the broader context of sustainable development, where economic, socio-cultural, environmental and political factors/goals are to be considered. Many angles have to be studied. One can use the tools of cost benefit analysis to assess the economic and financial acceptance of risk reduction measures, but it is preferred to use to CBA in conjunction with other decision support methods, such as such as cost-efficiency or multi-criteria analysis.

In order to justify public investments in risk reduction for a certain hazard we need to assess all costs and benefits associated with this risk reduction. Besides, we need to know how large the current risk is in terms of damage per year in order to compare with other types of hazards and to compare to other societal goals.

In disaster risk management the benefits are mostly the avoided or reduced potential damages and losses. For instance in a flood control project the benefits can be reduced potential flood damages and a higher income /value of the land were the land is protected.

The reduced damages can either be direct or indirect damages or monetary (tangible) or non_monetary (intangible) (See session 6.2).

The aim is to reduce the risk, thus to decrease the area under the probability-loss curve. A schematic example is given in figure 7.30. Figure 7.30a shows the original situation with the annualized risk being the area under the red curve (the blue area). In figure 7.30b for a possible risk reduction measure (e.g a flood protection scheme protecting for floods up to the 100 yr recurrence interval) the new risk curve is indicated as the green curve. The new risk is indicated by the blue + orange area. The risk reduction is indicated with the yellow area. As long as the yellow area is not larger than the orange area the risk is reduced. How much and how the probability loss curve is shifted depends very much on the type of risk reduction measure.

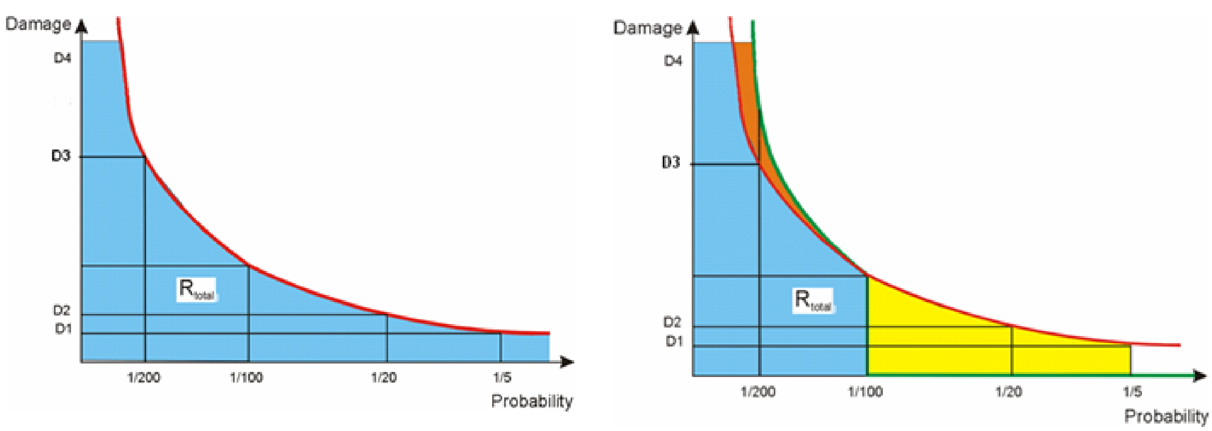


Figure 7.30: a: The amount of risk is, in the original situation, is the blue area under the red probability-damage curve. B: A risk reduction option is applied: the new amount of risk is the blue area + the orange area. The yellow area is the reduction in risk due to the risk reduction measure.

Cost Benefit Analysis as a tool for decision making.
Cost-Benefit Analysis (CBA) is a tool used in public decision-making and consists of a set of procedures for defining and comparing benefits and costs. The tool assists in identifying, measuring and valuing in monetary terms the benefits and costs of a project.
Resources such as capital, land, labour and management capacity are relatively scarce and can be allocated by a nation / agency/ person to different uses. What choice is made depends among others on the benefits that the specific allocation creates as compared to the costs of the project; you want to know whether a “project “is worthwhile and whether it is the best alternative.
Public agencies and development organisations will be particularly concerned with the question of whether a proposed project is a good investment in terms of its contribution to the welfare of society. CBA is an instrument that will assist in answering this question
CBA as applied in public decision-making typically takes the perspective of the society and is often referred to as the *economic* analysis or the economic CBA. This analysis is often complemented by a *financial* analysis of the project. The financial analysis compares the costs and benefits from the perspective of the project organisation or a specific target group (see text box below). If the CBA is extended to include aspects of income distribution, one speaks of *social CBA*.

Economic versus Financial appraisal.
Financial appraisal:
- Works with actual prices paid on the market;
- Perspective: private (single person or firm) ;
- Focuses on the actual financial burden.

Economic (or social) appraisal;
- Reflects the value of costs and benefits for the national economy as a whole , including impacts on intangible goods and services.
- Economic evaluation is the appropriate one to apply if calculations of hazard damage are to be designed for supporting public policy decisions.
- Economic appraisal attaches fictive prices to production factors (land, capital , labour) indicating the scarcity in the national economy;
- Maximize national income
- These fictive prices are called accounting prices, economic prices, social prices or shadow prices.
- Shadow prices are usually used for unskilled labour, taxed or subsidized consumer goods, and foreign exchange, interest.

CBA is one element in the overall appraisal (including technical, social, environmental, legal and institutional issues) of a project. CBA contributes to narrowing the margin for pure judgement in the decision-making on proposed projects. The output of a CBA might be a recommendation on the acceptance or rejection of a project, or the identification of bad project components, which could lead to adjustments in the project design (Dopheide, 2003).
In both economic and financial analysis, cost and benefits are assessed in the situation with- and without the project. Cost and benefits have their own ‘autonomous” development if no project is carried out (see figure)

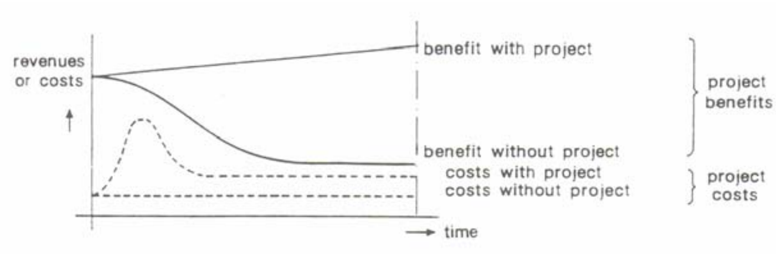


Figure 7.31: Benefits with and without the project

- Project benefits are benefits with the project minus the benefits without the project.;
- Project costs are the costs with the project minus the costs without the project.

