Multi-hazard risk assessment

Distance education course

Risk City Exercise book 2011

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Exercise 1: Introduction to ILWIS and the Riskcity dataset

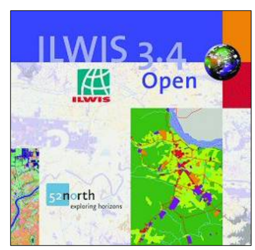
Expected time:	2.5 hour
Data:	data from subdirectory: Riskcity_exercises/exercise01/data
Objectives:	After this exercise you will be able to:
	- understand the basic functions and objects of the ILWIS software
	- display segment, polygon and raster images and analyze their properties
	- display and analyze the histogram of a high resolution elevation model
	- perform a simple map-calculation.

Introduction

This exercise gives an overview of the main aspects of ILWIS and a scheme of the structure of the software and the icons used. It also aims to explore the available input data for this case study, and show you some aspects of RiskCity and the associated hazards and risks

Each of the exercises will use its own dataset. So make sure that you copy the data for each exercise to your hard disk in a separate subdirectory. Do not use data for a previous exercise, as we will changes parts of it to make them suitable for the next exercise.

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 Aerospace Survey and Earth Sciences (ITC), Enschede, The Netherlands.

ILWIS Version 3.4 is open source software and can be downloaded for free from **52 North:** ***http://52north.org/***

As a GIS package, ILWIS allows you to input, manage, analyze and present geo-graphical data. From the data you can generate information on the spatial and temporal patterns and processes on the earth surface.

This exercise will give you an introduction on the basic functions of ILWIS, as we think the best way is to "learn by doing". ILWIS uses vector and raster data, but most of the analysis is done in raster. Below an overview is given of the main features of ILWIS.

ILWIS key features

- Integrated raster and vector design
- Import and export of widely used data formats
- On-screen and tablet digitizing
- Comprehensive set of image processing tools
- Orthophoto, image georeferencing, transformation and mosaicing
- Advanced modeling and spatial data analysis
- 3D visualization with interactive editing for optimal view findings
- Rich projection and coordinate system library
- Geo-statistical analyses, with Kriging for improved interpolation
- Production and visualization of stereo image pairs
- Spatial Multiple Criteria Evaluation

Starting ILWIS

This exercise shows you the basic ILWIS interface, with the ILWIS Objects and Domains.

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. The other text outside the boxes contains descriptions and explanations.

Watch Demo 1 for instructions

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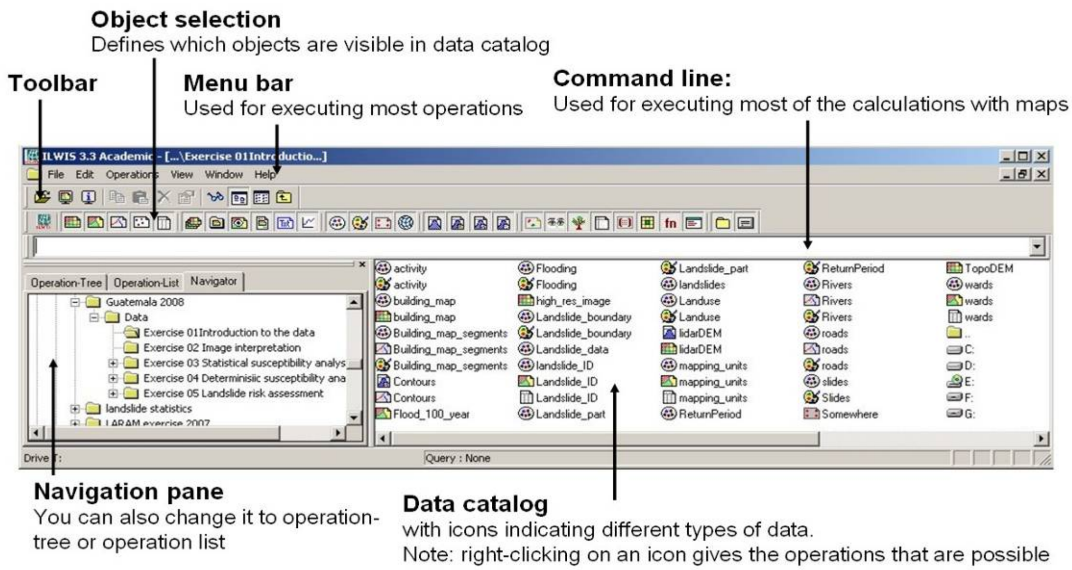
- To start ILWIS, double-click mouse the ***ILWIS*** icon on the desktop. After the opening screen you see the ILWIS Main window (see figure below). From this window you can manage your data and start all operations
- Use the ILWIS Navigator (Navigation pane) to go to the sub-folder of the first exercise. The Navigator lists all drives and directories (i.e. folders) in a tree structure.



The ILWIS Window contains a number of features:

- **Data catalog**: displays the icons and names of the objects inside the selected directory.
- **Standard Toolbar**: provides shortcuts for some regularly used menu commands

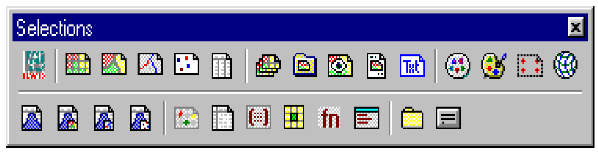
The Standard toolbar has the following buttons:

New Catalog	Properties
Open Map	Customize Catalog
Open Pixel Information	List
Copy	Details
Paste	cd..
Delete	

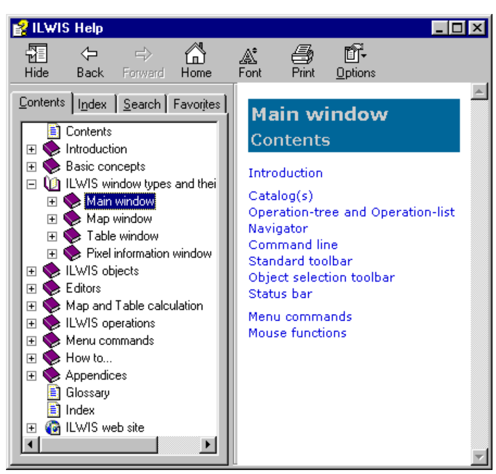
- **Navigation pane**: allows for fast navigation, and can also be changed to display all operations
- **Menu bar**: this is the main starting point for doing most of the operations in ILWIS. Check especially the options under Operations. The ILWIS Main window has six menus: **File, Edit, Operations, View, Window** and **Help**.

- **Command line:** this is a central facility in ILWIS. Here you type calculation statements (called **MapCalc**) which allows you to do a lot of analysis steps with raster maps. If you do an operation, the related ILWIS command is also displayed.

- **Object selection:** this allows you to select which objects are displayed in the data catalog



- **Getting HELP :** allows you to obtain information from any point within the program. The Help menu differs per window. The options are:
  - **Help on this Window**. You obtain help on the current window. Depending on the window from which you select this help option, you can get help on the Main window, the map window, the table window, the pixel information window, etc.
  - **Related Topics**. When this menu option is selected a dialog box appears with a list of topics that are related to the current window.
  - **Contents.** Displays the Help Contents. By clicking the links in the table of contents you can go to any help topic you like.
  - **Index.** The Index page of the ILWIS Help is displayed. Type a keyword or click any keyword in the list on which you wish help.
  - **Search.** The ILWIS Help viewer is opened with the Search tab selected. Type characters of the keyword or phrase on which you want to obtain help and press Enter, or click the List Topics button to get a list of topics. In the Select topic list box select the topic you want to display and click the Display button or press Enter ↵.

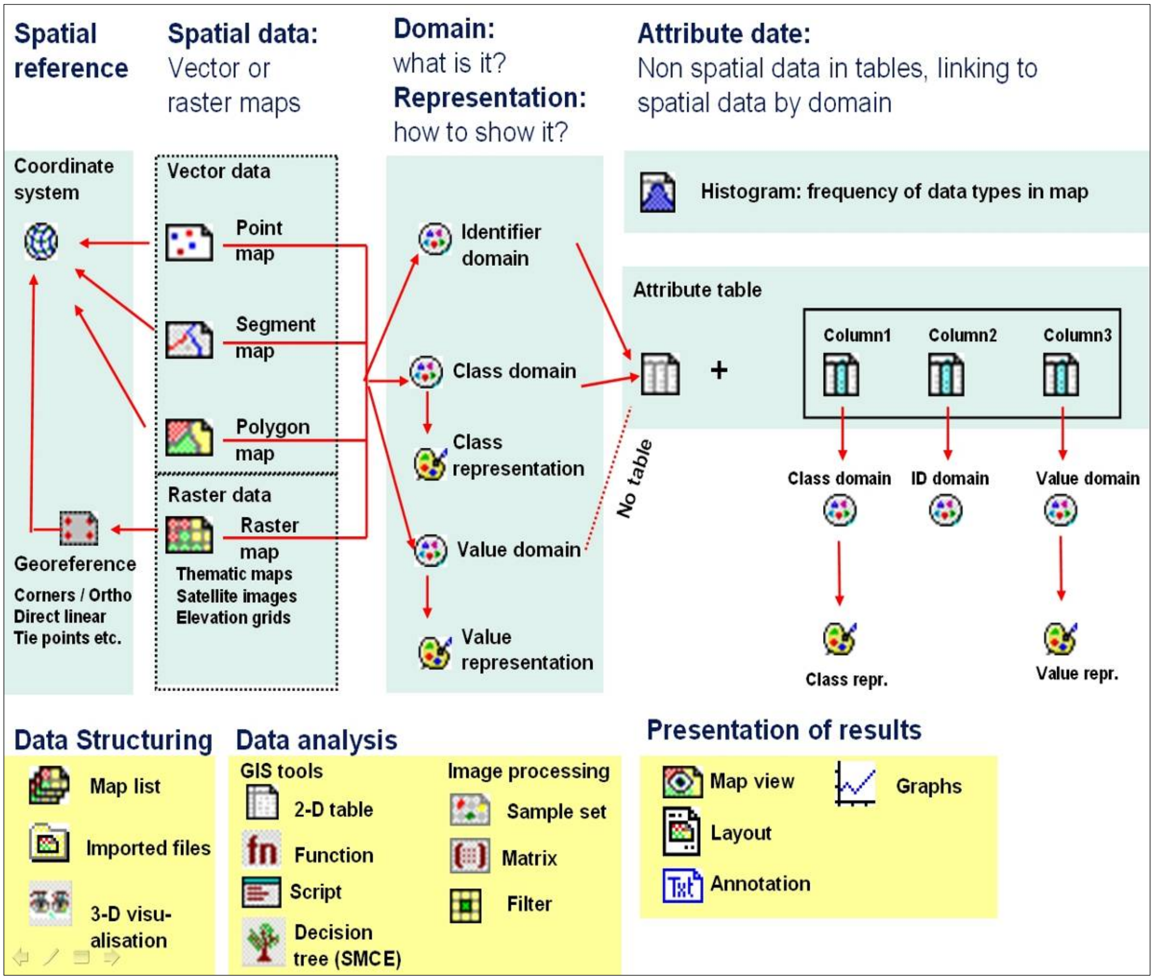


ILWIS Objects

Before we are going to display vector and raster maps and investigate the different types of domains, it may be useful to explain that ILWIS uses different types of objects.

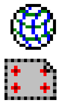
- ***Data objects.*** Raster maps, polygon maps, segment maps, point maps, tables and columns are called data objects. They contain the actual data.
- ***Service objects***. Service objects are used by data objects; they contain accessories that data objects need besides the data itself. Domains, representations, coordinate systems and georeferences are called service objects.
- ***Container objects.*** Container objects are collections of data objects and/or annotation: map lists, object collections, map views, layouts and annotation text.
- ***Special objects.*** Special objects are histograms, sample sets, two-dimensional tables, matrices, filters, user-defined functions and scripts.

A vector map needs a coordinate system, a domain and a representation. These service objects are also needed for raster maps, together with another type of service object: a georeference. In this chapter we will focus our view on data and service objects.



The icons in the **Data Catalog** of the exercise refer to some of the various objects that are possible in ILWIS. When you double-click an object in the Catalog, it will be displayed.

1. Objects for spatial reference:



They define the coordinate system, projection parameters, and size and pixel size of the raster maps in the dataset. Normally all spatial data has the same coordinate system, and all raster data shares the same georeference.

Watch Demo 2 for instructions

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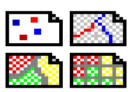
- Right-click in the Data Catalog the GeoReference **Somewhere** and after this select: *Properties*.

  In the Properties of Georeference window you see the corner coordinates of the GeoReference window and the Coordinate System Unknown. This means that the coordinate system of RiskCity is unknown for the exercise. Also the pixel size is indicated: 1 m.
- Select the Tab *Used By*. Now you see a list of all the raster maps which make use of this GeoReference. It means that they all have the same coordinate system, cover the same geographic area and also have the same pixel size.
- Note that there is no Coordinate System icon visible in the Data Catalog. This is because the Coordinate System Unknown is used, with is a standard type.
- Select the *Help* button for more detailed background information on the GeoReference object.

2. Objects for Spatial data:



This can be either vector data (point, lines called segments, and polygons, which are made from points and lines) or raster data (which can be images, thematic data derived from rasterizing vector maps, or interpolated values like Digital Elevation Models). See the **yellow box** on the next page for more information on the difference between point, line and area representation in vector and raster format.

Watch Demo 3 for instructions

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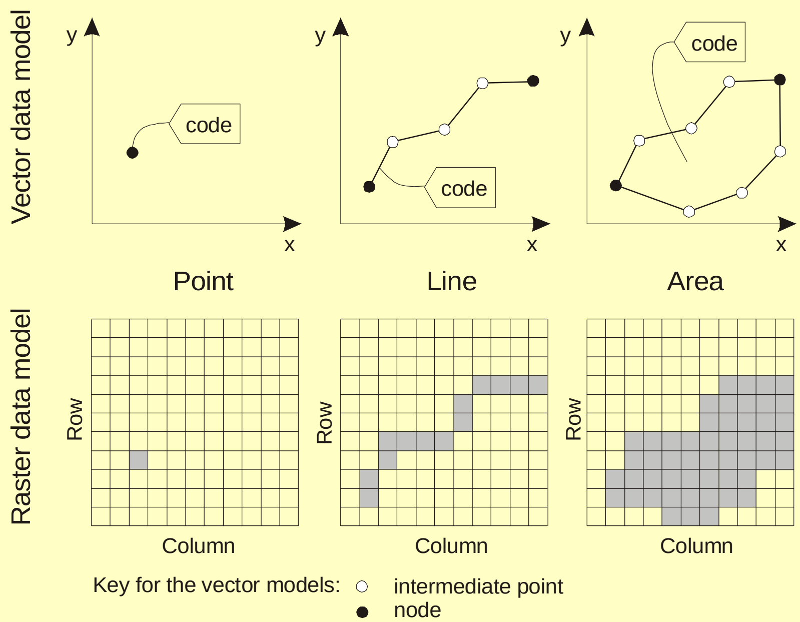
- Right-click in the Data Catalog the Segment map **Rivers** and after this select: *Properties*. In the Properties of Segment Map window you see the Coordinate System Unknown and the Domain Rivers. A domain defines the contents of the data; we will explain later in the exercise more about this object, which is typical for ILWIS
- Select the Tab *Used By*. You see that the segment map is not used by other maps.
- Display the Segment map **Rivers** by Double clicking the icon in the Data Catalog. See that in the Display Options of Segment map window the Representation Rivers is used, by which colors are assigned to the different segment classes. More on Representation under Domain (see below).
- Repeat the above steps also for the Segment Map **Roads**
- Select the *Help* for more detailed background information on the Objects of Spatial data.

Spatial features are represented in ILWIS in the following ways:

- **Points.** Many items can be represented as single points on a map. Points may refer to rainfall stations, houses, field observations, sampling points, etc.
- **Lines.** Linear features such as roads, drainage lines or contour lines.
- **Areas.** Features which occupy a certain area, such as land use units (e.g. forest), geological units, etc.

The spatial entities described above can be represented in digital form in two data models (see the Figure): *vector models* or *raster models*.

Both models store details on the location of entities and their value, class name or identifier. The main difference between the two data models is the way they store and represent the locations.



Vector and raster representation of points, lines and areas. The code of a feature is either a class name, an ID, or a value.

3. Domain:


This is the central component of ILWIS. A domain defines the contents of the data. Five domain types are possible:

- **Identifier domain**: ID domain in which each unit has a separate code,
- **Class domain**: all units with the same class have the same name, for instance. lithological units.
- **Value domain**: each unit contains a value, e.g. a Digital elevation Model. It has a default value ran**ge between -9999999.9 and 9999999.9,**
- **Image domain**: Value range from 0 – 256 for 8 bit satellite images,
- **Color Domain**: used for pictures such as photographs and scanned pictures, for instance maps.

The concept of **domains** is different from other GIS software and might seem a bit confusing in the beginning. However you will see that it is a very powerful component of ILWIS.

Domains are linked to representations, which define how the spatial data is displayed. You can create your own representations (only for Value and Class domains) or you can use standard representations.

Watch Demo 4 for instructions

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- Double-click in the Data Catalog the Class Domain **Rivers**; the Domain Class Rivers window opens. You see that there are five classes of the rivers. If needed, classes can be added or removed (we don't do this now!)
- Mouse-click the icon **Representation** belonging to this Class Domain. You see that there are colors assigned to the different river classes. The colors can be edited easily. Examples of other class domains are **Slides, Roads** and **Landuse.**
- Select the *Help* for more detailed background information on the Class Domain.
- Open in the Data Catalog now the Identifier Domain **Landslides.** You see that each individual landslide has an unique code from 1 to 187
- Select *Help* for more detailed background information on the **ID** Domain.
- Note that the **Value Domain** is not displayed in the Data Catalog. This is because it is a standard domain. It has a default value range between 9999999.9 and - 9999999.9. In the exercise it is used for the for the Segment map **Contour.** In this map the contours have values between 900 and 1315 meter above mean sea level.
- Use *Help* for more detailed background information on the **Value** Domain**.**

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4. *Tables and histograms*:

Attribute data is stored in the form of tables, which are linked to the spatial data through the domains. Only ID and Class domains can have a table.

Statistical information on the spatial data is stored in Histograms, containing the frequency information (area, number of pixels, number of points, lines etc). Tables have columns which also have either a Class, ID or value domain (some exceptions are possible)

There are also separate icons for organizing the data, for GIS analysis, image processing and for visualization of the data, but we will not mention these now.

Watch Demo 5 for instructions

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- Double Mouse-click in the Data Catalog the Table **Landslide_ID.** Now the table opens, with is linked to the Landslide map. You see that there are several columns with different types of data.
- Double Mouse-click the column name (top of column); the Column Properties window opens with the Domain used.
- Select: *Help* > *Help on this window* for more detailed background information on the Table
- Use *Help* for more information on Histograms**.** We are not using this in this phase of the exercise.

Dependency in ILWIS

ILWIS is an object-oriented GIS and image processing software. This means that the various objects mentioned above are related to each other. You therefore need several objects to define for instance a thematic raster map:

- Coordinate system,
- GeoReference,
- Segments of digitized line,
- points containing information on the units,
- polygons made from the segments and points,
- raster map made from rasterizing the polygon map, and
- a table.

Also when one object is produced from another object, ILWIS stores the history of how the file was made. This is called Dependency.

The concept of **dependency** is one of the key features of ILWIS. ILWIS stores for each file the history of how it was made, and the user can easily update a map or table if one of the source data was changed.

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- Right-click in the Data Catalog on **Table** **Landslide_ID**. Choose Properties Select the Tab **Used By**. You see that the table is used by the polygon map Landslide ID

Other Dependencies have been removed in this first dataset. But you will create new ones yourself at a later phase of the exercise.

Some important points on file management in ILWIS:

There are some things you need to know about using ILWIS data files that will prevent problems when you are using them in the course. Due to the dependency and the object oriented structure of the ILWIS data, individual files are linked to others, and several files are needed to display a map, table or other object. Therefore you have to know the following tips:

- **Do NOT use Windows Explorer to copy / delete or rename individual files**. Use the options in ILWIS itself (under Edit) to copy or delete files. You can copy files in ILWIS by going in the main window to Edit and select Copy.

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Right-click in the Data Catalog on **mapping_units**. Select Copy. Then go to another directory with the ILWIS Navigator and select Paste. You see that not only the polygon file is copied but also the other objects that are needed for this file (domain, representation, coordinate system, table etc.)

- You can check the links between the different object by selecting the properties of a file. You do that by right clicking an icon and selecting “properties” from the context sensitive menu
- ILWIS has a very extensive **Help**. Consult this whenever you have specific questions on the functionality of the software.

Exploring the input data

In the data catalog you see the icons of the available input data for this introduction to the case study. The following input data gives an overview of the thematic data and how they are derived.

Name	Type	Meaning
Image data		
High_res_image	Raster image	This represents a high resolution colour image derived from an IKONOS image. It has been orthorectified, and the panchromatic band is fused with the colour bands, and resampled to 1 meter pixel size.
Elevation data		
LidarDEM	Raster map	This is a Digital Surface Model which has been derived from a laser scanning flight. The original data points have been interpolated into a 1 meter resolution raster map.
Contours	Segment map	This file contains contour lines with 2.5 meter contour interval. These have been digitized from a series of 1:2000 scale topographical maps.
TopoDEM	Raster map	Digital Terrain Model showing the elevation of the terrain made by interpolating contour lines into a raster
Elements at risk		
Wards	Polygon map	A polygon map representing the administrative units within the city. In the accompanying table information is given on the number of buildings and number of people
Mapping_units	Polygon map and table	This map represents the mapping units used for elements at risk mapping, but now as polygons. Each of the mapping units has a unique identifier, so that in the accompanying table information can be stored for each unit. The units may be individual large building or plots with a specific land use, although they are mostly grouping a number of buildings. In the accompanying table information is given on the number of buildings and number of people
Building_map_1997	Raster map	Building footprint map of the city prior to the 1998 Mitch event. The map still contains the buildings that were destroyed by landslides and flooding during the Mitch event
Roads	Segment map	A segment map of the streets, roads and paths, made by digitizing from topographic maps.
Hazard data		
Landslide_ID	Polygon map	Landslides in the study area, with an attribute table containing information on the landslides.
Flood_100_year	Polygon map	Flood extend map for a 100-year return period, obtained through modeling with HEC-RAs hydrological software
Rivers	Segment map	A segment map of the drainage network in the city, digitized from topographic maps

Displaying satellite image data

Display options window: this allows you to define how you want the spatial data to be displayed. ILWIS will suggest you options. and

We start by looking at the high resolution image.

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- Open in the Data Catalog the raster map **High_res_image**. You can do this by simply double-clicking the icon. Accept the defaults in the Display Options Raster map window. Click: *OK.*
- The map is georeferenced to a UTM coordinate system. You can see both the image and UTM coordinates in the lower right corner of the display window:

  2656,1568 (477066.67, 1558845.57)

- Use the various options to zoom and pan, and have a good look at the image. You are looking at a small part of a larger city. Zoom in the map **High_res_image** until you can see individual buildings, and even cars
- Display the entire map with
- To measure distances and angles use

We can customize the Catalog in the following way:

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- Click the Customize Catalog button in the Standard toolbar of the Main window. The Customize Catalog sheet is opened.

The object Selection tab contains a list box in which the object types that are shown in the Catalog appear highlighted. You see that *all* ILWIS objects are selected. To show only the map and table objects, i.e. the objects with the icons , , , and :

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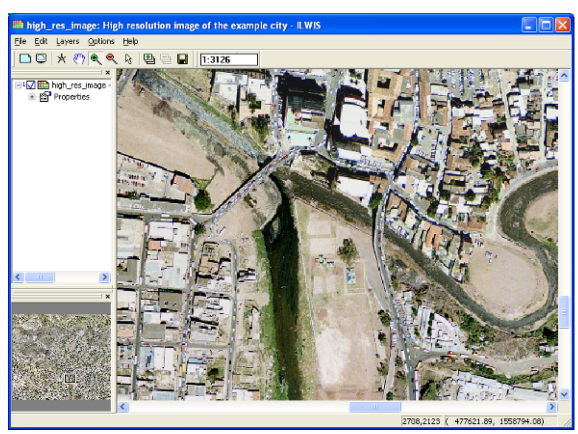
- Select on the object Selection tab the first object type (i.e. the Raster Map), keep the left mouse button pressed and move the mouse pointer to the last object you want to select.
- Release the mouse button and click: *OK*.

You will see that the Catalog has changed and that now only the map and table objects are shown in the current Catalog. The ILWIS Main window may show more than one Catalog. You can thus keep your data organized in different directories.



The city you are looking at has been severely affected by a major disaster some years before the image was taken.

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◆ **TASK** : Make a characterization of the usefulness of the high-resolution images for mapping elements at risk. Would you be able to map individual buildings, and screen digitize them as building footprints? Discuss with your neighbor.

- Do you see any sign of potential landslide hazards in the image? If so, which signs and where in the image (note down the X, Y coordinates).

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

Displaying Hazard data

The city has been affected by major Hurricane/Tropical cyclone which produced very high rainfall amounts (equivalent to a return period of 100 years). This produced large landslides and flooding in the area. These have been mapped and maps are available for both.

Transparency : you can display one map on top of the other and see both. On some computers this may not work, if you haven't adjusted the screen display to 32-bits.

Display attributes: allows you to display the attribute information stored in the associated attribute table.

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- Overlay the polygon map **Landslide_ID** on top of the **High_res_image**. in the following way:

  Select in the Display window: *Layers > Add Layer and choose Landslide ID.* Select in the Display Option window: *Transparency*: 50. Leave all other options default.
- Double-click on a landslide polygon and the corresponding attribute data is displayed in a window(not in version 3.7). This data is taken from table **Landslide_ID**. Check for recent landslides and reactivated landslides.
- Also the landslide **Activity** can be displayed as an attribute in a separate window. To do this Right-click in the displayed **High_res_image**, and select *Display Options*, and after this **Landslide_ID**.

  In the Display Option window, select the Box *Attribute* and after this *Activity*. Select also the Option Button *Representation* and after this the representation *Activity*. If done: *OK.*

◆ **TASK :** The activity of the landslides is evaluated for 4 different years: 1977, 1998, 2001 and 2006. Check the activity for every year.

- Also overlay the polygon map **Flood_100_year** on top of the **High_res_image** (Also with a transparency of 50%). Compare the hazard features with the signs of damage that you have observed earlier.

The areas were mapped using multi-temporal image interpretation. In exercise 2 we will look more in detail how to do this, and how to generate the images needed for that. The landslide information is stored in a table, with the same domain as the landslide map.

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- Open the Landslide table **Landslide_ID** by clicking the table icon in the Data Catalog. Check the information available in the table.
- Double-click on the column header to see the properties of the columns. As you have seen before: they have different Domains

❖ **TASK:** Find out the total landslide area
Tip: make sure the **View Statistics Pane** is on in **View** menu.

- Close the table and close the Map window.

Displaying elements at risk data

Elements at risk : all objects and features that might be affected/ damaged/ destroyed/injured or killed by the hazardous phenol-mena.
In this exercise we limit ourselves to buildings, popu-lation and roads.

In order to be able to make a risk assessment for RiskCity we also need information on the elements at risk. For RiskCity we have this information at three different levels:

Wards: Some of the statistical information of the population and the buildings is only available at ward level. It contains a large part of the city and is too large for doing the risk assessment

Mapping_units: this is the main level for which we will do the risk assessment. It contains more or less homogeneous groups of buildings. We need to collect information on the number of buildings, type of buildings, and populations numbers for each mapping unit.

Building_map_97: This is the so-called building footprint map, containing the outline of each building in the area. This map was made before the disaster happened, so it also contains all destroyed buildings. The boundaries of the buildings are in the map **Building_map_segments**.

Roads: This is the road network.

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- Open the **high_res_image** again.

❖ **TASK** : Make a characterization of the usefulness of the high-resolution images for mapping elements at risk. Would you be able to map individual buildings, and screen digitize them as building footprints? Discuss with your neighbor.

- Overlay the segment map **Building_map_1997** on the high resolution image by selecting: *Layers > Add Layer*. Use in the Display options- Segment Map window Representation: **Building_map_segments**.
- Zoom in to see the boundaries of the individual buildings.
- Overlay also the polygon map **Mapping_units** using only the boundaries. You can do this by selecting in the Display Options-Polygon Map the Box: *Boundaries Only*. Select for Boundary Color: Green and Boundary Width: **2** to make the lines thicker.
- Zoom in and check the contents of the attribute table of the map **Mapping_units.**
- The urban land use can be displayed as an attribute in the following way: Right-click in the layer management pane on the polygon map **Mapping_units** , select *Display Options*, and select *Mapping_units*.

In the Display Options window click out *boundaries only*, select *Attribute,* and **Pred_Landuse**. Select representation ***Landuse*.**

- Finally also display the polygon map **Wards** and the segment map **Roads.** Check their contents.
- Close the map window

Altitude data

Digital Elevation Model : General terms for **D**igital **E**levation **M**aps

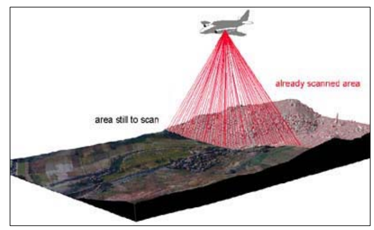
DTM = Digital Terrain Model, displaying the altitude of the terrain.
DSM = Digital Surface Model, displaying the altitude of the objects on the terrain, such as buildings' and vegetation.

In order to be able to make a risk assessment for RiskCity we also need information on the altitude of the terrain, and on the altitude of the objects such as buildings and vegetation. For that we have the following datasets:

Contours: digitized contourlines from large scale topographic maps. The maps used for the RiskCity exercise have a contour interval of 2.5 meters.

TopoDEM: Digital Terrain Model showing the elevation of the terrain made by interpolating contourlines into a raster map

LidarDEM: This is a Digital Surface Model which has been derived from a laser scanning flight. The original data points have been interpolated into a 1 meter resolution raster map



Apart from the digitized contourlines we are also using a high-resolution Digital Surface Model which has been derived from a laser scanning flight. This is also called LiDAR (Light Detection And Ranging).

The principles of LiDAR are explained in Chapter 2 of the Guidance Notes.

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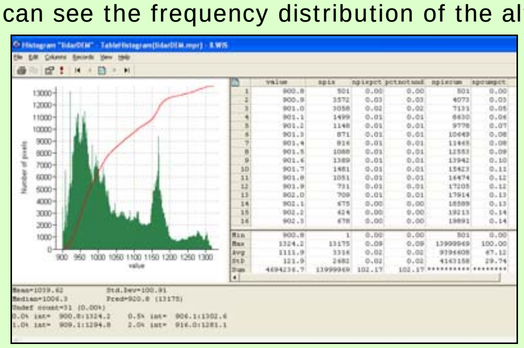
- Open the Segment map **Contours**, and make sure to select in the Display Options – Segment Map window the option *Info*. Use Representation file: *Pseudo***.** Click OK. Check the values of the contour lines in meters altitude by clicking them with the mouse.
- Add as a layer on top of the contour map the raster map **TopoDem**. Accept the default values for stretching (900 and 1315). Check with the mouse some of the altitude values (meters above mean sea level). Also change the representation to "Gray" (right click in the map, select: *Display options > Seg contour*, and select the "Gray" representation).
- In the Data Catalog, right-click on the raster map icon of **Topo_DEM** and select: *Statistics > Histogram*. The histogram files opens from which you can see the frequency distribution of the altitude values. See the image.



- Which altitude is most common? What is the average altitude?
- Close the histogram.

Image stretching : General term for the way a value map is displayed with optimal colour range.

When you stretch an image in ILWIS, you define the minimum value that will be displayed in one extreme part of the available colour range (e.g in Black) and the maximum value that will be displayed in the other extreme (e.g. in white)

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- Overlay the raster map **LidarDem**. Display the map with a "*Gray*" representation. Accept the default values for stretching (909.1) and 1294.8).
- Zoom in on the center of the city. You will hardly be able to see individual buildings now. This is due to the stretching of the image, as 900.8m and 1324.2 m are the minimum and maximum elevations in the map.
- Use different stretch options (e.g. between 900 and 950). What do you see?

To see all buildings you can also make a hillshading image, by using a filter,. A shadow filter applies artificial illumination (from the Northwest) to the DEM. As a result, higher parts in the DEM become more pronounced because they obtain a shadow.

Filtering : Filtering is an image processing technique, which can also be applied to continuous surface maps such as DEMs. A filter is an odd sized matrix moving over a map and applying a certain function on the pixels it considers (e.g. the avg3x3 filter considers 9 pixels at a time, until the whole map is done). The answer of the function is assigned to that pixel in the output map which was currently the at the center of the matrix. The output value for each pixel thus depends on the value of the pixel itself and on the values of its neighbors

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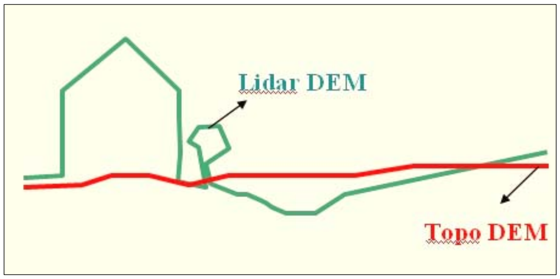
- Generate a hillshading image from the Lidar map. Use *Operations > Image processing > Filter*. Select the raster map LidarDEM and the linear filter **Shadow**. Name the output map: **Shadow**. Use precision of 1.
- Display the map **Shadow**, using a gray representation, and stretch between –25 and +25. When you zoom in you will now be able to see the individual buildings
- Open the high resolution image: **High_res_image** and compare this image with the hillshading image **Shadow**. Zoom in on the stadium in both images. You will be able to see recognize in detail the same features.

In principle the difference between the Lidar Digital Surface Model (representing the height of all objects, including buildings and vegetation) and the Digital Terrain Model (TopoDEM made by interpolating the contourlines) represents the height of the objects in the area. Therefore we can analyze the building height by subtracting the two Digital Elevation Models.



We will do that using a MapCalc formula, that we will write on the command line.

Map Calculation : Map calculation could be considered to core of ILWIS. It uses formulas written on the command line, which operate on maps. For instance: output_map:=Mapa-Mapb. The equations can be of different types. One that is very often used is the IFF, THEN, ELSE equation, which has the form:

Output_map:=iff (A, B, C). Meaning: if A is true, then B, else C.

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- On the command line of the main ILWIS window type the following command:

  Altitude_dif:=LidarDEM-TopoDEM
- Display the result, using a pseudo representation, and stretch between 0 and 10. When you zoom in you will now be able to see the individual buildings and read the height of the buildings.
- Overlay the segment map **Building_map_1997.** What do you conclude?

You can also explore the other data layers of the dataset.

The Pixel Information option allows you to see a lot of information for the same location

Watch Demo 6 for instructions

☞

- Open the **high_res image**.
- Click the Pixel Information button on the main screen 
- Add the maps: **Mapping_units**, **Wards**, **Landslide_ID**, **etc** and select *Options >Always on top*.
- Now browse through the image and try to find out which of the wards you consider to have the highest landslide risk.

Pixel Information :

The pixel information window is a very handy tool that allows you to read many types of information simultaneously, both the spatial data as well as the associated attribute data. The pixel information window can be opened on from the icon on the main ILWIS window. Make sure to select: *Options*. *Always on top*. The maps you want to query are dragged into the pixel information window.

For experienced ILWIS users:

This is an optional exercise, which allows you to test you skills using ILWIS. If you are new to ILWIS, or if there is not enough time, you better skip this part.
The answers for the advanced exercises can be found in the answer sheets on the DVD and/or Blackbaord.

Watch Demo 7 for instructions

Cross operations: performs an overlay of two raster maps. Pixels on the same positions in both maps are compared. These combinations give an output cross map and a cross table. The cross table includes the combinations of input values, classes or IDs, the number of pixels that occur for each combination and the area for each combination.

Calculating the number of destroyed buildings. (do not use ilwis 3.7)

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- Go in the catalog and right click on the polygon map **Mapping_Units** and then *vector operations, attribute map*. Select **Pred_landuse** as attribute and name the output **Pred_landuse**. See the image below.
- Open the polygon map **Pred_landuse** and check the results. Close the map.
- <u>Convert the polygon map to raster map</u>. In the main window of ilwis, go to *operations, rasterize, polygon to raster*. Select the polygon map **Pred_landuse**. Name the output raster map in the same way and use the **Somewhere** GeoReference. See the image below. Click on the Show button to start the rasterizing operations.
- Go to *operations, raster operations, cross* and select the **Building_Map_1997** and the **Pred_Landuse**. Call the output table **Landuse_Buildings**. Do not ignore the Undefs (undifined) values.