Discounting.
Costs and Benefits occur in different amounts and at different time periods during the project, so in order to compare these costs and benefits, both costs and benefits have to be discounted (against a certain interest rate). Since money today is worth more than money in the future . Example: Two financial concepts;

- If a person lends money to another person, he is entitled to some kind of reward. This reward is called interest.
- A certain sum of money today, earning interests from year to year will grow to become a larger sum of money in the future depending on the rate of interest; this is called **compounding**. Conversely, a certain sum of money at some time in the future is equivalent to a smaller sum of money today, depending on the interest rate.; this is called **discounting**.

Compounding: What an initial amount of money becomes when growing at compounding interest.
Compounding: from present to future;

Compounding formula:

$$X_t = X_0 (1 + i)t$$

X_0 = present value
X_t = value in year t

Example 1:
Suppose an amount of € 100 (X_0)on a bank account;
Interest rate =10%
Calculate the amount after 1 year (=X_1), after 2 years (=X_2) and 3 after (=X_3) years ?

$X_1 = 100(1 + 0.1)^t = 100(1.1)^1 =$ €110
$X_2 = 100 (1+ 0.1)^2 = 100 (1.1)^2 = 100 * 1.21 =$ €121
$X_3 = 100 (1+ 0.1)^3 = 100 (1.1)^3 = 100*1.331 =$ €133.1

Discounting: What is the present value of a known future amount , or
How much a known future amount of money is worth today.
Discounting: Present value = Future value * discount factor.

Discounting formula:

$$X_0 = X_t / (1 + i)t \quad \text{or} \quad PV = FV * 1/ (1 + i)t$$

X_0 = present value PV = present value
X_t = value in year t FV = future value

Example 2:
What is the present value of €133.1 received at the end of year 3 from now, assuming an interest rate of 10%.

$$X_0 = X_t / (1 + 0.1)3 = 133.1 / (1+ 0.1)^3 = 133.1 / 1.331 = 100$$

Basic CBA steps (Dopheide,2003):

1. Define scope of the project: public/private, time horizon, physical boundaries of the study
2. Identify the type of costs and benefits (See table 7.8)
3. Put monetary values on costs and benefits. Special care should be taken with inflation. Usually cost and benefits are considered without taking inflation into consideration
4. Compare costs and benefits. Organize costs and benefits over time.
5. Calculate profitability indicators/decision criteria
6. Sensitivity analysis
7. Make recommendations

In table 7.8 an overview is given showing costs and benefits occurring in different years and the resulting incremental benefits or cash flow.

Table 7.8: Example of organizing costs and benefits in time.

Year	0	1	2	3	4
Investment	500				
Recurrent costs (e.g. maintenance)		50	50	50	50
Benefits		200	200	200	200
Net incremental benefits or Cash flow	-500	150	150	150	150

Calculate profitability indicators/decision criteria.

N**et Present Value (NPV):** The NPV is the sum of the discounted net incremental benefits of a project at a prevailing discount rate**.** For financial appraisal the commercial bank rate is usually taken.

$$NPV = \sum_{i=1}^{n} \frac{values_i}{(1+rate)^i}$$

Values = series of net incremental benefits;
i = discount rate

The NPV is an indication of the feasibility of the project. In both financial and economic analysis the NPV should always be positive to make the project acceptable.

Table 7.9: Example of calculation of NPV.

Year	0	1	2	3	4
Investment	500				
Recurrent costs (e.g. maintenance)		50	50	50	50
Benefits		200	200	200	200
Net incremental benefits or Cash flow	-500	150	150	150	150
Present value at 10 % interest rate	-500	136	124	113	102
NPV	-25				

Internal Rate of Return (IRR): Is that discount / interest rate at which the discounted costs equal the discounted benefits i.e the NPP = zero. It represents the average earning power of the money used in the project. This indicator is used by most financing agencies in cases where projects are not mutually exclusive.

There are financial IRR's and economical IRR's. Whenever the IRR is higher than the opportunity cost of capital or the external discount rates offered at the bank the project is economically or financially feasible . When two projects are mutually exclusive, that means that the implementation of project A excludes the implementation of project B, the NPV is the required indicator for comparison of projects.

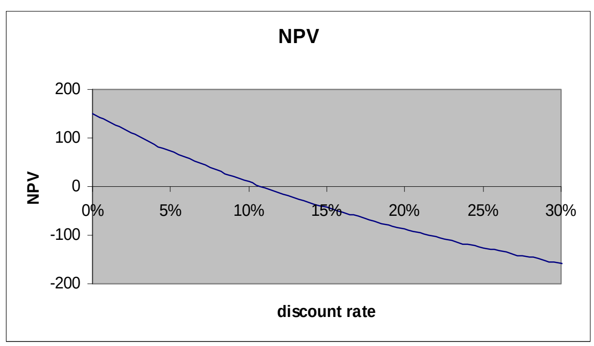


Figure 7.32: Plotting NPV at different discount rates

Example: When the choice is between project A with an NPV = 400, and project B with an NPV = 2000, project B is chosen. The IRR can be calculated in by plotting the NPV at different discount rates.

Benefit-Cost Ratio (BCR): The benefit / cost ratio is defined as the ratio between the discounted incremental benefits and the discounted incremental costs, calculated at current commercial or accounting discount rates. This indicator should be higher than 1 for a project to be acceptable. If projects are to be compared which are not mutually exclusive, the IRR is a better indicator than the B/C ratio, because IRR is independent of external discount rates and independent of the way associated costs are dealt with. The BCR is rarely used because different classifications of costs lead to different outcomes.

Net benefit-investment ratio (N/K ratio). The net benefit-investment ratio gives more consistent results than the BCR as a clear distinction is being made between investment costs and costs made after the investment. The N/K ratio gives the ratio of the present value of the net benefits and the investment at a prevailing discount rate. Net benefits are given by the net incremental benefits in the years where the net incremental benefits are positive, whereas the investment is given by the incremental net benefits in those years that the net incremental benefits are negative.