Now we need to know which buildings are damaged after the disaster. You can do that aggregating the building pertaining to the vacant damaged area in the landuse type.

Aggregate functions: Is a very important and useful potentiality of ILWIS. You can get one aggregate value, for instance the average or the sum, of a whole column, or one value per group of class names. You can read further explanation about the aggregate functions in the ILWIS guide.

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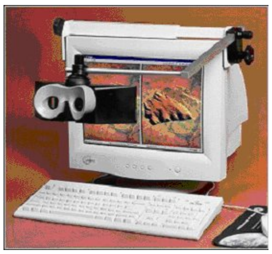
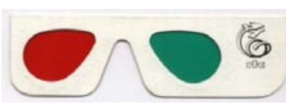
- Open the table **Landuse_Buildings**.
- In the menu of table, go to *column, aggregations* and select the column **Building_map_1997**, use the **count** function and group by the **Pred_landuse**. Create an attribute table called **Building_distribution** and call the output column **Nr_buildings**.
- Open the table **Building_distribution** and check the result. The number of buildings damaged is the value that you can read in correspondence to the class **Vac_damaged**.

Exercise 2. Creating and interpreting multi-temporal digital stereo images.

Expected time:	2.5 hours
Data:	data from subdirectory:/**exercise02**
Objectives:	This 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 interprete the urban development and landslide activity in RickCity from different periods (1977, 1998, 2001 and 2006).





Stereo viewing in ILWIS: A stereo pair allows you to view raster maps, scanned photographs or images in stereo, using a stereoscope mounted onto your monitor or red-green or red-blue glasses (anaglyph). A stereo pair can be calculated:

- with the **Epipolar stereo pair** operation which requires two raster maps with overlap as input, for instance two scanned aerial photographs with overlap; in the output stereo pair you can view the area of overlap in stereo;
- with the **Stereo pair from DTM** operation which a single raster map as input, for instance a scanned photograph or an image, and a Digital Terrain Model (DTM); in the output stereo pair, you can view the whole area of the input map displayed over the DTM in stereo.

A stereo pair is automatically calculated when it is opened for display. The stereo pair then contains:

- two resampled output raster maps,
- where each raster map uses a new georeference which retains original coordinates.

A stereo pair can be displayed:

- in a stereoscope window, while using a stereoscope, and
- as an anaglyph in a map window, while using red-green or red-blue glasses.

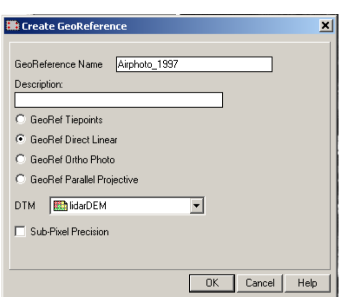
In this exercise we will only generate a stereo image using the option “Stereopair from DTM”, since we have a very good DEM (LidarDEM) which includes also the buildings and will allow to give optimal results. Input data:

Name	Type	Meaning
Image data		
Airphoto_1977_original	Raster	Scanned airphoto from 1977 imported into ILWIS
Airphoto_1977_ortho	Raster	Orthorectified airphoto, after generation of a georeference direct linear and resampling to the common georeference of the area.
Airphoto_1977	Stereopair	Stereopair generated from the Airphoto_1977 and the Lidar DEM. It can be visualized using a screen stereoscope or using anaglyphs
Airphoto_1998_ortho	Raster	Orthorectified airphoto from 1998 taken just after the landslide and flood disaster, made after generation of a gereference direct linear and resampling to the common georeference of the area.
Airphoto_1998	Stereopair	Stereopair generated from the Airphoto_1998 and the Lidar DEM. It can be visualized using a screen stereoscope or using anaglyphs
Image_2001_ortho	Raster image	This represents a high resolution colour image derived from an IKONOS image. It has been orthorectified, and resampled to 1 meter. The original colour image was converted to black and white, in order to display it using anaglyphs
Image_2006_Original	Raster image	High resolution image downloaded from Google Earth, which can be georeferenced and resampled in order to use it for the stereo image interpretations.
Altitude data		
LidarDEM	Raster map	This is a Digital Surface Model which has been derived from a laser scanning flight. The original data points have been interpolated into a 1 m raster map.
Landslide data		
Landslide_boundaries	Segment	Landslides in the study area, interpreted from the available images
Landslide_ID	Point map	Points within each of the interpreted landslides with associated attribute table
Landslide_ID	Table	Attribute table with information on the landslides in the area.
Other data		
Building_map_1997	Segment map	Boundary lines of the buildings in the area. Can be used to assess the quality of the orthoimages.

Georefencing an image and making an orthoimage

Note: if you are not interested in learning how to generate an ortho image, you can simply skip this part of the exercise and go to the part dealing with the generation of the stereo images.

Georeference Direct Linear : It is recommended to create a georeference direct linear when you have small format photographs, i.e. photographs taken with normal camera and photographs without fiducial marks, the terrain covered by the photograph has clear height differences, i.e. you need to correct for tilt and relief displacement, a Digital Terrain Model (DTM) of the area is available. By creating a georef direct linear and displaying the photograph, you can for instance directly digitize on the displayed non-rectified photograph on your screen.
A georef direct linear is calculated by a Direct Linear Transformation (DLT):
Row = (aX + bY + cZ + d) / (eX + fY + gZ +1)
Col = (hX + iY + jZ + k) / (eX + fY + gZ +1)
A georef direct linear requires at least 6 tiepoints (also called control points). For each tiepoint, RowCol numbers from the photograph and real world XY-coordinates are stored. Height (Z) values can be supplied by the user, otherwise these are obtained through the XY-coordinates from the DTM. The flying height, the camera projection center (X0, Y0, Z0), the camera axis angles (a, b, g) with the X, Y, Z axes are calculated from the tiepoints.



A georeference defines the relation between rows and columns in a raster map and XY-coordinates. The location of pixels in a raster map is thus defined by a georeference. It is advised that raster maps of the same area use the same georeference. A georeference uses a coordinate system which may contain projection information. Polygon, segment and point maps merely use a coordinate system. A georeference is a service object, usually for several raster maps.

There are five main types of georeferences:

- **georeference corners**: a North-oriented georeference to be used during rasterization of vector data or as the North-oriented georeference to which you want to resample maps;
- **georeference tiepoints**: a non-North-oriented georeference to add coordinates to a satellite image or to a scanned photograph, a scanned map, etc. without using a DTM;
- **georeference direct linear**: to add coordinates to a scanned photograph while using a DTM;
- **georeference orthophoto**: to add coordinates to a scanned aerial photograph while using a DTM and camera parameters;
- **georeference 3D**: to create a three dimensional view of maps.

Normally, the use of orthoimages is the best for the generation of stereo images. An orthophoto is a rectified (North-oriented raster map with square pixels) scanned photogrammetric aerial photograph with corrections for tilt and relief displacement. An orthophoto is obtained by resampling a photograph which has a georef orthophoto to a georef corners. In order to be able to generate an orthoimage specific information on the camera that was used for the airphoto flight is needed. Unfortunately this information is not available in our case. Therefore we will use the other option: georeference Direct Linear.

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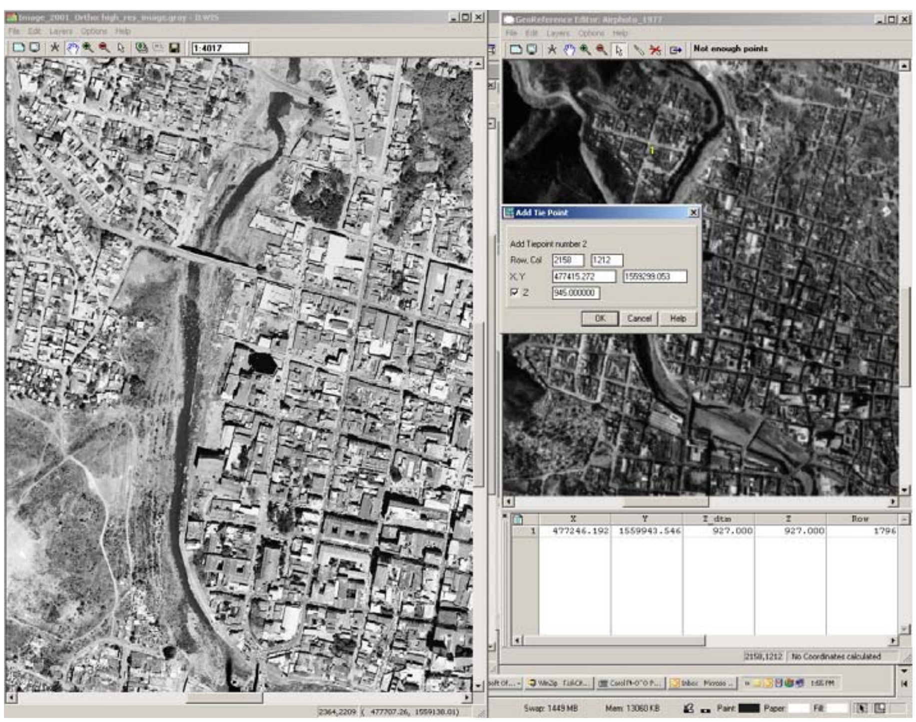
- Open the image Airphoto_1977_original.
- Select *File/Create/Georeference*. Select **Georeference Direct Linear**. Select: *DTM*: **LidarDEM**. *Georeference name*: **Airphoto_1977**.
- The georeference window now opens. Open also the map **Image_2001_ortho**, and arrange the two windows in a similar way as indicated in the figure displayed on the next page.
- Find a similar point in the two images. Zoom in large enough. Select the point in the right image, then select the same point in the left image. Then click the button Z in the Add Tie point window. Click OK
- Repeat this for at least 10 tiepoints. Check whether the sigma is acceptable (should be less than 1 ideally).

Watch Demo 8 for instructions

Tiepoints distribution : It is important to distribute equally the Tiepoints over the image, do not leave empty zones, and fix with the tie points the area near the corner of the image. You can see in the next image to have an idea on how distribute the Tiepoints. In this exercise we will use only 10 tie points but it should be a good habit use about 20 Tie points.



After generating a georeference direct linear with sufficient accuracy, you can then proceed by resampled the airphoto from 1977 to the common georeference used for all the data. This georeference is called “Somewhere”.

☞

- Select *Operations/Image Processing/Resample*. Select *Raster Map*: **Airphoto_1977_original**. Select *Output raster map*: **Airphoto_1977_rectified** *Georeference name*: **Somewhere**. *Interpolation method*: **nearest neighbour**
- The calculation will take some time. Display the end result and overlay the building map on it to check how good it is.

Creating a stereopair from a DEM.

Stereopair from DTM:
Look angle: The input raster map will be projected twice on the terrain; the input map will be resampled into a left output raster map and a right output raster map. The shift between the left and right output map is determined by the specified look angle. The look angle thus determines the angle by which the left and the right output map are projected over the terrain.
Look modus: You can choose to divide this look angle equally over both output maps (look modus Both), i.e. when the look angle is specified as 30°, the left output map will be projected at 15° left over the terrain, and the right output map at 15° right.
You need to provide a *reference height,* that is the altitude (of the DTM) that should appear at the level of your screen when viewing the stereo pair.
When viewing the stereo pair, larger height values in the DTM will appear 'outside of your monitor', while smaller height values in the DTM will appear 'inside your monitor'.

The Stereo pair from DTM operation creates a stereo pair from a single raster map and a Digital Elevation Model, which can be of the Terrain (DTM) or can be of the surface including the objects (DSM). In our case we are using a DSM: LidarDEM. As input is needed:

- a raster map that you wish to display over the terrain, for instance a scanned aerial photograph, a satellite image, or a 'normal' raster map;
- a Digital Terrain Model (DTM), i.e. a raster map with height values. A DTM is also known as a Digital Elevation Model (DEM).

☞

- Select *Operations/Image Processing/Stereopair from DTM*. Select *Raster Map*: **Airphoto_1977_ortho**. Select *DTM*: **LidarDEM** *Output stereopaire*: **Photo_1977**. *Accept the default settings.* Click show.
- The calculation will take some time. The end result will first display as dual window. Close this and then select the stereopair **Photo_1977** in the catalog, right click**,** *visualization, as anaglyph*. Use the option: **Red-Blue**.
- Display the end result as Anaglyph and overlay the **building_map_ 1997** by **s**electing *Layers/Add Laye*r and check how good it is. .

Stereo pair: **Photo_1977**

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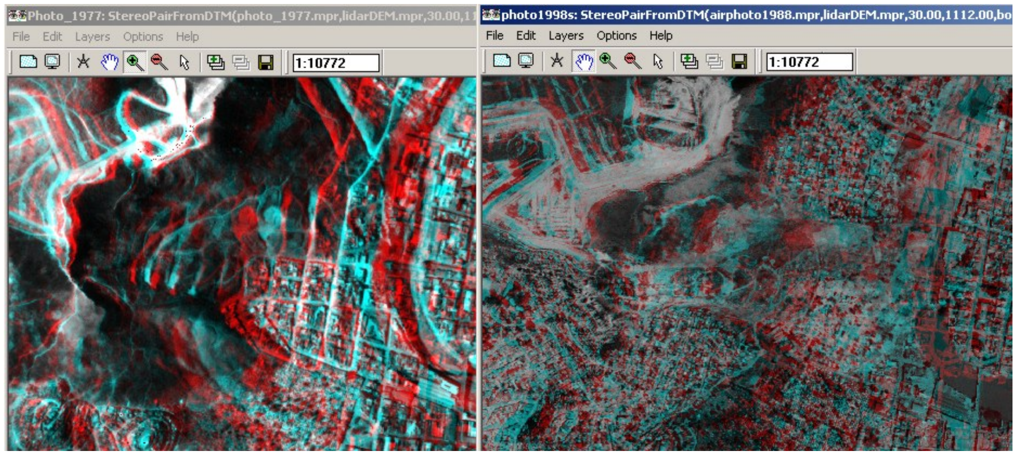
- Repeat this also for the other 3 periods: 1998, 2001 and 2006. Display two anaglyph images of the same area next to each other (see below) so that you can compare the images well.

After this you have obtained 4 stereopairs for RiskCity: Photo_1977, Photo_1998, Image_2001 and Image_2006. These can now be used in the image interpretation.



Creating a stereopair of a Lidar image.

It is also possible create a stereopair of a lidar image using the lidar itself as a DEM. As image we will use the hillshade of the lidar, then convert in an image and then create a stereopair from it. This procedure will generate a stereopair images where you will be able to easily appreciate the morphologies of the area.

☞

- Go to *operations, image processing, filter* and select the raster map **LidarDEM**, the filter type **linear** and the filter name **Shadow**. Call the output map **Hillshade_lidar**.
- When you visualize the **Hillshade_lidar**, use the **gray** rappresentation.
- Chose the stretch that you think shows better the object on the area. (we used a stretch between -20 and 20).

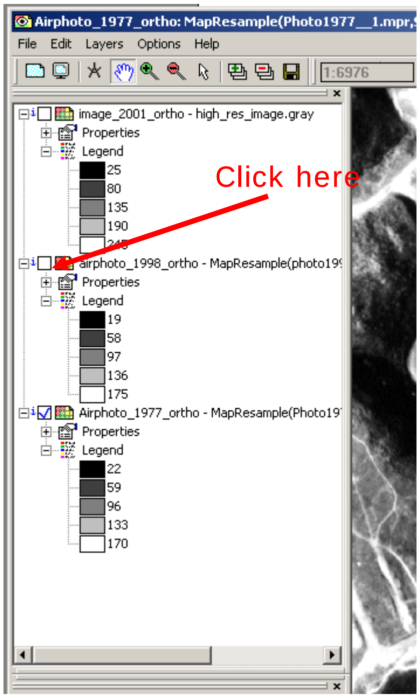
Anyway this stretch is only on visualization and so is temporary. It means that if we close the map and we open again we will lose the stretch applied before. In order to have a fix image stretched we need to apply the permanent stretch.

☞

- Go to *operations, image processing, stretch*. Select the raster map **Hillshade_lidar**, the **linear** stretch, and select stretch from -20 to 20, the domain **image**, and call the output **stretch_hillshade_lidar.**
- Show the result map.
- We can now create the stereopair. Go to *Operations, Image processing, Stereo Pair from DTM*. Select the raster map **stretch_hillshade_lidar**, the **lidarDEM** as DTM and call the output **Lidar_stereopair**.
- Show the results and try recognize them.

Comparing datasets from different dates

With ILWIS it is also possible to compare different orthoimages by displaying them in the same map window, and click the display button on and off. We will do this with three images: Airphoto1977_ortho, Airphoto_1998_ortho (taken just after the disaster event) and Image_2001_ortho.



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- Display the image **Airphoto_1977_ortho**. Stretch between 22 and 170.
- Select Layers, Add Layers and select the image **Airphoto_1998_ortho** Stretch it between 19 and 170.
- Select Layers, Add Layers and select the image **Image_2001_ortho** Stretch it between 25 and 245.
- Deselect in the left part of the window the boxes to display the last two images. Now you only see **Airphoto_1977_ortho**. By clicking the box of **Airphoto_1998_ortho** on and off you can compare the same areas in both images.
- You can do the same for **Image_2001_ortho**. This way you can compare two dates quite well.
- You can also add the segment maps **Building_map_1997**, and **Landslide_boundary**

n changes between the three images:

	1977 to 1998	**1998 to 2001**
Main differences in urban areas		
Main differences in morphology		

Mapping from digital stereopairs

Interpeting a digital stereopair:
Since the stereopair has a georeference it is possible to everlay vector information, and use the 3-D information for interpretation. You can directly screendigitize over the 3-D image. This might gie some difficulties in those cases where there is a high difference in elevation. The vector files projected over the terrain do not have an altitude themselves, and appear to be located on the same level. In those cases it is advised to digitize the vector files on top of the ortho image and compare with the stereo image.