Table 7.10: CBA decision criteria

Indicator	**Decision**	
	Accept	**Reject**
NPV	NPV > 0	NPV < 0
IRR	IRR > discount rate	IRR < discount rate
BCR	BCR > 1	BCR < 1
N/K ratio	N/K > 1	N/K < 1

Uncertainty, assumptions and sensitivity analysis:
In this step the elements that are most uncertain or risky are identified and the the assumptions made during the analysis are indicated. Sensitivity analysis is applied to relevant parameters in order to obtain an indication of the robustness of the assumptions made. These parameters could include costs, benefits, prices and the timing of costs and benefits; Calculate the switching values on the most relevant parameters.

Final recommendations

- Formulate a final recommendation based on the results of the economic and financial CBA.
- An unambiguous conclusion on the profitability of a project is formulated if the economic and financial CBA have the same result (e.g. economic and financial NPV are both positive or both negative).
- If a project is economically unfeasible but financially sound, the project should not be supported on economic grounds but might be attractive for the private sector to implement.
- If the project is economically sound but financially unfeasible, a solution might have to be recommended for the weak financial basis that might prove a risk to the sustainability of the project.
- -Structure the recommendation within a context by making special reference to the effects that could not be monetised, to the assumptions, and to the uncertainty and gaps in knowledge.

Cost-Benefit Analysis and Inflation
Net present value calculations provide a valuable theoretical approach for handling financial and economic analyses. One practical issue that often raises questions concerns the treatment of *inflation* in cost-benefit analyses. Inflation refers to a general increase in prices throughout the economy*. Inflation should be separated from and not be confounded with the time value of money*. Common practice in cost-benefit analysis is to express all cash flows in constant or real prices as if there is zero inflation. This is valid as long as it is reasonable to assume that prices of all inputs and outputs change in a same degree. Moreover, setting up the cash flow in nominal prices (rather than constant or real prices) requires an inflation forecast, which is a difficult if not impossible task. There are no economic tools that allow us to forecast inflation as far into the future as required for the life of a typical project. Therefore it is preferable to use constant or real prices for cash

flows in financial and economic CBA. This implies that a real interest or discount rate (I.e. corrected for inflation) has to be applied.

Limitations:
It is preferred to use to CBA in conjunction with other decision support methods, such as such as cost-efficiency or multi-criteria analysis . This is because CBA has its limitations e.g. the “distributional issue” that CBA does not address the distribution of benefits and costs. Societal welfare is maximized by simply aggregating individual welfare over all people affected and changes therein due to projects and policies. A focus on maximizing welfare, rather than optimizing its distribution is a consequence (Dasgupta and Pearce, 1978 in Mechler, 2008) .

Task 7.10: RiskCity exercise: Cost benefit analysis for risk reduction measures (duration 3 hours)

After calculating the expected losses for the different return periods, and the average annual risk,in the exercises of session 6, we would now like to analyze the various options that the municipality has to mitigate the risk, using a basic cost/benefit analysis. Go to the description of this exercise in the exercise book and follow the instructions.

7.7 SEA for risk assessment and management

Strategic Environmental Assessment (SEA) is an iterative decision support tool that helps planners and decision-makers to assess the environmental, social and economic impacts of proposed **Policy, Plan or Programme (PPP)** initiatives and its alternatives at the **earliest** possible stage of decision making. SEA is now in many countries an integral part of the development of any large scale plan, programme or strategy, and may include national or local risk management policies or plans.
Risk assessment and management is a process of identifying and evaluating the adverse risks associated with natural and/or human induced hazards and developing strategies to manage it. The following stages are usually taken in the decision making process:

1. Flood risk management objectives
2. Establish decision-making criteria
3. Assess the risk
4. Identify options/measures
5. Assessment of options/measures
6. Make decision and prepare plan
7. Implement Plan
8. Monitor

The SEA approach seeks to identify key environmental, social and economic issues, define SEA objectives and appraisal criteria and promote a sustainable plan process. The SEA process comprises six main stages which are linked to the plan stages. Stakeholder participation and involvement are an essential part of the SEA and should be undertaken throughout the different stages of the SEA and plan process (see figure 1 below).
Subsequent stages of the SEA will involve the assessment of identified risk management options using the SEA objectives to inform the choice of preferred option(s).

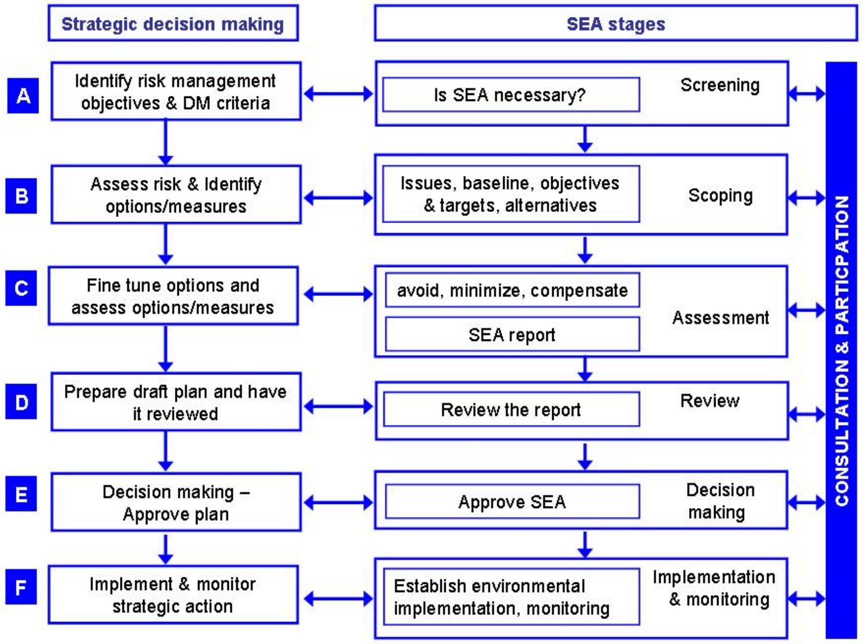


Figure 7.?: Integration of SEA in Decision-making for Risk Management.

Selftest

In order to evaluate whether you have understood the concepts that were presented in this session. Please make the following test, and upload the answers in Blackboard.

Question: Disaster risk management
Hazard and risk maps are used in the following phase of disaster risk management:
A) Disaster prevention.
B) Disaster preparedness.
C) Disaster response.
D) All of the above.