The Stereo pairs that were generated in the previous exercise can now be used to interprete the urban development and the landslides in the various images. We will concentrate here only on the 1977 photos, and 1998. The 1977 image gives the best picture of the situation prior to the landslide events, and also since the building density is not so high, allows to best map the old landslides in the area. The photo from 1998 was taken just after the events, and shows the best result for landslide interpretation

☞

- Open the stereo pair **Airphoto_1977***as anaglyph with Red-Blue colour. Use the anaglyph glasses.*
- Overlay the segment map: **Landslide_boundary**. Now you can compare the landslides that you see in the image with those interpreted in the landslide map.
- Also display the point map **Landslide_ID** , select single symbol, and make them with yellow colours. Each point is related to a landslide component (scarp or body).
- When you double click on a point, the attribute information for that landslide appears. You can now check the activity information, and you can adjust it whenever needed.
- Open also the stereo pair **Airphoto_1998**. Now you can compare the landslides and the flood event for the two periods, and adjust the attribute information
- Discuss the interpretation with your neighbor and outline those landslides where you don't agree on the classification.

Optional: Downloading a high resolution image from Google Earth

Note: if you are not interested in learning how to download an image from Google Earth, or if there is no Internet connection, you can simply skip this part of the exercise and go to the part dealing with the generation of the stereo images.

Hazard and risk assessment should be based on multi-temporal image interpretation and extensive fieldwork. It is important to try to get as many images from different dates as possible. Old images are very useful as they depict the situation which cannot be verified anymore in the field. Also the interpretation of old images allows to identify terrain features like landslides better in many urban area, as there wasn't as much urban expansion as there is today. Also recent imagery is very important as a basis for the field data collection. One important source of information can be Google Earth, which contains high resolution imagery for many parts of the world, including the RiskCity area (Tegucigalpa)

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- Open Google Earth
- If you don't have it installed you might like to try the trial version of the Goolge Earth Pro, which allows to download high resolution images. Go to: http://earth.google.com/intl/en/product_comparison.html
- Navigate to Tugucigalpa/ Honduras
- Zoom in in such as way that the screen covers the same area, as used in the exercises. Make sure to exclude the terrain option and all the text features.
- Before to save the image, make sure that the Navigation command is deselected. Go to *View, show Navigation*, and select *never*.
- Select File / Save/ Save Image (If you use Google Earth Pro select the largest file size). Save the file as Google_earth.jpg
  - Change the extension of the raster image Google_earth.jpg in Google_earth.TIF, or Google_earth.BMP. You can use some software as "paint" for example.
- Exit Goolge.Earth and open ILWIS. Import the file Google_Earth.jpg and convert it to ILWIS format (go to *import, map*, and select the extensions needed)
- You can then use the ILWIS georeference option to make a georeference tiepoints.
- (The procedure is the same of the next exercise, but you start opening the image Google_earth instead of Airphoto_1977_original.

For experienced ILWIS users:

If you have never digitized with ILWIS before it is better not to do this now. There will be another exercise where we will digitize (exercise 4A on the generation of an elements at risk database) which will explain the digitizing procedure in detail.

Vector Data Editing: It is possible to edit the polygon maps, segment maps, and point maps. A polygon map is created by a closed polyline and a label point in it. The point has to be given the attributes of the polygon.
Please consult the ILWIS guide for further explanation.

For experienced ILWIS users:

Editing the landslide map and updating it.

- You can improve the landslide inventory map by changing the segment in the file **Landslide_boundary**, and also changing the label points in the point map **Landslide_ID**.
- For the editing of segments, check the ILWIS help first on the most occurring problems. Make sure to connect all lines well. Use Check segments to check the results before proceeding.
- For the editing of the point data, make sure that each landslide part will have a unique ID. For new landslides you will have to add new ID's to the domain Landslide_ID, while digitizing new points. Make sure what the last ID value was before making a new one. Also update the information from the attribute table.
- Once you have edited the segment and point files you can generate the polygon file, and later rasterize this.

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- Overlay the **landslide_boundary**, and the **landslide_id** on a stereopair. To edit the segment map **Landslide_boundary**, go to *Edit, Edit layer* and choose the **Landslide_boundary**.
- Select **Insert Mode** to start to digitize new segments. You can also split existing segments to new ones, and after this "snapping" the new segment at the already existing one.
- Use the **Move Point** button to change the position of the points.
- Use the **Select Mode** button to select the object (segments or points).
- Click on the **Exit Editor** button when you finish.

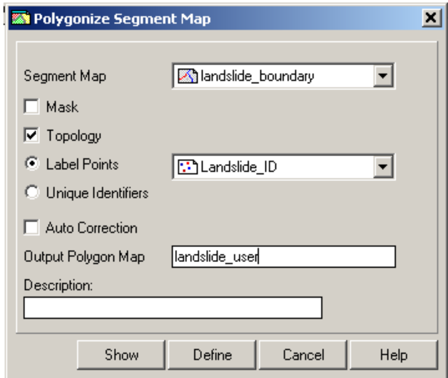
After having digitized the segments, you have to label them by creating label points. Digitize this label point somewhere in the middle of each segment.

It is very important that the polygons described by this segments, must to be closed.

☞

- To edit a point map, go to: *Edit, Edit layer* and select the **landslide_id** map. Use the same buttons as to be used for the editing of segments. After you insert a new point you have to type the new id. A window will automatically open. Select in this window the attributes of the landslide represented by the point just entered.

Before polygonizing a segment map with the label point, it is of extreme importance to check all segments first for errors. You have to remove in a careful – and sometimes time consuming way ! all the errors of the segments.



There are 4 types of errors possible digitizing a segment map:

Dead end in segment: The segment is not connected ("snapped") to another segment.

Intersection without node: The segment overlays another segment without a node.

The same segment is digitized twice : This may happen in large files, or in files you obtain from someone else.

Self Overlap .

☞

- In the catalog right click on the **landslide_boundary,** end select *edit*. From the menu of the editor, go to *File, check Segment* and select first **Self Overlap**. Correct the errors using the editing button.
- Check also the other kind of error in File, check segment.
- When there are not more errors you can convert the segment map into a polygon map. Right click in the catalog on the **landslide_segment**, *vectorize, segment to polygon*. Call output **Landslide_user**. See the image left.

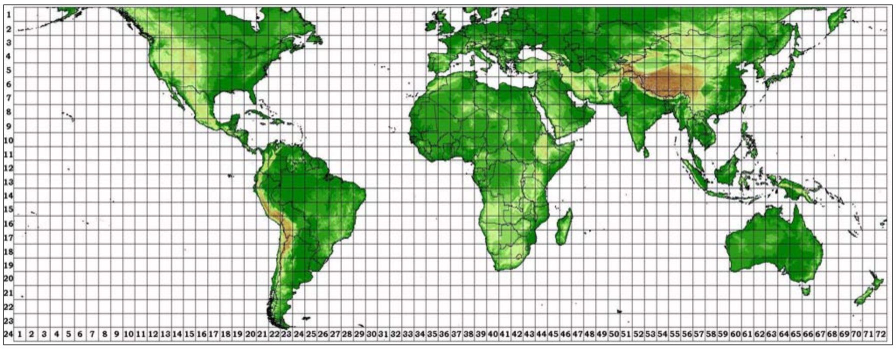
Download of Shuttle Radar Topography Mission data (SRTM) & import in ILWIS.

Global SRTM 3 arc second elevation data can be downloaded for free from the *CGIAR-CSI website: http://srtm.csi.cgiar.org/*. The data is already pre-processed to 90 meter pixels in GeoTIFF. This means that is has already a georeference of the World Geodetic System 1984, and Ellipsoid WGS1984.

A downloaded example SRTM data file is provided from the RiskCity area in Honduras (filename: RiskCity_SRTM). If the speed of your internet connection is fast enough, you can try to download SRTM data yourself.

First you select the SRTM tile to be downloaded on a global map; after this you download the data. The data, after being unzipped can be imported directly into the ILWIS program. Further processing can be carried out in the Hydro -DEM modeling module of ILWIS. In this module we can make a color hill shade, with good terrain expression.

More information on SRTM: http://srtm.usgs.gov/



A. Coordinates of area to be downloaded

First you select the coordinates in **Lat. / Long**. of area to be downloaded from the CGIAR website.

RiskCity (Tegucicalpa, Hond)	**Latitude**	**Longitude**	**UTM X (Zone 16)**	**UTM Y (Zone 16)**
Upper Left corner	14^{0} 15’ 00” N	88^{0} 00’ 00” W	448.000	1.570.000
Lower Right corner	13^{0} 30’ 00” N	87^{0} 00’ 00” W	497.000	1.532.000

Own study areav (optional):

Upper Left corner				
Lower Right corner				

B. Download of SRTM data from the CGIAR-CSI website

The SRTM data file has to be downloaded from the CGIAR-CSI Website in blocks of 5 x 5 degrees. Please note that the GeoTIFF data has an extension **tif** (so, without "Geo") This file in WGS 84 with Lat. / Long. Coordinates. Make sure that the ***.tif** file has the header file and ***.tfw** file attached to it.

☞

- Browse to the **CGIAR-CSI website**: [***http://srtm.csi.cgiar.org/***](http://srtm.csi.cgiar.org/)
- Select under **SRTM Content**: ***SRTM Data Search and Download***
- Select the Server to download from, the Data Selection Method and the File Format. You start with the following options: (later you can try different ones).

  <u>Remark:</u> Try first the server **JRC (IT)**, which gives also the header files for the WGS84 Datum.

  - Server: **JRC (IT)**
  - Data Selection Method: **Input Coordinates (Decimal Degrees** or **Degrees, Minutes, Seconds)**
  - Type from **Longitude** and **Latitude** the **Min**. and **Max**. values.
  - Select File Format: **GeoTIFF**
- If done select: ***Click here to Begin Search.***
  A next webpage opens with Quick-looks and image information of the selected area(s). Check the areas you want to download.
- Select for the tile(s): ***Data Download (FTP)***.
- Select: ***Save*** in the File Download window. Create one folder for all the SRTM data tiles.
- UNZIP the tile data. Make sure that not only the ***tif** file, but also the files ***.hdr** and ***.tfw** are given. (See example). .

Name	Modified	Size
readme.txt	9/19/2008 3:05 PM	2,479
srtm_19_10.hdr	9/20/2008 8:37 AM	1,140
srtm_19_10.tfw	9/20/2008 8:37 AM	156
srtm_19_10.tif	9/20/2008 8:37 AM	72,096,675

  Unfortunately this is not always the case with **TelaScience (USA)** and **AGDevSolutions**. <u>Therefore use **Server JRC IT** first.</u>
- Open the ***hdr** with Word. Read the details of the SRTM data.

C. Import and display of SRTM GeoTIFF data in ILWIS (Version ILWIS 3.6)

GeoTIFF data can be easily imported in the ILWIS program. The resulting file will still have Lat / Long coordinates and a pixel size in degrees. This size is 3 Arc Seconds, corresponding in the UTM coordinate system with approximately 92 meters.

☞

- Open the ILWIS program
- Browse with the Navigator to the folder with the downloaded and unzipped SRTM data
- Select in the ILWIS Main menu: ***File > Import > ILWIS***
  - Select : Raster
  - Select :Tagged Image File format
  - Input: srtm_tif
  - Output: default
  - Click: ***OK***
- Display the SRTM by double clicking the Raster Map icon. Select in the Display – Raster map window:
  - Representation: ***Elevation 1***.
  - Check Box: ***Info***
  - Stretch: ***Linear***
  - Leave all other values default
  - If done: ***OK***
- Browse with the cursor through the display of the SRTM DEM. The values are in meters altitude
- Click in the Properties of Raster Map window the pixel size and the Corner Coordinates. The pixel size and Coordinates are still in degrees and not yet in UTM WGS84 with meter values. The Domain should be made **Value**.

D. Creating a subset in UTM WGS 84 and 90 meter pixels

To give the data UTM coordinates in meters in stead of Lat / Long and degrees, the dataset has to be resampled to a new **GeoReference**. First a ILWIS C**oordinate system** has to be created. Finally the dataset has to be **Resampled** to a pixel size of 90 meters.

☞

- Select in the ILWIS Main menu: ***File > Create > Coordinate System…***
- Select or type in the Create Coordinate System window:
  - **Coordinate System Projection**
  - Type the **Coordinate system name**
  - If done: ***OK***
- Select in the Coordinate System Projection window:
  - Tab Projection: select: **UTM,** if done ***OK***
  - Tab Ellipsoid: select: **WGS 84**, if done: ***OK***
  - Tab Datum: select: **WGS 1984**, if done: ***OK***

Remark: You can find a list with UTM zone zones by searching ILWIS Help. Search for: **Projections: UTM zones**

- If done: ***OK***

For the GeoReference you need to have the UTM coordinates.

☞

- Select in the ILWIS Operation List :Transform Coordinates;

  Input Coordinate System: LATLON
  Input Coordinate : 14^0 15' 00" **N** 88^0 00' 00" **W**
  Output Coordinate system: the newly created coordinate system

Repeat for the other corner coordinates; 13^0 30' 00" N 87^0 00' 00" **W**

Finally create a **GeoReference** from the study area, using **UTM** coordinate system

☞

- Select in the ILWIS Main menu: ***File > Create > GeoReference..***
- Select or type in the Create GeoReference window:
  - **GeoRef Corners**
  - Type the **GeoReference name**
  - Select **Coordinate System** (the one you created)
  - Type the **Pixel size**: 90 (meters)
- Type the **Min X,Y** and **Max X,Y** coordinates in UTM of the study area

Finally the dataset has to be **Resampled** to the **GeoReference**, with a pixel size of 92 meters.

☞

- Select in the ILWIS Main menu: ***Operations > Image processing > Resample.***
- Select or type in the Resample Map window:
  - **Raster Map:** select the downloaded SRTM file in Lat / Long
  - Resampling Method: **Bicubic**
  - Type the name of the **Output Raster Map**
  - **GeoReference:** select the one you created before
  - If done: ***OK***
- Display the newly created SRTM file. Check the **Properties.**

E. Creation of a colour composite hill shade

A special colour hill shade script for elevation data has been developed by Koert. Sijmons, ITC.

☞

- Select in the ILWIS Main menu: ***Operations > DEM Hydro-Processing > DEM Visualization***
- Select in the DEM Visualization window the SRTM data; type the **Output File name**. If done: ***OK***

  A script is used to create the colour-hill shade. This can take some time.
- Study the color hill-shade map. Zoom in and out if you like.

Short explanation of the calculations by the script:

- First three shadow maps are created using the shadow filters ShadowW (West), Shadow (North-West) and ShadowN (North).
- The three shadow maps are stretched using linear stretching.
- The color composite that is created from these stretched shadow maps is a 24-bit color composite.
- Finally, temporary raster maps are removed and the output color composite is displayed.

Exercise 3.a - Frequency Analysis

Expected time:	2 hours
Objectives:	After this exercise you will be able to: - calculate the return period and the exceeding probability of an event - calculate the extreme value distribution by Gumbel method - determine intensity-duration-frequency relationships - plot and interpret a Gutenberg-Richter graph

Floods

Return period / exceeding probability

Percentage probability of the *N*-year flood occurring in a particular period

	N = Return period in years							
Number of years in period	5	10	20	50	100	200	500	1000
1	20	10	5	2	1	–	–	–
2	36	19	10	4	2	1	–	–
5	67	41	23	10	5	2	1	–
10	89	65	40	18	10	5	2	1
20	99	88	64	33	26	10	4	2
50	–	99	92	64	39	22	9	5
100	–	–	99	87	63	39	18	10
200	–	–	–	98	87	63	33	18
500	–	–	–	–	99	92	63	39
1000	–	–	–	–	–	99	86	63

Exercise

1. What can you say about the probability of the occurrence of Q50 during the next 100 years and during the next 5 years?
2. What about the probability of the occurrence of Q500 during the next 2 years?

   Calculate this probability with the following formula: $R = 1 - \left(1 - \frac{1}{T}\right)^n$

Extreme value distribution by Gumbel method

In this exercise a Gumbel distribution is made. With the help of the outcome, different return periods of rainfall/discharge can be determined. First, an example is given in order to show the procedure. This is followed by an exercise.

Example

For this example the yearly maximum floods of the Clearwater River in Idaho USA are selected (1911-1948) N=38 yrs.

1. Rank the yearly maximum flood values from low to high. So assign lowest rank 1 to the lowest data value and assign the highest rank N to the highest data value. Some authors apply a ranking from high (rank=1) to low (rank=N).