Question: Risk Visualization
Google Earth can be very helpful as a visualization tool in disaster risk assessment, because it can:
A) Help you to map the areas affected by a disaster immediately after a disaster has occurred.
B) Allows you to generate Digital Elevation Models of your study area that can be used in hazard assessment
C) Helps to map elements at risk from high resolution images if they are available for a particular area.
D) Allows you to monitor hazard events while they are happening.

Question: Disaster risk reduction measures
Examples of non-structural flood risk reduction measures are:
A) Insurance and reinforcement of buildings
B) Dikes and evacuation planning
C) Early warning system and land use zoning
D) Elevated buildings and awareness raising

Question: Cost-benefit analysis
In the economic cost benefit analysis for a particular risk reduction measure the following component(s) is/are important:
A) Investment costs
B) Period of investments
C) Risk reduction obtained
D) All of the above

Question: Risk reduction
An example of a structural risk reduction method for a flood hazard is
A) Early warning system
B) land use planning.
C) a levee
D) a cellar

Question: cost benefit analysis
The construction of a flood retention basin is subject to a cost-benefit analysis. The final analysis gives at a discount rate of 12% a Net Present Value of minus € 1,500.
This implies that the Internal Rate of Return (IRR) is:
A) most probably negative (below 0%)
B) most probably between 0 and 12%
C) exactly 12%
D) most probably higher than 12%

Further reading:

ADPC (2004). COMMUNITY-BASED DISASTER RISK MANAGEMENT. Field practitioners' handbook. Imelda Abarquez and Zubair Murshed. http://www.adpc.net/PDR-SEA/publications/12Handbk.pdf
Boardman et al. (2006), Cost - benefit analysis: concepts and practice. 3d edition, Prentice Hall, Upper Saddle River
Dixon, J.A. et al., 1995. Economic Analysis of Environmental Impacts (second edition). Earthscan Publications Ltd, London.
Mechler,R (2008) From Risk to Resilience: Working paper 1: The Cost_Benefit Analysis Methodology http://www.proventionconsortium.org/?pageid=37&publicationid=158#158
Messner, F. (2007) Evaluating flood damages: guidance and recommendations on principles and methods. Centre of Environmental Research, a member of Dresden Flood Research Center. FLOODsite .
http://www.floodsite.net/html/partner_area/project_docs/T09_06_01_Flood_damage_guidelines_D9_1_v2_2_p44.pdf
From Risk to Resilience: Working paper 1: The Cost_Benefit Analysis Methodology.
Reinhard Mechler (IIASA) &The Risk to Resilience Study Team; 10/2008. http://www.provention consortium.org/?pageid=37&publicationid=158#158

Literature references:

Bezuyen, M. J., van Duin, M.J , and P.H.J.A. Leenders (1997). Flood management in The Netherlands.
Dasgupta, A. K. and D. W. Pearce (1978). Cost-Benefit Analysis: Theory and Practice. London, Macmillan
Dopheide, E , (2003) Chapter 8 Cost Benefit Analysis in Groenendijk (2003) Planning and management tools. ITC publication.
ISDR, 2004 CENAT Monte Verita Workshop 2004. Coping with Risk due to Natural Hazards in the 21 st century. Dealing with Risk and vulnberability – the role of the United nations. Sálvano Briceno
Mechler, R. (2005). Cost-Benefit Analysis of Natural Disaster Risk Management in Developing and Emerging Countries. Manual. Working paper, GTZ, Eschborn.
Mechler, R. (2008). From Risk to Resilience: Working paper 1: The Cost_Benefit Analysis Methodology. http://www.proventionconsortium.org/?pageid=37&publicationid=158#158
IDB (2000). Facing the Challenge of Natural Disasters in Latin America and the Caribbean. An
IDB Action Plan. Washington DC, Inter-American Development Bank.
Kafle, S.K. (2005) A Framework for Community-Based Disaster Risk Management in South East Asia www.wyf.org.my/2005/Shesh%20Kanta%20Kafle%20.doc
Leveson,, David 1980 Geology and the Urban environment , Oxford University Press
Lindell, M.K. & Perry, R.W. (2004). *Communicating environmental risk in multiethnic communities.* Thousand Oaks CA: Sage.
Penning-Rowsell, E., C. Johnson C, Tunstall , S, Tapsell I, Morris J, Chatterton J, Coker A, Green C (2003) The Benefits of flood and coastal defence techniques and data for 2003. Flood Hazard Research Institute, Middlesex University.
Smith K, and Ward R (1998) Floods- Physical Processes and Human Impacts. Chichester.
Smith, K. 2001. Environmental Hazards. Third Edition. Routledge, London and New York.
UN /ISDR (2004). Living with Risk, United Nations .
UN/ISDR 2004, Disaster Risk Reduction, Governance & Development. UN/ISDR Africa Educational Series, Volume 2, Issue 4, December 2004
Venton, P and La Trobe, S (2007) . Tearfund Institutional donor progress with mainstreaming disaster risk reduction. A Tearfund research project in collaboration with UN/ISDR
Victoria, Lorna P. 2002. Community based Approaches to Disaster Mitigation In: Proceedings Regional Workshop on Best Practices in Disaster Mitigation, 24-26 September 2002, Indonesia.

Guide Book
Session 8:
Final project

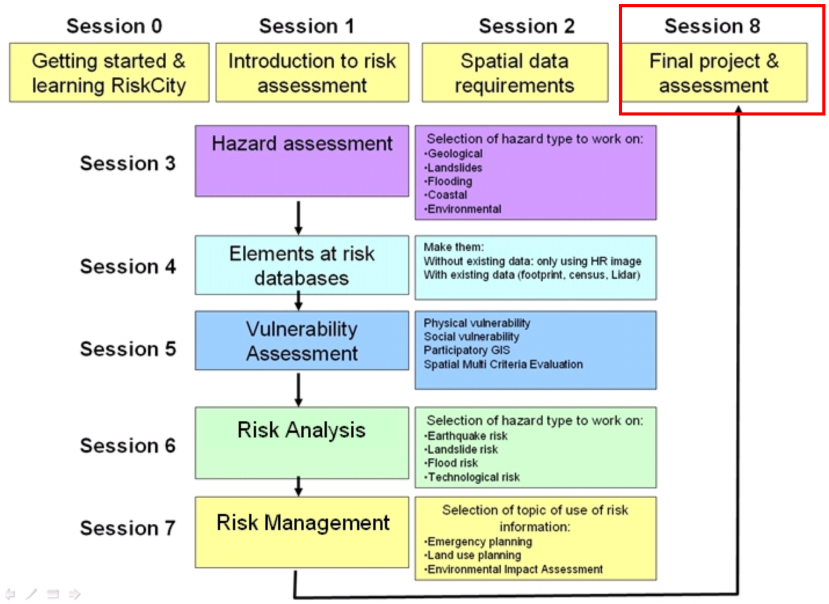
Objectives
After this session you should be able to:

- Translate a problem statement (related to hazards, elements at risk, vulnerability, risk assessment or risk management) into a plan of analysis
- Outline a flowchart and indicate the steps required to solve the problem
- Carry out an analysis using GIS and the RiskCity dataset
- Draw conclusions from the results of the analysis
- Write a small report with the procedure and result of your analysis and present this.

In this session you will use your knowledge obtained from studying the Guidebook and doing the RiskCity exercises by analyzing a particular problem by yourself, without the help of a fully written out exercise. This session contains a list of 25 topics from which you can select one. In the distance education course you will select a topic for yourself, and in a classroom course you select a topic for a group. In the classroom course the size of the group is determined by the overall group size of the course participants, but will be generally 2 to 3 people.
After selecting the topic from the list given in the following pages, you will evaluate which data you will need to analyze the problem. The data will be mostly coming from the Riskcity exercises, but it may be also required to do an additional literature study.

Part	Topic	Task	Time
8.1	Define the topic	Select the topic and inform the coordinator	2 h
8.2	Develop work plan	Make the work plan, division of tasks and discussion with staff	2 h
8.3	Data analysis	Carry out the analysis, produce output.	2 days
8.4	Report writing	Write the report and submit	1 day
8.5	Presentation and oral exam	Prepare presentation	4 hours
		Present yours and evaluate others	4 hours
		Total	**4.5 days**

8.1 Introduction to the final project



This last session deals with the final project in which you apply what you have learned in this course. You can select from a large list of 25 different topics that are related to session 3 (hazard assessment), 4 (Elements at risk assessment), 5 (Vulnerability assessment), 6 (risk analysis) and 7 (risk management). In fact most of the topics are related to the topic of risk management. Some of the topics can only be selected if you had done some related exercises in the earlier part of the course. Otherwise they would take too much time.

We start by selecting a topic:

Task 8.1: Selection of the final project (duration 4 hours)

- (In a classroom course: make groups of 3-4 persons)
- Read the topic descriptions below.
- Select one of the topics from the list below, and inform the course coordinator which topic is selected.
- Send an e-mail to the course coordinator with the name(s) of the group member(s) and the selected topic. If the topic is already selected, the course coordinator will reply you that you need to select another topic.
- A topic can only be selected by one person/group on "first come first serve basis"

After selecting the topic, start making a work plan. You will be assigned a staff member as your supervisor. This staff member is available every working day during one period of the day. Discuss this with the staff member, in order to make a schedule of supervision time.

Task 8.2: Make the work plan (duration 4 hours)

- For classroom courses:
  - Discuss with your group members how you are going to deal with the problem
  - Make a division of tasks in the group, and write down the tasks of the group members. The final report should contain this information, in order to be able to assess you individually. For example you can make one group member responsible for the report writing, one for the presentation, and one for the generation of figures. Divide also the analysis parts among the group members.
- Also gather the required information. IMPORTANT: you use the information that was provided to you in the Riskcity exercises. Use ILWIS to copy the relevant datasets for your project in a new directory.

After you have made the flowchart and have discussed this with your supervisor, you can start working on the analysis.

Task 8.3: Data analysis (duration 3 days)

- Classroom course:
    - o Divide the analysis in different parts, and see if members of the group can work on the different steps simultaneously.
- Keep track of the results, and make sure to give meaningful file names to the maps and tables that you generate. Otherwise you might loose track.
- When you have intermediate results, make sure to make a presentable output map / graph of it directly and store it in the Word file or Powerpoint file that you will use for the report/presentation.
- If you don't have the data, you can also "invent" it, but then mention it in the report
- Critically analyze the results. If the analysis results are not what you expected try to find the reason for it. Describe in the report why the results are different then what you expected.
- During the analysis phase you can get supervision during 1 period per day.

During your project the report and Powerpoint files will slowly grow with the results that you have obtained. At some point you have to decide to stop with the analysis and concentrate on the report writing and the presentation.

Task 8.4: Report writing (duration 1 day)

- Classroom course:
    - o One of the group members should have the main responsibility for the report writing, one for the generation of output maps, and one for the generation of the Powerpoint presentation
- The report should be maximum of 10 pages, including maps, and a minimum of 5 pages.
- The structure of the report should be:
    - o Problem statement
    - o Flowchart
    - o Input data
    - o Analysis and results
    - o Discussion and conclusion
    - o Subdivision of tasks in the project between group members.
    - o References and websites used
- We will also evaluate the report on the following aspects:
    - o Clearness of the report
    - o Soundness of the methodology used
    - o Creativity in analyzing the data and presenting the results
- The report should be submitted by the date indicated by the course coordinator.

Table 8.1: List of topics for the final project

Class	NR	Topic	Brief explanation
Hazard Assessment	1	Earthquake hazard assessment	Design an improved method to generate an earthquake hazard map for Riskcity with return periods derived from the earthquake catalog, and including local ground effects.
	2	Technological hazard assessment	Use the ALOHA model to generate scenarios for industrial accidents including wind speed and wind direction.
	3	Landslide hazard assessment	Improve the landslide hazard map by combining statistical, deterministic and heuristic methods, and use size probability information
	4	Flood hazardment	Improve the results of the exercise on flood modeling as input for the flood hazard assessment
Elements at risk	5	Multi-temporal analysis	Use the multi-temporal imagery to make map showing the development of RiskCity in the past 4 decades.
	6	Participatory GIS	Design an optimal method to carry out a larger PGIS survey for Elements at risk characterisation, vulnerability assessment and risk assessment
	7	Improved cost estimation	Design a method for an improved estimation of the costs of buildings and building contents.
	8	Improved building classification	Use the Lidar data and the image data to make an improved building classification with respect to land use.
Vulnerabi lity	9	Stage damage curves	Design a method for generating stage damage curves for flooding based on the participatory approach for different building types and number of floors.
	10	Vulnerability with SMCE	Design an improved method for the generation of a comprehensive vulnerability assessment using SMCE and the GTZ method.
Risk Assessment	11	Earthquake risk for buildings	Design a method for calculating the earthquake risk to buildings by using individual buildings, including slope effects and different levels of groundshaking.
	12	Earthquake casualty estimation	Desing a method for estimating the expected number of casualties in case of an earthquake in a daytime and nighttime scenario
	13	Improved landslide risk assessment	Design a method for improved landslide risk assessment, based on individual buildings, by incorporating detailed landslide vulnerability and expected landslide sizes.
	14	Shelter need assessment	Design as method for estimating the number of people that may need shelter after the occurence of a disaster, and evaluate whether the shelter capacity is adequate in RiskCity
	15	Risk prior to disaster	Calculate the risk prior to the 1998 disaster event and compare the risk with the losses from the disaster.
	16	Public/Private risk	Make a multi-hazard risk assessment in which you differentiate losses between private losses, business losses and public losses.
	17	Uncertainty in risk assessment	Design a method to evaluate the degree of uncertainty in risk assessment, based on uncertainties of the input parameters.
Risk Management	18	Risk communication strategy	Design an optimal risk communication strategy that involves all relevant stakeholders, and makes use of the appropriate media
	19	Risk Visualisation strategy	Design an optimal risk visualisation strategy that provides the different stakeholders with the right information in a spatial manner
	20	Insurance policy	Design an insurance policy for RiskCity that is based on the expected losses and number of households & companies that may buy an insurance in order to estimate the insurance premium.
	21	Earthquake risk reduction	Design a method for evaluating the best earthquake risk reduction measures in the city, based on a cost-benefit analysis
	22	Landslide risk reduction	Design a method for evaluating the best earthquake risk reduction measures in the city, based on a cost-benefit analysis
	23	Rapid damage mapping	Design a method for rapid building damage assessment after the occurrence of a major disaster
	24	Risk and Planning	Design a method to use the risk information together with other data for the planning of new neighbourhoods in RiskCity.
	25	Disaster preparedness	Design a method for an improved disaster preparedness planning based on the simulation exercise.

Topic 1. Earthquake hazard assessment
Prerequisite: You should have selected earlier the exercise on Earthquake hazard assessment
Objective: Design an improved method to generate an earthquake hazard map for Riskcity with return periods derived from the earthquake catalog, and including local ground effects.

Description: In the exercise on earthquake hazard assessment you looked at different seismotectonic zones within the country. Each one of them could be characterized with a magnitude-frequency relationship based on the earthquake catalog. Using the attenuation function this would allow to calculate what would be the relationship between MMI and return period for earthquakes from each zone, thus allowing a better frequency magnitude estimation for RiskCity. Also the local soil amplification effects could be better estimated using the information in the second part of that exercise. Work this out further and present this information. Combine this with the building loss estimation to evaluate how the risk curve would change based on this.

Topic 2. Technological hazard assessment
Prerequisite: You should have selected earlier the exercise on Technological risk assessment
Objective: Use the ALOHA model to generate scenarios for industrial accidents including wind speed and wind direction.

Description: In the exercise on technological risk assessment we used simple effect distance calculations to estimate the area that will be affected by Poolfire and BLEVE. Improve this method first by generating different effect distances related to different degree of damage and make a better estimation of the vulnerability of people within these zones. Additionally you can use the ALOHA model that calculates effect distances taking into account also the wind directions and windspeeds. Since this is a new topic, there is a document which generally describes the steps to follow for this project. This will be made available to you when you select this topic.

Topic 3: Landslide hazard assessment
Prerequisite: You should have selected earlier the exercise on landslide hazard assessment
Improve the landslide hazard map by combining statistical, deterministic and heuristic methods, and use size probability information

Description: In the exercise on landslide hazard assessment you used two methods: statistical and deterministic methods separately. In this exercise we didn't compare them. The aim of the project is to improve the landslide hazard map. This can be done in various ways. First of all you can use other factor maps in the statistical analysis that are more relevant for landslide occurrence. You can also make hazard maps for different landslide types. Secondly you could use the methods used in the previous module with a simple groundwater model to derive in fluctuations of the water level. You could also use the results of the deterministic assessment as factor maps in the statistical analysis. And you can also bring in heuristic rules to change the hazard of certain areas. Present success rates in your report. Finally you can also look at the size-frequency distribution to be able to say something on the probability of having a certain landslide size.

Topic 4. Flood risk assessment
Prerequisite: You should have selected earlier the exercise on flood hazard assessment
Use the results of the previous module on flood discharge modeling as input for the flood hazard assessment.

Description: The aim of this project is to carry out several model runs for rainfall of different return periods to come with a Magnitude-Frequency estimation for discharges in RiskCity.

One of these could be used in SOBEK to model the flood height and flow velocity in Risk City and compare this with the PGIS results.

Topic 5. Multi-temporal analysis
Prerequisite: none
Use the multi-temporal imagery to make map showing the development of RiskCity in the past 4 decades.

Dwescription: In the second exercise we have looked at the airphotos and satellite images from different periods. We have images from the 1970's, 80's , 90' and after 2000. You could use this information to make a evaluation of the growth of RiskCity. Based on teh building map of 1997 make an interpretation of the ages of the different parts of the city. Use this to calculate the growth rate of the city. Also analyze which landuse types have had the largest growth over the past decades, and evaluate the relation between hazard zones and newly developed areas.

Topic 6: Participatory GIS
Prerequisite: none
Design an optimal method to carry out a larger PGIS survey for Elements at risk characterisation, vulnerability assessment and risk assessment

Description: The aim of this project is to design a method to complement the information available from the building database with community based information. As we have seen the available information on population characteristics is limited to large areas within the city (wards or districts). We would like to involve more the local communities in the risk assessment, and we would like to obtain information on the vulnerability and capacity, the risk perception and the way disaster risk is evaluated in comparison with other types of risk for the local community. Information should be collected in such a way that it can complement the available GIS databases. Design a data collection project: which data will be collected, how the data will be collected, how local communities will be approached, how representative data at community level can be used to characterize the mapping units of RiskCity. Also "invent" the data for a number of sample points and show how this can be used in further analysis.