2. Calculate for each observation the left sided probabilities by:

$$P_L = \frac{R}{N+1} \quad \text{Eq 1}$$

Where:
P_L= left sided probability (probability of having less values in the series)
R= is the rank
N= number of observations

3. Determine the return period for each observation.

$$T = \frac{1}{P_R} = \frac{1}{1-P_L} \quad \text{Eq 2}$$

4. Determine the plotting position for each observation.

$$y = -\ln(-\ln P_L) \quad \text{Eq 3}$$

An exercise following this procedure can be solved with a spreadsheet as follows:

Table 1: Original data

Date	Discharge	Date	Discharge	Date	Discharge	Date	Discharge
6-May-11	34600	23-May-19	52000	7-May-31	40800	17-May-39	36400
17-May-11	29400	18-May-20	43600	14-May-31	36500	12-May-40	37100
4-Jun-11	35900	16-Jun-20	42900	16-May-31	36500	25-May-40	29600
13-Jun-11	39500	23-Apr-21	35200	14-Apr-32	28500	13-May-41	28900
21-May-12	55200	20-May-21	69700	14-May-32	72100	14-Apr-42	28900
20-May-12	61900	19-May-22	60600	21-May-32	62200	21-Apr-42	28900
21-Jun-12	38000	26-May-22	52100	13-Jun-32	35100	26-May-42	37100
20-Apr-13	29400	6-Jun-22	62400	15-Jun-32	35100	20-Apr-43	43200
27-Apr-13	30700	8-May-23	38800	27-Apr-33	35800	1-May-43	29600
11-May-13	45800	10-May-23	38800	4-Jun-33	71200	29-May-43	52200
26-May-13	76600	26-May-23	49600	10-Jun-33	81400	11-Jun-43	37100
18-May-14	42200	12-Jun-23	43200	23-Dec-33	43600	19-Jun-43	43200
23-May-14	41500	4-May-24	45600	30-Mar-34	32300	22-Jun-43	40100
3-Jun-14	30700	13-May-24	58900	14-Apr-34	37800	16-May-44	34200
19-May-15	28200	17-Apr-25	41800	25-Apr-34	45900	6-May-45	44400
28-Apr-16	30000	7-May-25	44800	8-May-34	34300	31-May-45	38400
7-May-16	44400	20-May-25	59800	24-May-35	44000	20-Apr-46	33300
5-Jun-16	36600	19-Apr-26	35900	31-May-35	34400	26-Apr-46	33700
9-Jun-16	36600	1-May-26	35900	6-Jun-35	29900	6-May-46	36600
19-Jun-16	56000	21-May-26	32400	19-Apr-36	50600	19-May-46	30000
29-Jun-16	36600	28-Apr-27	46400	5-May-36	49800	28-May-46	36100
15-May-17	63600	17-May-27	64200	15-May-36	63200	4-Jun-46	28300
30-May-17	69700	8-Jun-27	68600	28-May-36	34300	15-Dec-46	33900
9-Jun-17	56800	5-Nov-27	43900	1-Jun-36	32900	8-May-47	69900
17-Jun-17	70500	26-Nov-27	29200	19-May-37	34300	27-May-47	37600
29-Dec-17	37300	9-May-28	65700	28-May-37	32200	9-Jun-47	31200
30-Dec-17	37300	26-May-28	72100	19-Apr-38	63400	18-Apr-48	29400
5-May-18	52800	24-May-29	52700	1-May-38	39400	22-Apr-48	32600
15-May-18	35200	1-Jun-29	28500	17-May-38	31500	8-May-48	33800
10-Jun-18	52800	9-Jun-29	35800	28-May-38	60800	22-May-48	86500
29-Apr-19	30700	25-Apr-30	31000	4-May-39	46400	29-May-48	99000
						22-Jun-48	29600

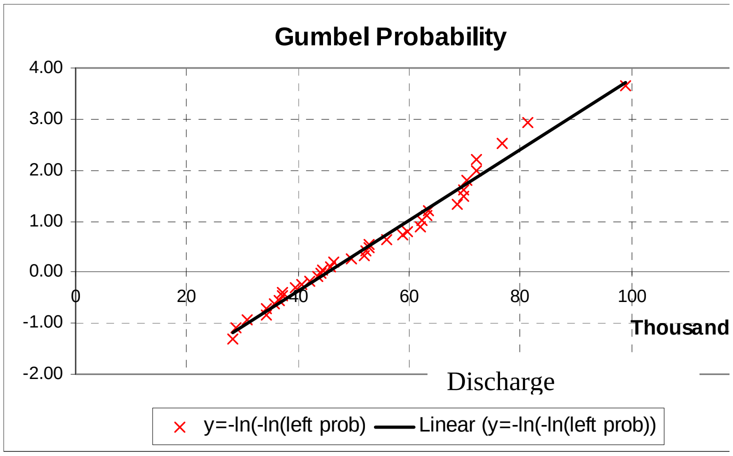
Process

In total 38 years of data. The maximum discharge per year is extracted from the original data and then the steps explained above can be done in a spreadsheet.

Table 2: Sorted values and Gumbel plot

Year	Year Max		Sorted	Rank	Left Prob	TR	y=-ln(-ln(left prob))
1911	39500		28200	1	0.03	1.03	-1.30
1912	61900		28900	2	0.05	1.05	-1.09
1913	76600		31000	3	0.08	1.08	-0.94
1914	42200		34200	4	0.10	1.11	-0.82
1915	28200		34300	5	0.13	1.15	-0.72
1916	56000		35900	6	0.15	1.18	-0.63
1917	70500		36600	7	0.18	1.22	-0.54
1918	52800		37100	8	0.21	1.26	-0.46
1919	52000		37100	9	0.23	1.30	-0.38
1920	43600		39500	10	0.26	1.34	-0.31
1921	69700		40800	11	0.28	1.39	-0.24
1922	62400		42200	12	0.31	1.44	-0.16
1923	49600		43600	13	0.33	1.50	-0.09
1924	58900		44000	14	0.36	1.56	-0.02
1925	59800		44400	15	0.38	1.63	0.05
1926	35900		45900	16	0.41	1.70	0.12
1927	68600		46400	17	0.44	1.77	0.19
1928	72100		49600	18	0.46	1.86	0.26
1929	52700		52000	19	0.49	1.95	0.33
1930	31000		52200	20	0.51	2.05	0.40
1931	40800		52700	21	0.54	2.17	0.48
1932	72100		52800	22	0.56	2.29	0.56
1933	81400		56000	23	0.59	2.44	0.64
1934	45900		58900	24	0.62	2.60	0.72
1935	44000		59800	25	0.64	2.79	0.81
1936	63200		61900	26	0.67	3.00	0.90
1937	34300		62400	27	0.69	3.25	1.00
1938	63400		63200	28	0.72	3.55	1.10
1939	46400		63400	29	0.74	3.90	1.22
1940	37100		68600	30	0.77	4.33	1.34
1941	28900		69700	31	0.79	4.88	1.47
1942	37100		69900	32	0.82	5.57	1.62
1943	52200		70500	33	0.85	6.50	1.79
1944	34200		72100	34	0.87	7.80	1.99
1945	44400		72100	35	0.90	9.75	2.22
1946	36600		76600	36	0.92	13.00	2.53
1947	69900		81400	37	0.95	19.50	2.94
1948	99000		99000	38	0.97	39.00	3.65

5. Using the graphic functionalities of Excel the probability graph can be constructed.



Plot=y	Prob	TR
4	0.981851073	55.09968
3.8	0.977877598	45.20305
3.6	0.973046194	37.10051
3.4	0.967177474	30.46688
3.2	0.960057401	25.03593
3	0.951431993	20.58969
2.8	0.941001954	16.94971
2.6	0.928417664	13.96993
2.4	0.913275261	11.53074
2.2	0.895114927	9.534245
2	0.873423018	7.900331
1.8	0.847640317	6.563416
1.6	0.817179487	5.469846
1.4	0.781455585	4.575729
1.2	0.739934055	3.845179
1	0.692200628	3.24887
0.8	0.638056167	2.76286
0.6	0.577635844	2.367625
0.4	0.511544834	2.047271
0.2	0.440991026	1.78888
0	0.367879441	1.581977
-0.2	0.294816321	1.41807
-0.4	0.224961794	1.290259
-0.6	0.161682814	1.192866
-0.8	0.108008978	1.121088
-1	0.065988036	1.07065

Finally since the 'y' axis is directly related to the probability or the return period, the values are exchangeable. The next step is to replace de values in the 'y; axis by the corresponding of P and Tr. This is not easy task in the spreadsheet so an extra table is built using the equations

$P_L = e^{-e^{-y}}$ and $T = \frac{1}{P_R} = \frac{1}{1-P_L}$

Exercise

For this exercise the maximum daily rainfall per year of RiskCity area is selected (1951-2001) N=51 yrs, see spreadsheet ExerciseFA-RiskCity.

1. Rank the yearly maximum rainfall values from low to high. So assign lowest rank 1 to the lowest data value and assign the highest rank N to the highest data value.
2. Calculate for each observation the left sided probabilities using Eq.1.
3. Determine the return period for each observation using Eq.2.
4. Determine the plotting position for each observation using Eq.3.;
   Plot in Excel (sorted) rainfall (x-axis) versus plotting position Y (y axis); see example above and define the trend line equation.
5. Fill in the box:

Rain for Tr = 10 years	
Rain for Tr = 40 years	
Rain for Tr = 100 years	

Tr for rain = 65 mm	
Tr for rain = 80 mm	
Tr for rain = 90 mm	

6. Is there any outlier in the series?
7. Assuming that there is no error in the measurement, what does this "outlier" mean?
8. How can the outlier be treated?

Intensity-duration-frequency relationships

Example

Determine the design precipitation intensity and depth for a 20- minute duration storm with a 5-year return period for Figure 1.

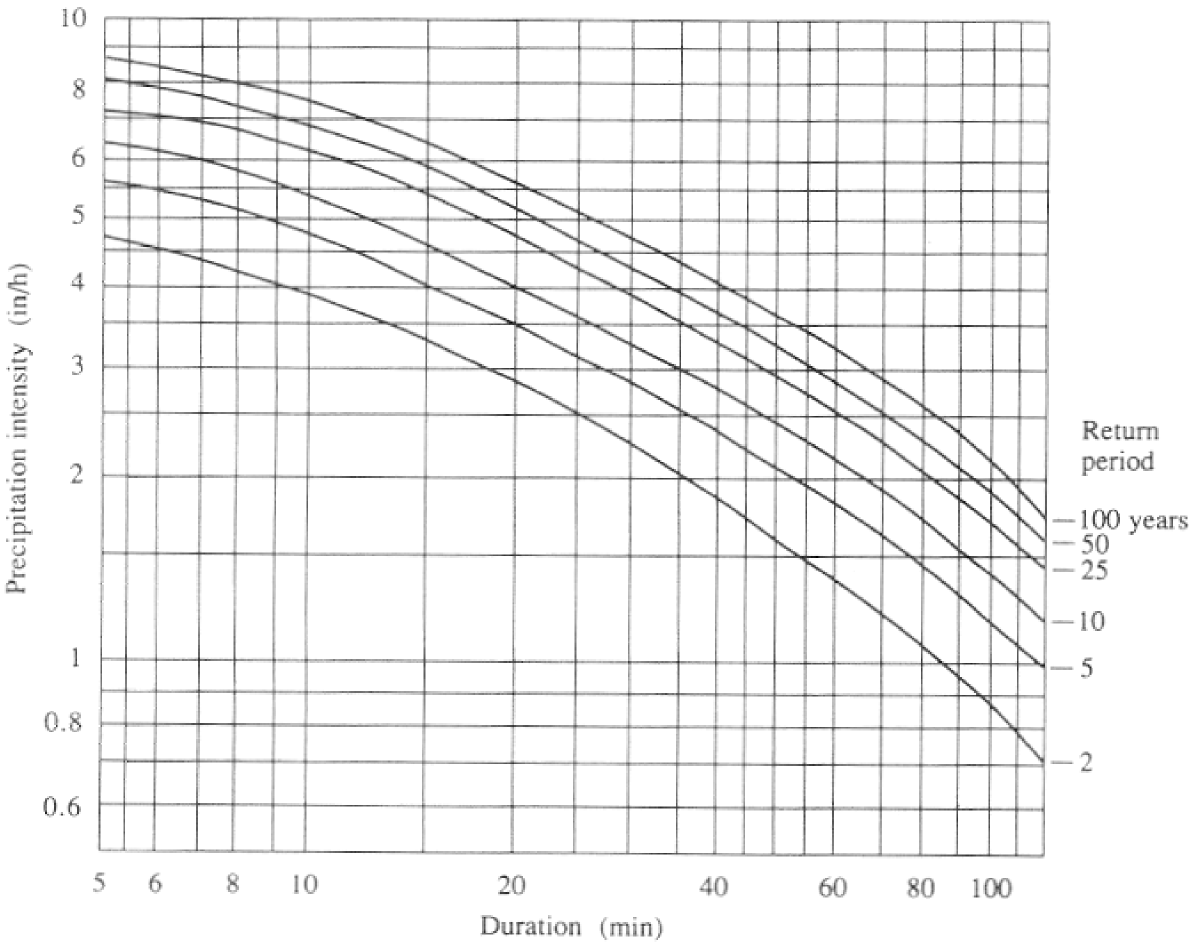


Figure 1: IDF curves are calculated for a certain station and it cannot be extrapolated to other areas.

Solution: From the IDF curves, the design intensity for a 5-year, 20-minute storm is i = 3.50 in/h. The corresponding precipitation depth is given by P= i*Td with Td = 20 min =0.333 h.
P= i*Td= 3.50* 0.333= 1.17 in.

Exercise
The data of RiskCity can be found in the spreadsheet: ExerciseFA-RiskCity.

1. Determine the design precipitation intensity and depth for 80- minute duration storm with a 20-year return period for the RiskCity area.
2. Determine the design precipitation intensity and depth for 10- minute duration storm with a 50-year return period for the RiskCity area.

Earthquakes

THE GUTENBERG-RICHTER RELATION

Concept: By plotting, on a logarithmic scale, the number of earthquakes greater than or equal to a given magnitude in a set period of time against that magnitude, a basic characteristic of the seismicity rate in an area -- the *b* value -- can be determined.

Procedure:
Beno Gutenberg and Charles Richter were two of the pioneers of modern seismology; each contributed greatly to the development of the field as a modern, quantitative science. In the 1930s, as instrumental recording of earthquakes was becoming a reality in many areas of the world, these two scientists described a pattern in the seismic data that related the number of earthquakes in a given area (or around the entire world) over a fixed period of time to the magnitude of those earthquakes. Using Richter's recently developed magnitude scale and the newest instrumental records, they found that the number of earthquakes greater than magnitude 6 that would occur in a given area over, say, 10 years, was proportional to the number of earthquakes greater than magnitude 5 in that area, which was proportional to the number greater than magnitude 4, and so on.

This activity consists of two exercises designed to familiarize you with the "Gutenberg-Richter relation", as the pattern described by these early seismologists came to be known. The exercises are outlined below. Each has its own set of instructions and review questions. Work through each as directed within the exercise itself.

In the first exercise you will be given a set of data to graph. Once you have determined which kind of graph to use and have plotted the data, it will be up to you to figure out the equation that describes the Gutenberg-Richter relation.

In the second exercise, you'll use the NEIC USGS earthquake catalog data to work on your own data set from Honduras.

Exercise 1 ◆ California and the World

Your introduction to Gutenberg-Richter plots will be a relatively easy one. The data will be provided; you only need to determine what sort of graph to make, and then plot the pre-made data sets. You'll start with a set of data from southern California, then plot worldwide totals of earthquakes against this and compare.

For southern California, the data set below was compiled according to the following guidelines:

- Start date: January 1, 1987; End date: December 31, 1996.
- "Southern California" is defined as that area between 32° and 36.25° North latitude, and 114.75° and 121° West longitude.

- Only earthquakes of magnitude 2.5 and greater were used, because the Southern California Seismic Network's (SCSN) database is almost certainly incomplete below this magnitude for the area, as outlined above.

Earthquake Numbers in Southern California, 1987 through 1996

Magnitude (M) Range	*Count per **M** Range*	*Cumulative Total Above Lower **M** in Range*
2.5 - 2.9	9471	13590
3.0 - 3.4	2784	4119
3.5 - 3.9	912	1335
4.0 - 4.4	285	423
4.5 - 4.9	90	138
5.0 - 5.4	32	48
5.5 - 5.9	10	16
6.0 - 6.4	3	6
6.5 - 6.9	2	3
7.0 - 7.4	1	1

Before you can do any graphing, you'll need to decide what type of graphing scale to use. Choose a simple x-y plot, with magnitude **M** as the x-axis and number of earthquakes greater than magnitude **M** as the y-axis.

Note that the x-axis data, the magnitudes, are very much linear in scale, increasing in half-unit steps. However, look how greatly our y-axis numbers change -- we'll need to plot the number 1 and the number 13590 on the same graph! If we used a proportional linear scale for each axis, the y-axis would be huge, while the x-axis would be miniscule!

But note that numbers we want to plot on the y-axis jump about a factor of ten for every unit in magnitude increase. This suggests that we could use a y-axis based on powers of 10, or a **logarithmic** scale, while we use a linear scale for the x-axis.

Introduce the data above in an excel sheet. You are now ready to begin making your first graph of the data set above. Do so now. Remember to pay attention to the scale for each axis, but don't worry too much about making your points exact. When you finish plotting the data, work through the questions below.

1. In roughly what form did the points you plotted fall? (What shape or pattern?) Or are they completely random, with no form at all?
2. You should see a roughly linear arrangement of points. Using a straight edge (after printing your graph) , draw a single line that best represents the set of points you've plotted. That line does not need to run through the centre, or even touch, all of the points in your set.

You now have a line that represents the data you graphed -- the numbers of earthquakes with respect to magnitude over 10 years in southern California (1987-1996). You are ready to describe the Gutenberg-Richter relation just as the two of them did, decades ago.

The equation for a line on a simple x-y plot is **y = bx + a**, where **a** is the y-intercept and **b** represents the slope of the line. To keep **b** positive at all times, we can think of the above equation as true for positive-sloping lines (going up as you move left-to-right), and the equation **y = a - bx** as true for negative-sloping lines.

3. Is the slope of your graphed line positive or negative?
4. Your graph has a y-axis that is logarithmic. Thus, a negative-sloping line on this graph would be described as **log y = a - bx**. Indeed, instead of calling it the y-axis, think of it as a function **N** of the magnitude, **M**, which itself can be substituted for x (since the x-axis is magnitude). Make these substitutions in the equation given above. What do you get?

You now have a mathematical expression that represents the Gutenberg-Richter relation, the correlation between the magnitude of earthquakes and their relative numbers. It should look something like

$$\log N(\mathbf{M}) = a - b\mathbf{M}$$

Had you come up with this 70 years earlier, this expression might have been named after you!

But do all data sets of earthquakes counted according to magnitude plot in this same linear manner? And even if they are all linear, does the slope of different sets vary significantly?

To begin to answer these questions, let's plot another set of data -- this time, the average values of an entire year's worth of worldwide seismicity. Using that same piece of graph paper you used to plot the southern California data set, plot the set of data given in the table below, then answer the questions that follow.

Average Worldwide Seismicity Totals for a Single Year

Magnitude (M)	*# Greater Than* ***M***
3.0	100000 +
4.0	15000
5.0	3000
6.0	100
7.0	20
8.0	2

5. Did this set of data plot as a line, too? If you haven't already, draw a line that is the best fit for these new data points.
6. How does the slope of this new line (worldwide seismicity) compare with that of the southern California data?

Use a ruler to actually measure the slope of each line you graphed. Pick any segment of each line and sketch out a right triangle, with the legs parallel to the axes, and the line itself forming the hypotenuse. Measure the height of the vertical side of the triangle and divide this by the length of the horizontal side. Your answer will be the slope of the line, otherwise known as the ***b* value**.

Another way to find the ***b* value** is to note the value of N(**M**) at each of two points along the line, exactly one magnitude unit (i.e. in the x-direction) apart. Divide the larger number (the point on the left) by the smaller number (the point on the right), and then take the logarithm of this quotient. That answer is the ***b* value** of this line.

7. Using whichever method you prefer, what numerical values do you get for the *b* value of each line?

As it turns out, when Gutenberg-Richter plots are made for various data sets all over the world, most end up having a *b* value very close to 1, usually slightly less. This basic relation seems to be a universal property of seismicity.

Exercise 2 ◆ Seismic hazard in Honduras

In this exercise, you will again be making a Gutenberg-Richter plot for Honduras. This time, however, you will not be provided a pre-formed data set; you must sort and bin the data yourself! The data is already collected for you (see Honduras_EQ.xls). You will need to use the histogram function (“tools > data analysis”). If not installed, please go to “tools > add-ins > and select “analysis toolpack”. Now you will find under tools the ‘data analysis’ option.