Topic 7: Improved cost estimation
Prerequisite: none
Design a method for an improved estimation of the costs of buildings and building contents.

Description: in the exercise on economic loss estimation we have used a very simple method for estimating the costs of buildings, by using an average cost per building and contents per square meter and multiplying that with the floorspace of the building. The aim of this project is to improve this. This can be done by analyzing the building costs and the contents costs separately in more detail. Building costs could be analyzed in two ways: by finding information on building prices from real estate agents. You can for example take your own city as example and look at websites of real estate agents. The second method is to look at construction costs per square meter, based on the construction type and the landuse. For the content cost estimation develop a method where you take a number of buildings as example and describe the items that would be in such a building (e.g. electrical appliances, furniture etc.) Then use these standard contents packages to make a better estimate of the building costs per landuse class. Also include the aspect of intangible costs (that you cannot express in money) and also try to make a differentiation in costs per floor which would be important for flood risk assessment.

Topic 8: Improved building classification
Prerequisite: none
Use the Lidar data and the image data to make an improved building classification with respect to land use.

Description: the building classification that is used in RiskCity is often not so very accurate. If you look at the building_map_1988 it contains a description for each building of the number of floors, land use, building type and number of people. Develop a method with which you could check the quality of the existing building map, and with which you could improve it. For instance, very large building in squatter area are most probably not squatter buildings but others. You can also use the high resolution image available to make samples to check the landuse type. Also make use of Google Earth and evaluate what information is available about Tegucigalpa that could improve the building classification. Finally also make an estimation of the error that would be involved in the risk assessment due to the wrong classification of buildings.

Topic 9. Stage damage curves
Prerequisite: none
Objective: Design a method for generating stage damage curves for flooding based on the participatory approach for different building types and number of floors.

Description: In the exercise on the use of PGIS for stage damage curves we generated a general stage damage curve for all building using the average water height values. Try to improve this by estimating the variation in damage that would result if we would use the full range of recorded damage values and not just the average. Also make vulnerability curves for sperate building types, and see if it is possible to do that also for different number of floors. Compare the stage damage curves with others derived from the literature. Finally make a plan how you could make similar stage damage curves for earthquakes and landslides (you could also invent some damage survey to ilustrate your method).

Topic 10 Vulnerability assessment with SMCE
Prerequisite: none
Objective: Design an improved method for the generation of a comprehensive vulnerability assessment using SMCE and the GTZ method.

Description: The aim of this exercise is to improve the results of the analysis of vulnerability in RiskCity using the Spatial Multi-Criteria Evaluation tool of ILWIS. Based on the exercise that was done in the course you are asked to improve the vulnerability and capacity indicators, and obtain better results for the various types of vulnerability. You are also asked to include other types of vulnerability, such as economic vulnerability, and environmental vulnerability, and to select suitable indicators for that as well.

Topic 11. Earthquake risk for buildings
Prerequisite: none
Objective: Design a method for calculating the earthquake risk to buildings by using individual buildings, including slope effects and different levels of groundshaking.

Description: In the RiskCity exercise we have made a calculation of earthquake risk for mapping units, making use of building estimations that were made according to exercise 4ª (generating an elements at risk database from scratch). This estimation was based on a number of sampled mapping units, where the actual numberof buildings was counted, and was then extrapolated over the other mapping units with the same landuse type. Now you will use the building map (building_map_1988) to make a more accurate estimation of the building losses for the different earthquake scenarios. Use the minimum and maximum expected building losses. Check the literature for other vulnerability curves used for earthquakes and try to use these with the dataset as well. Evaluate the difference in the output.

Topic 12 Earthquake casualty estimation
Prerequisite: you should have done the exercises on earthquake hazard and risk assessment
Desing a method for estimating the expected number of casualties in case of an earthquake in a daytime and nighttime scenario

Description: based on the building loss calculation for earthquakes and the population information per building it is also possible to estimate the population losses in 4 severity classes discussed in the lectures. Use the population information per building and calculate the minimum and maximum casualties for both a daytime and a nighttime scenario.

Topic 13 Improved landslide risk assessment
Prerequisite: you should have done the exercises on landslide hazard and risk assessment
Design a method for improved landslide risk assessment, based on individual buildings, by incorporating detailed landslide vulnerability and expected landslide sizes.

Description: In the exercise on landslide risk assessment we have made a number of shortcuts or simplifications. We calculated the number of buildings affected per mapping unit, and we made a very simple vulnerability estimation. In this project use the building map (building_map_1998) as the basis. Calculate for each building whether it is located in a high, moderate or low susceptible area. Design a method to make a vulnerability estimation for every individual building based on the building type and the floorspace. Also evaluate whether buildings are located close to existing landslides, which would increase their vulnerability. Then include the hazard information and calculate the risk per building. Aggregate the results per mapping unit and also for the whole city.

Topic 14 Shelter need assessment
Prerequisite: none
Objective: Design as method for estimating the number of people that may need shelter after the occurence of a disaster, and evaluate whether the shelter capacity is adequate in RiskCity

Description: in the case of a major disaster there will be a number of people that will be homeless, and need to go to shelters. This topics analyses the number of people that need shelter and the availability of shelters. For calculating the number of people that need shelter, you will first have to select certain scenarios for earthquakes, flooding , landslide and technological hazards. For these you have to use the calculated building losses that were evaluated in session 6. Based on the information of the number of people per house you then have to estimate the number of people without a house (think about whether you use daytime or nighttime population and for which landuse type). For the shelter availability also use the landuse as the basis. Is the building itself still intact, and which buildings can be used as shelters?

Topic 15 Risk prior to disaster
Prerequisite: none
Objective: Calculate the risk prior to the 1998 disaster event and compare the risk with the losses from the disaster.

Description: In 1998 there was a major disaster in RiskCity which generated a lot of damage due to landslides and due to flooding. The aim of this exercise is to evaluate the risk situation prior to the 1998 event, and compare this with the actual damage that happened in 1998. We have a map showing the buildings in 1997. Use this as a basis for doing a landslide and flood risk assessment. Look particularly to the 100 year return period, which was the return period of the event. Compare the results then with the actual number of destroyed buildings in 1997. How good was the risk assessment?

Topic 16 Public/Private risk
Prerequisite: none
Objective: Make a multi-hazard risk assessment in which you differentiate losses between private losses, business losses and public losses.

Description: In the loss estimations that we have done in the exercises we looked at the overall risk to all buildings, without making any distinction between losses to residential buildings, commercial and industrial buildings and to public buildings. The aim of this project is to calculate the building losses and associated economic losses separately for residential buildings, commercial buildings and public buildings. You would have to separate the buildings based on the landuse, and make a separate loss estimation for them. Then you can also look at how this could be used to make a general estimation of the indirect losses. For instance for each residential building you know the number of people, and from the PGIS survey the number of workers. You could calculate how many days the households would be without work, and make an estimation of the indirect losses due to loss of income. Also for the businesses you could calculate how many people work there and estimate the loss of production assuming general production figures per employee.

Topic 17: Uncertainty in risk assessment
Prerequisite: none
Design a method to evaluate the degree of uncertainty in risk assessment, based on uncertainties of the input parameters.

Description: Loss assessment also has a large degree of uncertainty. This is coming from the number of elements at risk, the vulnerability and the hazard. The aim of this project is to evaluate which components of the risk assessment have the highest level of uncertainty, and describe these conceptually. Also it might be possible to illustrate the uncertainty for a certain type of hazard (e.g. for earthquakes) by calculating the minimum and maximum losses.

Topic 18. Risk communication strategy
Prerequisite: none
Objective: Design an optimal risk communication strategy that involves all relevant stakeholders, and makes use of the appropriate media

Description: The risk information which was estimated in the RiskCity exercises should be communicated to the local authorities, communities and to other actors. The aim of this small topic is to define who are the actors? How can we involve the actors? Which activities should be involved? How can we visualize the risk? Which information should be made available for whom? Please use examples from RiskCity to illustrate these. Would it be useful to make the materials available using a WebGis application? Which data should be shown?

Topic 19: Risk Visualisation strategy
Prerequisite: none
Design an optimal risk visualisation strategy that provides the different stakeholders with the right information in a spatial manner

Description: The risk information which was estimated in the RiskCity exercises should be communicated to the local authorities, communities and to other actors. The aim of this topic is to make different types of output maps to different actors? How can we visualize the risk? Which information should be made available for whom? Use examples from RiskCity to illustrate these. Use the WebGis application that has been developed for RiskCity as well?

Topic 20. Insurance policy
Prerequisite: none
Objective: Design an insurance policy for RiskCity that is based on the expected losses and number of households & companies that may buy an insurance in order to estimate the insurance premium.

Description: One of the ways to reduce the risk in RiskCity is to implement a system for disaster risk insurance for buildings. Suppose you are asked to design disaster insurance at municipal level. The insurance is on a non-profit basis, and is of course based on the principle of solidarity. Many people will pay insurance premium for their house, and the accumulated insurance premium should be sufficient to cover disaster damage costs for the persons having such insurance. Companies may pay higher premiums than individuals, and residents can pay premium depending on their socio-economic level. Think about how such a system should be designed, and use the information on the economic loss estimation for the various types of hazards calculated in the exercises. Perhaps you may even use a cost-benefit analysis to evaluate the height of premiums. See for a start for example: http://en.wikipedia.org/wiki/Insurance

Topic 21. Earthquake risk reduction
Prerequisite: none
Objective: Design a method for evaluating the best earthquake risk reduction measures in the city, based on a cost-benefit analysis

Description: Based on the work done in the exercise on cost-benefit analysis, it would be good to make a list of the possible disaster risk reduction measures for earthquake hazards. You may have to carry out a new risk assessment taking into account these risk reduction measures, or you would have to estimate how much they would reduce the risk. For a number of these you could carry out a basic cost-benefit analysis, but also include other

Topic 22. Landslide risk reduction
Prerequisite: none
Objective: Design a method for evaluating the best earthquake risk reduction measures in the city, based on a cost-benefit analysis

important non-economic considerations for the implementation of these measures.
Description: Based on the work done in the exercise on cost-benefit analysis, the aim is to make a list of the possible disaster risk reduction measures for landslide hazards. You may have to carry out a new risk assessment taking into account these risk reduction measures, or you would have to estimate how much they would reduce the risk. For a number of these carry out a basic cost-benefit analysis, but also include other important non-economic considerations for the implementation of these measures. Take also into account that there are a lot of non-economic issues involved as well.

Topic 23. Rapid damage mapping
Prerequisite: none
Objective: Design a method for rapid building damage assessment after the occurrence of a major disaster

Description: The results of the building and population loss estimation for RiskCity can also be used to plan a rapid damage assessment, after a major disaster has occurred, such as an earthquake. Important questions to be answered are: where are the damages to be expected to be the highest? How many people should be trained for the rapid damage assessment? Where should they be located? How should the data they collect be incorporated in the database? Design a method and show an example based on the RiskCity case study. To give you an idea of what to do, have a look at the Msc thesis of Diana Contreras from UPM programme in 2009.

Topic 24. Risk and Planning
Prerequisite: none
Objective: Design a method touse the risk information together with other data for the planning of new neighbourhoods in RiskCity.

Description: In this exercise you have to evaluate the best location for an urban extension. The municipality of RiskCity would like to construct housing for 5000 people in the coming 5 years. However, they don't know the best location yet. You are asked to provide them with several alternatives. In this exercise you will have to use SMCE and develop a decision tree with different groups of factors. Obviously the hazards are an important factor, but also other factors play a role, such as the distance to the city centre, the slope steepness, the ecological value of the land, and the land ownership. One option is also to upgrade the squatter areas to residential areas with more floors. Decide also what type of buldings should best be constructed, and with how many floors. Present the options in order of preference and include then reasons for it.

Topic 25. Disaster preparedness
Prerequisite: none
Objective:Design a method for an improved disaster preparedness planning basic on the simulation exercise.

Description: Consider the risk assessment that was done in RiskCity, and which areas are mostly at risk, also defining the types of hazards. Based on this information design a method for improved disaster preparedness: e.g. what types of disaster preparedness could be carried out and for which types of hazards. Look at community awareness, early warning systems, location of emergency response centers, evacuation shelters. How many people need to be involved in awareness raising activities, which organizations should be involved in early warning, can early warning also be done at community level? Where should new evacuation centers be constructed?