In excel 10: File> Options > Adds-Ins> Analysis Toolpak and Analysis Toolpak VBA
Click GO > Check/ Select both Analysis Toolpak and Analysis Toolpak VBA and Click OK
Go to the tab Data here you find now Data Analysis> Select histogram

Do the following:
Create on your excel sheet a separate list of bin-ranges that you would like to use. You can use as example the bin-ranges as used in exercise 1.

Use filter to delete the blanks.

- Select the histogram option from “tools > data analysis > histogram”.
- Select as input the data you would like to investigate (magnitude), select as bin-range the bin-values you have created, as output you can select a separate sheet or in your present sheet.
- Calculate Gutenberg-Richter relationship for the whole catalogue. If you haven't already, draw a line to best fit your set of graph points. Then measure

the slope of this line. What is the *b* value of this data set (to the nearest tenth)? Compare this with the values observed for the World and California.

- Calculate now the Gutenberg-Richter relationship for:

  1. period till 1980
  2. period between 1980 till 1990
  3. period between 1990 and 2000
  4. period from 2000 till present

  Do you observe any differences for the various periods (in terms of completeness, overall seismic activity, *b* values?

Session 3.C Task 3-A

Hazard analysis of cyclone flooding in Bangladesh

***Part A**: Analysis of historic cyclone events*

Expected time:	1.5 hour
Data:	Data file: **3C Task 3 CycloneHazardModelling.zip**
Objectives:	After this exercise you will be able to: **-** understand how to analyze historic cyclone events; - analyze cyclone data using Table Calculation on surge height, wind speed, number of casualties, etc; - display the results in graphs.

1. Introduction

During the years 1797 to 1991, Bangladesh was hit by 59 severe cyclones, of which 32 were accompanied by storm surges. Concerning 20 of these cyclones, information for the whole of Bangladesh is stored in the ILWIS table Landfall on Wind Speed, Wind Surge height, number of Casualties, Tidal Height during the event, etc.

Despite the fact that the Bangladesh Government issued warnings of the impending flooding, for the April 1991 cyclone, through its Cyclone Preparedness Program, and about 3 million people moved to safety, many inhabitants remained behind to protect their property.

During this disaster an estimated 138.000 people were killed and large numbers of houses, agricultural lands and infra-structural works were destroyed. Hundreds of schools were damaged and seven to eight thousand vessels were lost. Almost every bridge and culvert in the area was damaged and roads were washed out.

Within two days government air drops of food and medicine started, but they were hampered by continuing bad weather associated with the storm. Nearly two weeks had passed before massive international aid could react to the disaster and it was many months before the area returned to normal.

The Banskhali study area is situated in the East of Bangladesh, South of the city of Chittagong. Maps and attribute tables are given of the geomorphology, village population, the Union-districts, roads, embankments, cyclone shelters, and the elevation of the terrain with centimeter accuracy. Also available are Landsat Thematic Mapper and (scanned) SPOT panchromatic satellite images. For a general introduction you can make use of a geomorphological overview map of the whole coastal zone of Bangladesh as well as ten ground photographs of the Banskhali area.

In Part A of Task 3 you will display graphically the relationships between the data in the different attribute columns for the whole of Bangladesh. This will be repeated for the Chittagong coastal zone after a selection has been made using TableCalculation in ILWIS. Finally the return period is given for the cyclone events, as calculated by Khan (1995).

Some GIS files are derived from:

– Sirajur Rahman Khan (1995) - "Geomorphic Characterization of cyclone hazards along the coast of Bangladesh", ITC - MSc study.

Other important information on the area has been taken from:

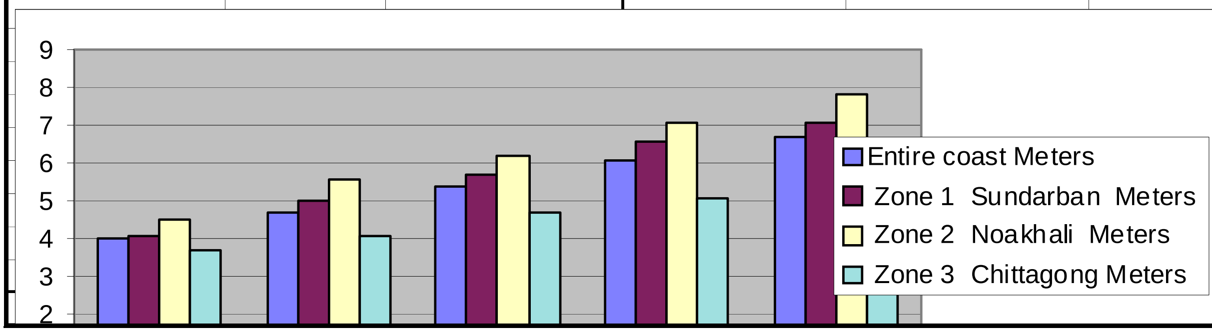
– "GIS technology for disaster management", prepared by the Irrigation support project for Asia and the Near East (ISPAN), as contribution to the Bangladesh Flood Action Plan (FAP19); and

– Stephen T. Ray (1994) - "An assessment of the potential of applying GIS to two aspects of disaster management: Storm surge modeling and Cyclone shelter analysis". MSc thesis of the University of Nottingham, UK

Table 1:

Cyclone Surge Heights for different coastal tidal zones and different return periods

Return Period	Entire coast	Zone 1 Sundarban	Zone 2 Noakhali	Zone 3 Chittagong
Years	Meters	Meters	Meters	Meters
5	4	4.1	4.5	3.7
10	4.7	5	5.6	4.1
20	5.4	5.7	6.2	4.7
50	6.1	6.6	7.1	5.1
100	6.7	7.1	7.8	5.6



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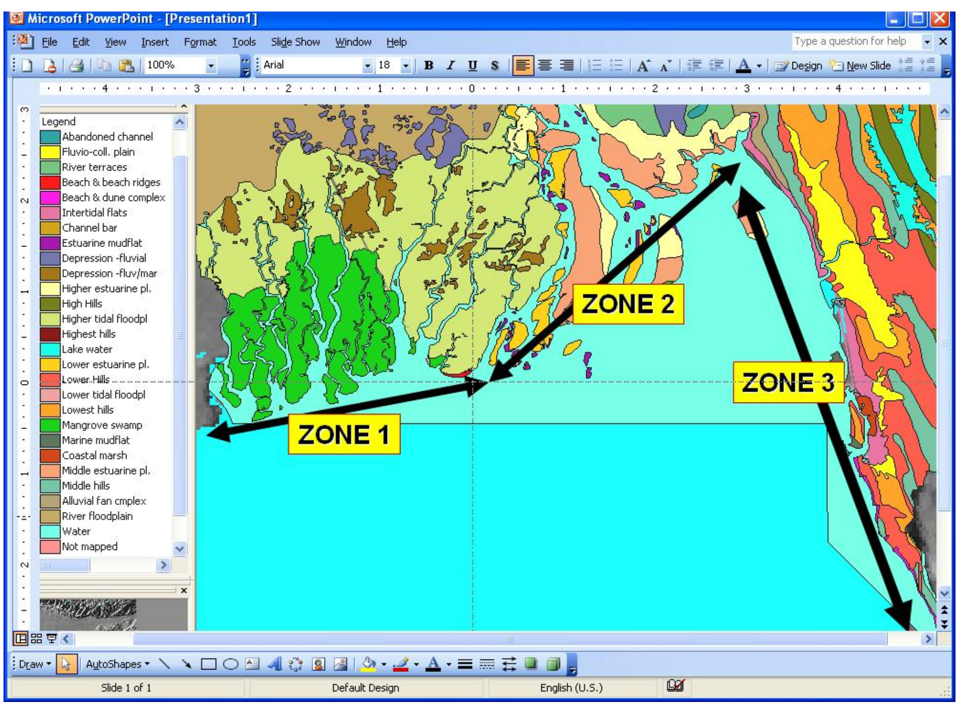

Figure 1:

Three coastal zones of Bangladesh based on tidal amplitude: zone 1: low; zone 2: medium & zone 3: high.

2. Exploring the input data

In the data catalog you see the icons of the available input data for this introduction to the case study. The following input data gives an overview of the thematic data and how they are derived. For Part 1 of the exercise we only use the maps and tables **Bdesh, Bdgeom** and the table **Landfall.**

Name	**Type**	**Meaning**
Bdesh	Raster map	Hill-shading map made out of a low resolution DEM of the whole of Bangladesh
Bdgeom	Polygon map	Main Geomorphological Units of Bangladesh.
Landfall	Table	Information on Cyclone Events, Causalities, etc.
Landform	Polygon map	Landforms, including Rivers and Dikes.
Baskhali data for part 2 of the exercise:		
Shelter	Point map	Locations of Cyclone Shelters.
Roads	Segment map	Main- and Secondary- roads.
Village	Polygon map	Villages, including a table on Population.
Eleva	Point map	Point elevation in cm above mean sea level.
Waterlin	Segment map	Digitized coastline of the area.
Batm90b2->7	Raster map	Landsat-TM image 31-10-1990, bands 2, 3, 4, 5 and 7.
Baspotx	Raster map	SPOT panchromatic image, scanned from a paper print.
Photos 1-10	Raster photo	Scanned ground photographs of November 1994 taken by M. Damen.

3. Displaying the entire coastal zone of Bangladesh & data points of cyclone landfall

Display of the geomorphological map of Bangladesh

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- Display the raster map **Bdesh.** This is a hill-shading map of the whole of Bangladesh and surroundings. The pixel size is 1461.5 meter
- Add the geomorphological map **bdgeom** as an extra data layer. To do so, select: ***Layers > Add Layer….***

  Select from the Add Data Layer dialog box the polygon map **Bdgeom**. Type **0** for the boundary width in the Display Options dialog box. Click ***OK.***
- Zoom-in to the colored geomorphological map. Click the left mouse button to display the names of the geomorphological units.

  You will see that the geomorphological units do not fit very well on top of the hill-shading map due to scale differences and inaccuracies caused by the digitizing, etc.

Display of the Points of Cyclone Landfall and adding information from a table.

☞

- Make sure that the maps **Bdesh** and **Bdgeom** are displayed. Add the point map **Landfall**. Display the symbols with size **10** and a **red fill** color.
- Double-click the points to display attribute data from the table **Landfall**. Read the attribute information, such as number of casualties, tidal height during the landfall, etc.
- Open the table **Landfall.** Browse through the table and try to understand the meaning of the records.
- Close all the maps and tables.

4. Analysis of historic cyclone events

First you are going to analyze the table Landfall and make a graph of different column combinations. Next you select the values from only the Chittagong / Banskhali area.

☞

- Double-click the table **Landfall** from the ILWIS Main window. Display the table in a full screen for a good overview. The table has the columns :

  - Domain of the table;
  - *Zone* number;
  - the name of the Zone (our study area is Chittagong);
  - the Year of the landfall;
  - the Month of the landfall;
  - the Wind Speed in km/hr;
  - the Wind Surge height in meters;
  - the Tidal Height at the moment of the landfall in meters;
  - the number of Casualties.
- Select:  to open the Create Graph window. Select WindSpeed for the **X-**axis and WindSurge for the **Y**-axis. Click: *OK*.
- As you see, the "cloud" of points is rather large. The reason for this is that the relation between the wind speed and the wind surge height differs in the various coastal zones. The relation will be better if we select the data from only the Chittagong zone (*Zone 3).*
- Close the graph.

Now do the same for the Chittagong area (Zone 3). First you have to make extra columns of data from *Zone 3* using Table Calculation:

☞

- Type in the Command Line of the Table the following TabCalc formula:

  WindSpeed_3:=iff(Zone=3,WindSpeed,0)↵

  Meaning: **iff** the value in the column Zone =3 (Chittagong zone), **then** select the values from the column WindSpeed, **otherwise** give value 0.

- Repeat the above described procedure and make the columns:

  WindSurge_3 (from the old column WindSurge), and

  TidalHeight_3 (from the old column TidalHeight).
- For the real height of the actual wave height at the coast we have to add the wind surge height to the tidal height. Use MapCalc formula:

  WaveHeight_3:= WindSurge_3+TidalHeight_3 ↵
- Create a graph (points) of the following table column combination: WindSpeed_3 in the **x-axis** and WindSurge_3 in the **y-Axis**.
- Do the same (in the same graph window) for :

  x-axis: WindSpeed_3 **y-axis:** WaveHeight_3

  x-axis: WindSpeed **y-axis:** Casualties

  x-axis: WindSurge **y-axis:** Casualties
- Add different types of Least Square fits to the point graphs. Right-mouse click in the Graph window and select: Add Graph, Least Squares Fit…

  For selecting the best function etc. use the ILWIS Help function for further information.
- Evaluate the results. Draw conclusions.
- Close the graph window and the table window.

References

Only the references of the exercise are listed. At the end of the word file appendix.doc a much longer list is given.

Cyclone 91 (1991). *An environmental and perceptual study*. Bangladesh Centre for Advanced Studies.

ISPAN. (1993). *GIS technology for disaster management*. Contribution to the Bangladesh Flood Action Plan - FAP19.

Khalil, Gazi MD. (1993). The catastrophic cyclone of April 1991: Its impact on the economy of Bangladesh. *Natural Hazards*, 8:263-281, Kluwer Academic Publishers, The Netherlands.

Khan, S.R. (1995). *Geomorphic Characterization of cyclone hazards along the coast of Bangladesh*. MSc Thesis, ITC, Enschede, The Netherlands.

MCSP. (1992). *Multipurpose Cyclone Shelter Programme*. Draft Final Report, Vol. IV. Planning and Development Issues, UNDP, World Bank.

Ray, S.T. (1994). An assessment of the potential of applying GIS to two aspects of disaster management: Storm surge modelling and cyclone shelter analysis. Msc theses, University of Nottingham, UK.

Session 3.C Task 3-B

Hazard analysis of cyclone flooding in Bangladesh

Part B *Cyclone flood hazard modelling for different return periods*

Expected time:	3 hours
Data:	Data file: 3**C Task 3 CycloneHazardModelling.zip**
Objectives:	After this exercise you will be able to:
	- display satellite images of the Baskhali study area;
	- display ground photographs of selected points;
	- display the available segment and point data layers;
	- interpolate the point elevation data to an elevation raster map;
	- understand and apply cyclone flood impact modeling for different return periods using ILWIS script language.

1. Introduction

During the years 1797 to 1991, Bangladesh was hit by 59 severe cyclones, of which 32 were accompanied by storm surges. Concerning 20 of these cyclones, information for the whole of Bangladesh is stored in the ILWIS table Landfall on Wind Speed, Wind Surge height, number of Casualties, Tidal Height during the event, etc.

Despite the fact that the Bangladesh Government issued warnings of the impending flooding, for the April 1991 cyclone, through its Cyclone Preparedness Program, and about 3 million people moved to safety, many inhabitants remained behind to protect their property.

During this disaster an estimated 138.000 people were killed and large numbers of houses, agricultural lands and infra-structural works were destroyed. Hundreds of schools were damaged and seven to eight thousand vessels were lost. Almost every bridge and culvert in the area was damaged and roads were washed out.

Within two days government air drops of food and medicine started, but they were hampered by continuing bad weather associated with the storm. Nearly two weeks had passed before massive international aid could react to the disaster and it was many months before the area returned to normal.

The Banskhali study area is situated in the East of Bangladesh, South of the city of Chittagong. Maps and attribute tables are given of the geomorphology, village population, the Union-districts, roads, embankments, cyclone shelters, and the elevation of the terrain with centimeter accuracy. Also available are Landsat Thematic Mapper and (scanned) SPOT panchromatic satellite images. For a general introduction you can make use of a geomorphological overview map of the whole coastal zone of Bangladesh as well as ten ground photographs of the Banskhali area.

In Part B of Task 3 you will first display the different data layers of the Banskhali area. Also field photographs from the ground can be displayed. Next you rasterize the segment and vector maps for further map calculation and also perform point interpolation to create the elevation map. Finally flood hazard maps are created using ILWIS script for different return periods, as calculated by Khan (1995).

Some GIS files are derived from:

– Sirajur Rahman Khan (1995) - "Geomorphic Characterization of cyclone hazards along the coast of Bangladesh", ITC - MSc study.

- See also the table of contents.

Table 1:

Cyclone Surge Heights for different coastal tidal zones and different return periods

Return Period	Entire coast	Zone 1 Sundarban	Zone 2 Noakhali	Zone 3 Chittagong
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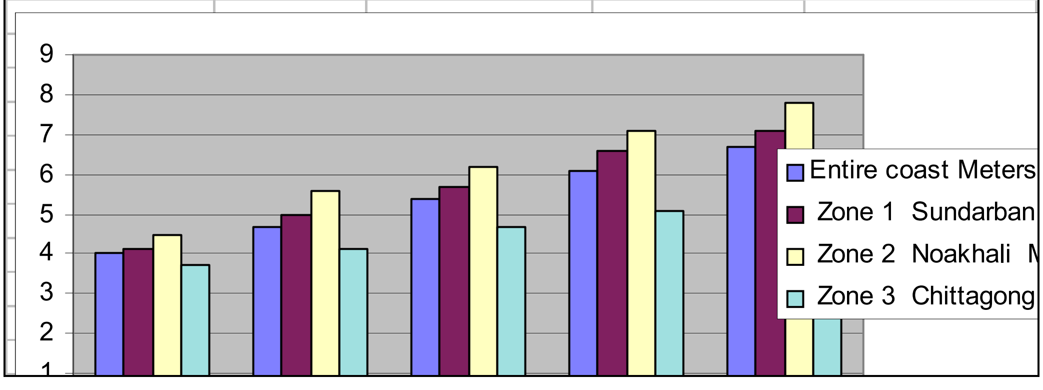
100	6.7	7.1	7.8	5.6



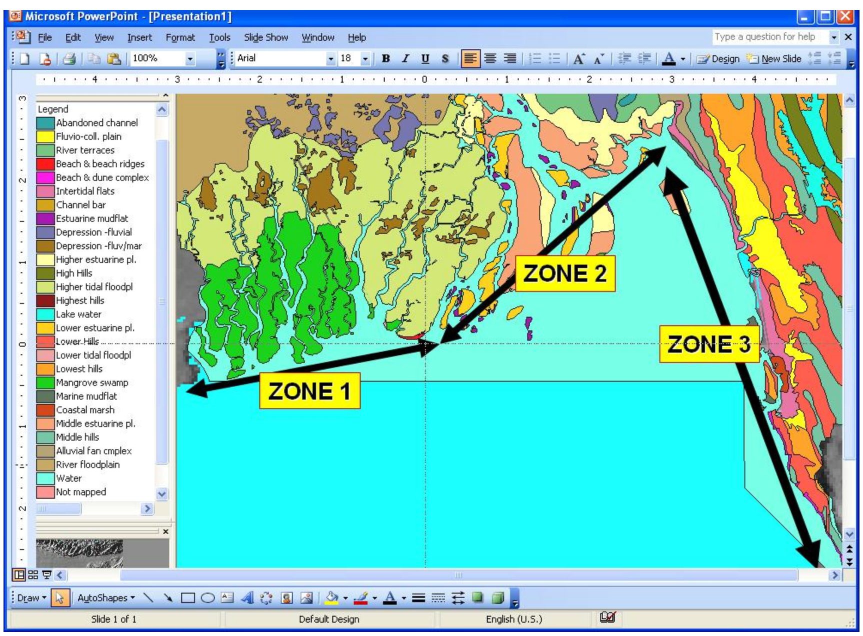


Figure 1

Three coastal zones of Bangladesh based on tidal amplitude. Zone 1: low; zone 2: medium & zone 3: high.

2. Exploring the input data

In the data catalog you see the icons of the available input data for this case study.

- In **Part A** of the exercise on cyclone flood hazard modeling you displayed already the data for the whole of Bangladesh.
- In **Part B** we are going to use also the data from the Banskhali area.

Name	Type	Meaning
Bdesh	Raster map	Hill-shading map made out of a low resolution DEM of the whole of Bangladesh
Bdgeom	Polygon map	Main Geomorphological Units of Bangladesh.
Landfall	Table	Information on Cyclone Events, Causalities, etc.
Landform	Polygon map	Landforms, including Rivers and Dikes.
Baskhali data for part 2 of the exercise:		
Shelter	Point map	Locations of Cyclone Shelters.
Roads	Segment map	Main- and Secondary- roads.
Village	Polygon map	Villages, including a table on Population.
Eleva	Point map	Point elevation in cm above mean sea level.
Waterlin	Segment map	Digitized coastline of the area.
Batm90b2->7	Raster map	Landsat-TM image 31-10-1990, bands 2, 3, 4, 5 and 7.
Baspotx	Raster map	SPOT panchromatic image, scanned from a paper print.
Photos 1-10	Raster photo	Scanned ground photographs of November 1994 taken by M. Damen.

3. Displaying satellite images of the Banskhali area

Of the Landsat Thematic-Mapper image of 31 October 1990 the bands 2 - 5 and 7 are given. The bands are geocoded and geometrically corrected.

The raster map **Batm90b453** to be made provides information on the terrain characteristics. From west to east you first have the sea (blue color). The beach has a light image tone; the wider zone in the south is a tidal flat. Clearly visible is a north-south running river with some tributaries. In the east you find the Chittagong hills consisting of soft sedimentary rocks; the eroded parts have a light image tone. Other image tone differences are caused by various types of land use, such as homestead gardens, rice fields and roads.

☞

- Make a color composite of Landsat Thematic Mapper bands 4, 5 & 3 for red, green and blue. Use for this: *Operations > Image processing > Color Composite*. Use the default values for this.
- Save the result as **batm90b453**
- Study the colors of the image, and zoom-in at selected sites.
- Close the map window when finished.

Now look at the SPOT panchromatic image with filename **Baspotx**. The image is from the 22nd of January 1994 and is scanned from a paper print and re-sampled to the original pixel resolution of 10 m.

☞

- Display the raster map **Baspotx**.
- Browse through the image. Study the image characteristics such as grey tone and pattern. Try to recognize the homestead gardens of the villages, the hills, the roads, and the lower parts in the terrain. Zoom-in, if necessary. Do you also see the embankment near the coastline?
- Look also at the map properties by selecting *File > Properties*. You now find information on the size of the map, the pixel size, and the domain: Image. Close the Properties dialog box.

4. Displaying ground photographs taken from point locations

Ten ground photographs taken by M. Damen in November 1994 can be displayed. The pictures are intended to give an impression of the terrain and the cyclone shelters; the points are not always at the exact location from which the photo have been taken.

☞

- Add as new data layer to the map **Baspotx** the point map **Photos**. Choose an appropriate symbol size and color.
- Select: *Layers > Double Click Action > Execute Action*, *OK.*
- Double-click a point to display a ground photograph. Repeat from other photographs
- Close the map window.

5. Display of the segment and point data layers

In this exercise the SPOT panchromatic image will be combined with other data layers, such as the landuse (map: **Village**), the geomorphology (map: **Landform**), the roads (map: **Roads)** and the point elevation data (map: **Eleva**).

☞

- Display the map **Baspotx**.
- Add as data layer the Polygon map **Village**. Select: Boundaries Only and boundary color green. Click: *OK* and you see the boundaries of the land use in green. These are digitized segments.
- Compare the map **Village** with your own visual interpretation.
- Look also at the map properties by selecting *File > Properties*. Information is displayed on the map size, the Identifier domain **Village** and the number of polygons. Note that also the table village is linked to the map

- Close the Properties dialog box.

All landuse data is stored in the table **Village**. You can display this data using the pixel information window.

☞

- Open from the ILWIS Main menu the Pixel Information window . Select: *Options > Always on Top.* Make sure that this window is displayed next to the SPOT image and that also the Catalog in the Main window is still visible.
- Drag-and-drop from the ILWIS Main window the polygon map **Village** into the Pixel Information window. Remark: You can also use: *File > Add Map…*
- Read the table information while browsing through the village areas.
- Add also the data layer **Landform** to the map window (polygon map with **red** boundary color).
- Drag-and-drop polygon map **Landform** into the Pixel Information window and "browse" again through the SPOT image.

☞

- Also drag-and-drop polygon map **Union** into the Pixel Information window. Union means local district; the total population is given.
- Finally add the polygon map **Union** (display only the boundaries in orange) and the segment map **Roads**.
- Change the layers **Union, Village, Landform** and **Roads** in the list in the Layer Management dialog box by clearing the checkbox for each of them. The maps are not shown anymore.

Finally, the elevation point information can be displayed as follows:

☞

- Add as new data layer to the map window the point map **Eleva**. In the Display Options window select: Attribute: **Eleva_cm**.
- Choose an appropriate symbol color and size. Click an elevation point to display the elevation. Remark: if you click in between the elevation points, not the elevation but the pixel value of the satellite map is being displayed!
- Drag-and-drop to the Pixel Information window the raster map **Eleva** This is the Digital Elevation Model of the area, created by interpolation of the individual elevation points (in point 7 of the exercise you can do this yourself).
- Right mouse-click the map **eleva** in the Pixel Information window and display the Properties dialog box; read the information. The domain is Value. Close the box.
- Browse through the images to know the information from the maps **Landform** and **Eleva**.
- Close the map windows and the Pixel Information window.

6. Rasterizing the maps

For the surge hazard modeling you need to perform several MapCalculations. For this you have to rasterize the maps first.

☞

- Rasterize the map **Landform** using the option Polygon to Raster in the Operations-list under Rasterize. Give the output raster map the same name. Use the Georeference : Baspotx.
- Repeat the same procedure for the polygon maps **Union** and **Village** using the same Georeference.
- Rasterize the segment maps **Waterlin** and **Roads.** Save the rastermap with the same name and use for all the maps the georeference **Baspotx.** Check the results.

7. Creation of the elevation map yourself by point interpolation

☞

- Select from the main menu: *Operations > Interpolation > Point, Interpolation > Moving Average*. Select from the point map **Eleva** the Column: **Eleva_cm**. (click for this selection the small box with the cross in front of the map icon **Eleva**).
  - o Use the georeference: **Baspotx**; and a value range: 0-1500 with a precision 1. Remark: the domain of the selected column is: Value
  - o Select Weight function: Inverse Distance; Weight Exponent: 1 and Limiting Distance: 700. The output map name is **Eleva**.
- Click*: Show*. Overwrite the already existing file **Eleva**.

8. Cyclone flood modelling - methodology

During this part of the exercise you will make a map of the floodwater depth during the April 1991 cyclone in the Chittagong/Banskhali area. For this two models will be used:

1. A surge model based on historical records of cyclone flooding in Bangladesh; and
2. The Digital Elevation Model (DEM) of the area (this is the map **eleva**).

The Surge Decay Coefficient (*SDC*)

Before starting the calculations for the Surge Model, you have to find out how the cyclone surge depth decreases inland. This is the so-called *Surge Decay Coefficient **(SDC)***, which will be different for each wave height at the coast. The ***SDC*** is a function of the friction caused by surface forms (morphology, embankments and elevated roads) and land cover (houses, rice fields, homestead gardens with trees, etc.).

The contribution to the friction of all the terrain elements to the ***SDC*** is not fully understood and is still under investigation. However, we know from historical records that in areas with low or no dikes along the coast the surge inundation depth will be more or less constant in the first strip along the coast. After this it will decrease until a certain distance inland.

The data from the total limit to inundation from the coastline for different Wave Heights have been taken from the Multi-purpose Cyclone Shelter project (MCSP, 1993) in Bangladesh. Some of these data for the whole coast of Bangladesh are presented in the Table 2 below.

Table 2: Relation Wave Height at coastline and Inundated area (Whole of Bangladesh)

Wave Height at Coastline (meters)	**Area with Constant Surge Depth** (distance from the coastline in meters)	**Total Inundated Area** (distance from coast in meters)
3.7	415	2000
4.1	520	2900
4.7	580	3900
5.1	670	4200
5.6	760	4400
6.0	880	4700
6.5	1000	5000

Various reports of the April 1991 cyclone event in the Chittagong/ Banskhali area indicate a Wave Height at the coastline of about 6.5 meter; the surge extended approximately 5000 m. inland.

The Wave Height included a tidal height during the time of landfall of + 1.7 meter. This means that the actual Wind Surge Height at the coastline in the Banskhali area was "only" 6.5m - 1.7m = 4.8m.

For the modeling we take a constant surge depth of 1000 meter starting at the coastline (see Table 1). Further inland the surge depth decreased with the ***SDC*** (see also Figure 2 on the next page).

The ***Surge Decay Coefficient*** **(*SDC*)** is calculated as follows:

$$\mathrm{SDC}_{RP} = \frac{\text{Wave height at coastline - Avg. elevation of terrain at end of surge}}{\text{Width total inundated area - Width area with constant surge}}$$

Filling in the values from Table 2 in the above equation for a wave height at the coast of 6.5 meter, we find:

$$SDC_{Surge\ 650cm\ in\ Chitt.} = \frac{(650 - 267)\,cm}{(5000 - 1000)\,m} = 0.096\ cm/m$$

The SDC value will be used in the next part of the exercise on surge modeling

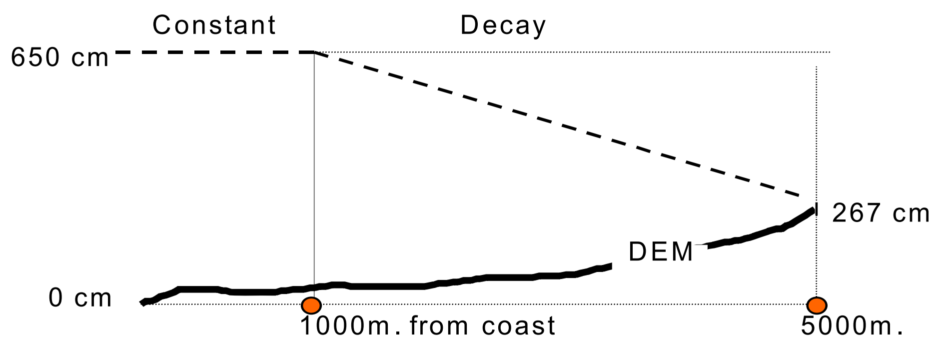


Figure 2: Cross section illustrating the surge decay inland of a Wave Height of 650 cm at the coastline

9. Cyclone surge modelling – Steps to be followed

The two steps for a surge modeling of a 650 cm. high Wave Height at the coastline are the following:

Step 1

Creation of a distance map starting at the coastline to at least 5000 m. inland. The coastline is given in the raster map **Waterlin**. First we remove the sea part. After this we save the result as the map **Codist**.

Step 2

Creation of several maps of the Surge Inundation depth for a wave height near the coast of 650 cm:

- One map from the coastline until 1000m inland, as if there is no decay and relief. To be saved as **In650a**.
- Another map from the decay starting at 1000 m. inland and giving linear decreasing values until 5000 m inland, to be saved as **Sdc650**.
- A map in which the values from the map **Sdc650** are subtracted from the map In650a. This map should be saved as **In650b**.
- Finally you subtract the values of the elevation map Eleva from the map **In650b**. This is the map **In650c**.
- To exclude the area at more than 5000m from the sea we remove all negative values. The final map is the cyclone flood hazard map and should be saved as **Haz650f**.

Step 1 – Creation of distance map starting at the coastline

☞

- Calculate a distance map using **Waterlin** as the starting map. Give precision 1.0. The output map is: **Distance.**
- Display the result and check the image values.
  The distance calculations are also performed in the direction of the sea. Exclude the sea with the formula:

  Codist:=iff(Landform="Sea",?,Distance)↵

Step 2 – Creation of a surge inundation map (650 cm surge)

Distance calculation: this operation assigns to each pixel the smallest distance in meters towards user-specified source pixels, for example distance to schools, to roads etc. The output is called a *distance map*. Input for a distance calculation is a *source map* and optionally a *weight map*. Check the ILWIS guide to read further explanation about the Distance calculation.

In this steps is explained how a surge inundation depth map for a surge height of 650 cm. can be made. According to Table 2 is the width of the inundated area for this surge height 5000 meters.

In part 10 of the exercise you will make maps for different surge heights "automatically" using an ILWIS script.

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- Type the following MapCalc formula in the command line to make the inundation map until 5000 m from the coast for a coastal wave height of 650 cm as if there were no decay and no relief:

  In650a:=iff(Codist<=5000,650,0)↵

  Save the map with domain Value and precision 1.0. Check the values.
- Make a map of the surge decay from 1000 until 5000 from the coast. Type the formula:

  Sdc650:=iff (codist>1000,0.096*(Codist-1000),0)↵

  The formula describes that for each meter distance from the coast (starting at 1000 m.) the map values will be reduced by the Surge Decay Coefficient (SDC). Save the map with domain Value and precision: 1.0. Check all the values.

- Subtract the pixel values of the **Sdc650** map from the pixel values of the **In650a** map. Save the resulting map as **In650b** with domain Value and check the pixel values.
- Subtract the elevation map from **In650b**. Save the map as **In650c** with domain Value and check the pixel values. As you will see, some pixels in the East have a negative value.
- Finally exclude the negative values in **In650c**, which make no sense for further calculations. The final hazard map is:

  Haz650f:=iff(in650c<=0,0,in650c)↵
- Display the map and check the pixel values. Close the map.

10. Cyclone surge modelling using ILWIS script

In this exercise you will make several hazard maps per return period. In the maps you include per return period, the extend of the flooded area and the flood depth per pixel (magnitude of the hazard).

The procedure is as follows:

a. For each recurrence interval the corresponding Surge Decay Coefficient has to be calculated using the data from Tables 1 and 2. Do not include the tidal influence in the calculations.

b. Flood Hazard maps per return period have to be made (inundation depth maps). This can be done relatively fast by using the ILWIS script option. With a script you make a sequenced list of ILWIS operations, equivalent to a batch file. In the script dialogue box, type your lines of calculations and operations. The parameters in a script must be written as %1, %2, %3, etc. The script can be run from the command line in the Main window of ILWIS.

c. Name the final hazard maps Haz***ret***y (***ret*** = return period).

a. Calculation of the Surge Decay Coefficient (Chittagong zone)

Example: Return period 5 years. Corresponding Wave Height at the coast: 370 cm.

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- Calculate SDC for all return periods using the SDC formula.
  First you have to fill in all data in the table below using the information from the tables 1 and 2.
- After this, you estimate the average elevation at the end of the flooded area::

  First make a map of the terrain elevations at the total flood distance from the coast using the maps **Codist** and **Eleva** (or DEM).
  Example MapCalc for the elevations at approx. 2000m from the coast (strip of 10m wide):

  elev370:=iff(inrange(codist,1995,2005),eleva,?)
- Next display the histogram of the map **elev370,** and read at the bottom of the histogram table the Average value (**Avg)**.
- Calculate the value of SDC using a pocket calculator and the existing function **SDC.** Write the result manually in Table 3.
- Repeat this for the other maps; fill in the table below.

Table 3: Table to be completed manually

Return period	Wave height Chittagong (cm)	Area under const. Surge (meters)	Inundated Area (meters)	Avg. elev. at end of surge (cm)	SDC (cm/m)
5 yr.	370	415	2000	274	0.061
10 yr.					
20 yr.					
50 yr.					

b. Flood hazard mapping per recurrence interval using ILWIS script

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- Open the script: **Surge.**
- Study the Script file (which is printed below). **Do <u>not</u> change it!** The Script file gives all the steps for the calculation of the surge inundation depth (as explained in section 3.5).
- Exit the script file.

Script file:

```
%1:=iff(Codist<=%2,%3,0)
%6:=iff(codist>%5,%4*(Codist-%5),0)
%7:=%1-%6
%8:=%7-Eleva
%9:=iff(%8<=0,0,%8)
```

Explanation :

% 1 : flood map as if there were no decay and relief (in<u>x</u>a.mpr) <u>x</u>:flood height

% 2 : the width of the inundated area

% 3 : the flood wave height at the coastline (surge plus tidal height)

% 4 : the value of the Surge Decay Coefficient (SDC)

% 5 : the width of the area with constant flood depth (strip near the coast)

% 6 : the map Sdc<u>x</u>.mpr (reduction by the SDC)

% 7 : the map In**<u>x</u>**b.mpr (**<u>x</u>**: Wind Surge height at the coastline)

% 8 : the map In**<u>x</u>**c.mpr (**<u>x</u>**: Wind Surge height at the coastline)

% 9 : the final hazard map Haz***<u>ret</u>***y.mpr (***<u>ret</u>***: return period of the Wind Surge)

Landform, Eleva, Codist: existing maps used for the calculations

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- Type in the command line of the main window the following for the 5 year return interval with a Wind Surge height along the coast of 370 cm (values from first row in the above table):

  Run Surge In370a 2000 370 0.061 415 Sdc370 In370b In370c Haz05y
- Meaning: run surge %1 %2 %3 %4 %5 %6 %7 %8 %9
- Press Enter and wait until the calculations have been finished. Now the maps **In370a-c, Sdc370** and final hazard map **Haz05y** are made.

For the flood hazard modeling for the different recurrence intervals we first have to make a table with all the data necessary to run the script files. For the Wave Heights at the coast we take the Storm Wave heights per return period (Table 3.1) and do not take into account the unknown effects of tidal variations.

Table 4: Table to be completed, containing input parameters for the script

	%	5 yr.	10 yr.	20 yr.	50 yr.
Wave height at coast (cm)	**x (cm)**	**370**			
Map: Inxa	**% 1**	In**370**a			
Width of inundation (m)	**% 2**	**2000**			
Flood height at coast (cm)	**% 3**	**370**			
SDC	**% 4**	**0.061**			
Width of constant surge (r	**% 5**	**415**			
Map: Sdcx	**% 6**	Sdc**370**			
Map: Inxb	**% 7**	In**370**b			
Map: Inxc	**% 8**	In**370**c			
Map: Hazrety	**% 9**	Haz***05***y	Haz***10***y	Haz***20***y	Haz***50***y

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- Create the formulae to be typed in the command line of the main window for return intervals of 10, 20 and 50 years:

  Flood hazard map with 10 year return interval - **Haz10y:**

  Run Surge ____ ____ ____ ____ ____ ____ ____ ____ ____
  %1 %2 %3 %4 %5 %6 %7 %8 %9

  Flood hazard map with 20 year return interval - **Haz20y:**

  Run Surge ____ ____ ____ ____ ____ ____ ____ ____ ____
  %1 %2 %3 %4 %5 %6 %7 %8 %9

  Flood hazard map with 50 year return interval - **Haz50y:**
- Run Surge ____ ____ ____ ____ ____ ____ ____ ____ ____
  %1 %2 %3 %4 %5 %6 %7 %8
  %9
- Type the first in the command line and press: *Enter*. Make sure that there is always one space in between the parameters.
- Repeat this for the other formulae.
- Check the hazard maps: **Haz05y, Haz10y, Haz20y** and **Haz50y.**

References

Only the references of the exercise are listed. At the end of the word file appendix.doc a much longer list is given.

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Ray, S.T. (1994). An assessment of the potential of applying GIS to two aspects of disaster management: Storm surge modelling and cyclone shelter analysis. Msc theses, University of Nottingham, UK.

Session 3.C Task 8

Analysis of coastal areas vulnerable to Enhanced Sea Level Rise

Example from Java, Indonesia

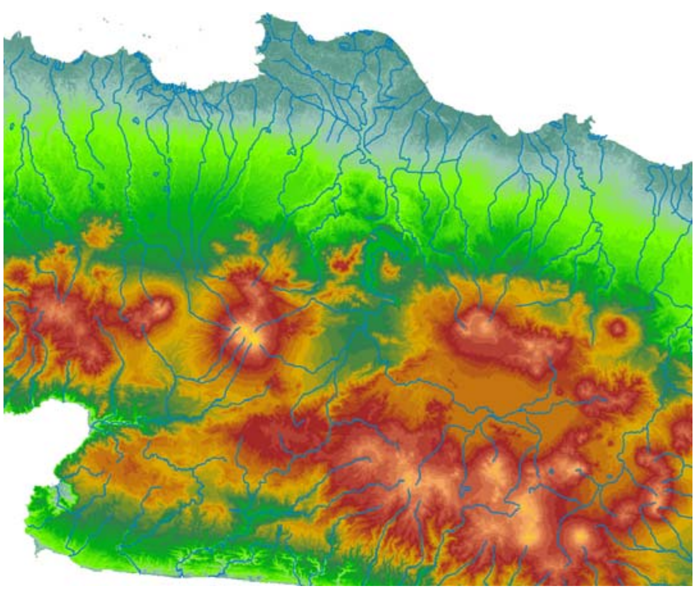
Expected time:	1 hour
Data:	Data file: Session 3.C Task 8 : **Java-Bali_SRTMData.Zip**
Objectives:	After this exercise you will be able to: **-** Display an SRTM elevation model with a color representation - Change the color representation for values between 0 and 1 - Calculate the pixel size of SRTM - Calculate the surface areas vulnerable to Enhanced Sea Level

1. Introduction

Indonesia is a country with many islands and therefore highly vulnerable to Enhanced Sea Level Rise (ESLR). The freely available Shuttle Radar Elevation Data (SRTM) is an excellent source for the impact analysis of ESLR on coastal areas at medium scale. As an exercise example we only use the island of Java and Bali.

The procedure is as follows: First the areas between 0 and 1 meter are displayed in red by changing of the color representation. After this the total surface area between 0 and 1 meter elevation will be calculated by analyzing the histogram of the SRTM.

Figure 1: SRTM Elevation model & drainage lines- Central Java, Indonesia



2. Exploring the input data

In the data catalog you see the icons of the available input data for this exercise. This includes a SRTM elevation model of the islands Java and Bali and a color representation of the elevations to be used in combination with the SRTM data.

The SRTM elevation map has been downloaded from:

The Drainage lines are downloaded from the Maproom of the Digital Chart of the world:

http://www.maproom.psu.edu/dcw/

The coordinate system used is in degrees: latitude / Longitude**.**

Name	**Type**	**Meaning**
Java_Bali_SRTM	Raster map	Digital Elevation Model of the islands Java and Bali, Indonesia. Source: Shuttle Radar Topographic Mission (SRTM)
IndDrainage	Segment map	Drainage lines of the islands Java and Bali
Java_Bali_SRTM	Representation	Color representation of the elevations to be used in combination with SRTM data
Java_SRTM	Georeference & Coordinate system	Georeference of the SRTM data and coordinate system in Latitude / Longitude (degrees)

3. Analyzing the SRTM data of Java and Bali

Display of the SRTM elevation model with the representation and drainage lines

- Display the raster map **Java_Bali_SRTM** with the Representation **Java-Bali_SRTM.** This is an SRTM elevation map in meters of Java and Bali
- Mouse-click to see the elevations in meters. Zoom in at different places.
- Add the Drainage map **IndDrainage** as an extra data layer. To do so, select: ***Layers > Add Layer….***

  Select from the Add Data Layer dialog box the segment map: **IndDrainage**. Type **1** for the boundary width in the Display Options dialog box. Click ***OK.***

  You will see that the drainage lines do not follow at all places very well The lower places of the terrain, such as valleys in between the volcanoes. At other places they cross the coastline. This is due to inaccuracies of Both the SRTM elevation model and position of the drainage lines.
- Zoom-in to different places along the coast
- Select: Properties of the raster map **Java_Bali_SRTM.** As you will see is the Pixel Size: 3 Arc Seconds. This is the original pixel size of this global dataset. If you open the Georeference Java-Bali you will see however that the pixel size is 0.001 m. This is of course not correct; the reason of this error is that ILWIS by default is using meters in stead of Arc Seconds. To calculate surface areas we preferably use correct values in meters.

Question1

What is the pixel size of the SRTM elevation model in meters?

Hint: use for the calculation of the circumference of the earth the radius value near the equator. You can find this value in meters by double-clicking the **Java_SRTM coordinate** system (value **a**).

Give answer of **Question 1**

Pixel size of SRTM …………………….. meter

4. Display & calculating areas vulnerable to Enhanced Sea level Rise

To display the areas that will be affected by a future sea level rise of for instance 1 meter we can adjust the map representation. To analyze the areas that will be affected by a future sea level rise you create a histogram of the SRTM elevation map. After this you multiply the pixel size (answer Question 1) with the number of pixels present between 0 and 1 meter elevation.

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- Open the Map Representation: **Java-Bali_SRTM.** Now the Representation window opens.
  In the left of the window elevation values are given (0, 5 10, 50, 100, 200, 400, 800 200 and 3500) and the colors of the elevations in between these values in a stretched mode.
- To change the 5 m. into 1 m. and to also change the color to red, you do the following: Select: ***Edit > Insert Limit***… Fill in Value: **1** and select Color: **Red.** After this select: ***OK***
- To give also the 0 m. elevations a Red color you double mouse-click the color bar next to 0 m. to open the Edit Limit window. Select: **Red** as a color. After this select: ***OK***.
- Change the stretch option between the values **1** - **0** and **5 – 1** into: **upper**. Leave all the other colors in **stretch** mode !
- Save the Representation value: ***File > Save Copy As...*** Use a new filename: **Java_Bali_SRTM_SLR 1m**
- Display the map **Java-Bali_SRTM** with the new representation. If you zoom in, you will see that the elevation map is not very accurate in details. Try another display with a stretch between the limits **0 -3.**
- To calculate the surface area between 0 and 1 m. elevation you first create a histogram by selecting: ***Operations> Statistics > Histogram.*** Select the map: **Java-Bali_SRTM** and after this select: ***Show***
- Multiply the number of pixels with values 0 and 1 with the pixel size (answer Question 1). Fill in the answer for Question 2

Give answer of **Question 2**

Surface area in km^2 of elevations between 0 and 1 meter: ……………………km^2

Session 3.C – Task 10

Modelling of Land Subsidence & Sea level rise in Semarang city, Indonesia

Expected time:	2.5 hour
Data:	Data file: 3**C Task 10_ModellingSubsidenceSemarang.zip**
Objectives:	After this exercise you will be able to:
	- analyze flooded areas with a Landsat ETM image;
	- compare the coastline of 2001 with an older digitized one (1871);
	- analyze and interpolate point data of elevation and rate of subsidence;
	- to model with multi temporal DEMs future relative sea level rise from different scenarios;
	- display of the results maps in clear colors.

1. Introduction

The exercise deals with the use of GIS for the study of the impact of land subsidence and sea level rise in the city of Semarang, Central Java, Indonesia.

Semarang city is suffering from two types of flooding: from rivers and high tides. The extend and magnitude of the floods seriously increased in recent years. This appears to be related to the ongoing processes of land subsidence and global sea level rise that this coastal city is faced with. The rate of subsidence in the city is at places up to a maximum of 12 cm/yr. Medium estimates of sea level rise in the region indicate that the sea level in Indonesia will rise by 9, 13, and 45 cm for the years 2010, 2019, and 2070 respectively.

To assess the combined effect of these phenomena and its spatial distribution, a procedure has to be applied which combines up-to-date geo-information sources on terrain elevation and land use.

In the exercise, a Digital Elevation Model (DEM) will be generated using a point map of photogramm-etrically- derived data.

The present land use in the area can be assessed using high-resolution satellite imagery of Landsat-7 ETM+

Also available is a scanned topo map of the area.

In the exercise you are asked to make result maps of the land subsidence and sea level. It aims to be applicable to other 'sinking cities' as well.

The methodology for the exercise has been derived

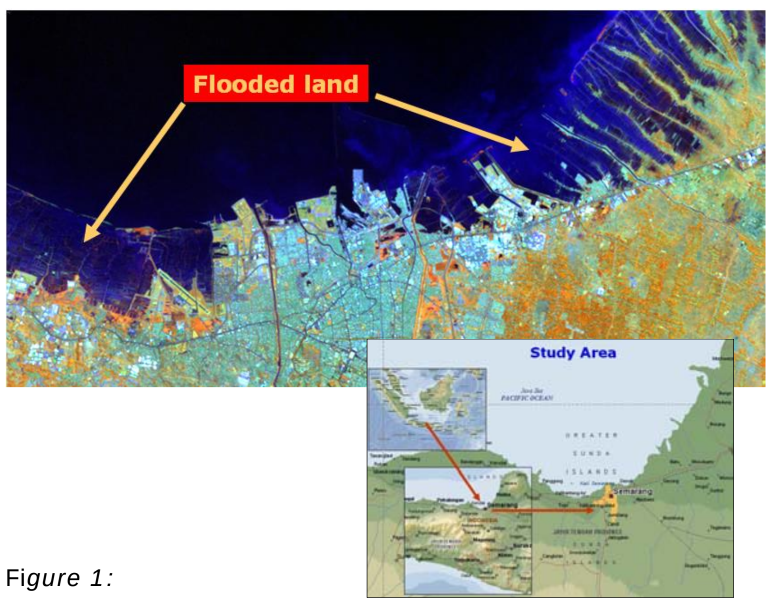


Figure 1:

Landsat TM image of Semarang showing flooded areas along the coast from:

- Heri Sutanta (2002) - "Spatial modeling of the Impact of Land Subsidence and Sea Level Rise in a Coastal Urban Setting", ITC-MSc study.

2. Exploring the input data

In the data catalog you see the icons of the available input data for this the case study.

Name	Type	Meaning
ETM01b1,…b2,…b3,…b4, …b5,…b8	Raster	Enhanced Thematic-Mapper image of 2th August 2001, bands 1 →5 and band 8. Resolution bands 1 → 5 is 30m and of band 8: 15 m.
Topo_1871, Topo_1908, Topo_1937, Topo_1992	Raster	Scanned topographical maps of the years 1871, 1908, 1937 and 1992 with a pixel resolution of 5.
Administration	Segment, polygon and table	Administrative subdivision of the city of Semarang in 'kampungs' and the population densities in a table.
Benchmarks	Point	Point map of benchmarks with a known subsidence rate in mm per year
Eleva01	Point	Point map of the elevations in 2001, in the central part of Semarang in meters
Coastlines	Segment	Digitized Coastlines based on the topographical maps of 1871 and 1992.
Waterbodies	Segment and polygon	waterbodies, such as the Java sea, rivers and canals (digitized from topographical map)
Roads	Polygon	Polygon map of the main roads
SubsMask	Raster & polygon	Raster, polygon map. Mask of study area for subsidence
StudyArea	Segment	Segment map of the boundary of the study area.

3. Comparing the Landsat ETM image of 2001 with the digitized coastline of 1871

First display the Landsat Thematic Mapper image of 2001 as a color composite. You will see in the Catalog of the Main Window the list of individual Landsat image bands, displayed with a raster icon.

- Double mouse-click the **ETM01b5** image. Accept the default settings in the "Display Options- Raster Map" window by selecting OK.
- Browse through the image with the mouse pointer and try to recognize certain surface features; for instance the difference between the land and sea area, the infra-structure of Semarang, etc. Zoom in at certain

areas.

- Do the same for **ETM01b8**. Compare the result in screen windows next to each other. As you will see, the image ETM01b5 has a lower spatial resolution (30 m pixel size) than the panchromatic ETM01b8 (15 m pixel size).
- Create a color composite of the Enhanced Thematic Mapper bands: **4**, **5** & **3** for **red**, **green** and **blue**. Save the result as: **ETM01b453**

  To do this select from the Menu Bar:
  - Operations, Image Processing, Color-Composite…
  - Select in the Colour-Composite window the following bands:

    Red – Green – Blue: ETM01b4–ETM01b5–ETM01b3
  - Type for Output Raster map: **ETM01b453**
  - Keep the defaults and Press: Show
- Study the colors of the image, and zoom-in at selected sites.

Comparing the coastline of 1871 with the coastline during image acquisition

The coastline of Semarang and surroundings, as visible on the color-composite of the Enhanced TM Image can be compared with the historic coastline, digitized from a topographical map of 1871

- First display the Landsat ETM color-composite image.
- Add the data layer **Coastlines** by selecting from the Map window: Layers > Add Layer…
- In the Add Data Layer window select the segment map: **Coastlines**, OK. In the Display Options-Segment Map window select all defaults by also OK.
- Zoom in at the coast and compare the historical coastline (1871 – orange color) with the more recent one (1992 – red color)

4. Display of elevation point data and topographical maps

First we will have a look at the administrative map and table, and the point map of the elevations, from which the Digital Elevation Model has to be constructed.

- Select the polygon map **administration**. In the Display Options – Polygon Map window you keep all defaults. Select: OK.
- Double mouse-click in the administrative units (“**desas**”) of Semarang. An Attribute window pops-up with information on the population density in that unit(=**PopDens**).

  Note that the population density in the Java Sea is of course 0; population data of the surrounding Kabupaten is not known (= ?) and all population data are stored in the table Administration.

To add other data layers, such as a satellite image or a topographical map, you have to display the administration map with the boundaries only.

- Select in the Polygon Map window: Layers > Display Options > 1 pol. Administration. In the Display Options – Polygon Map window you select the Check Box Boundaries Only. Select: OK. Now, the Administration map is displayed with boundaries only in a red color.

- In the Polygon Map window select: Layers > Add Layer. Now you can choose a map to add to the polygon map.

  Add the maps one by one: **Topo_1992**
  or **Topo_1871**, **Topo_1908**, **Topo_1937** *or* **ETM01b453**,

- Study the change of the coastline and the extension of the city, compared to the historic data.

  You can use the layer management pane (left window) to hide or display maps of your own choice (find out yourself)

Remark You can add only ETM images, **or** Topo maps to the Adminstration map. This has to do with differences in the geo-reference.

The display of the point map of the elevations in meters, with mm accuracy, and the benchmarks of the land subsidence rate (cm/year), can be done as follows.

- Display a map, for instance the Landsat ETM image or the topographical map of 1992.
- Add as data layer the point map **eleva01** and/or **benchmarks.** Mouse click on the points to see the values.
- Improve the display of the points by selecting: Layers > Display Options > 2pnt_eleva01.
- In the Display Options – Point Map window press the Symbol button. Use the Help function for more information on the different display options.

5. Interpolation of the elevation points and benchmarks of land subsidence

To speed up the procedure of interpolation, only the city center of Semarang will be used as a test area. For this, a special **georefer_subsidence** is available with a pixel size of 30 m.

To make the DEM of 2001 we will use a simple interpolation algorithm: *Moving Average* with *Inverse Distance*. In ILWIS a more advanced interpolation is well possible, for instance kriging, but that will take too much time for the exercise.

- In the ILWIS Menu Bar select: Operations > Interpolation > Point Interpolation > Moving Average. In the Moving Average window Select or type:
  - o Point Map: **eleva01**
  - o Weight Function: ⊙ Linear Decrease
  - o Weight Exponent: default value
  - o Limiting Distance: 1500 (value in meters)
  - o Output raster Map: Eleva01 (value in meters)

- o Georeference: **Georef_Subsidence** (30 m pixels)
- o Value Range: default values
- o Precision: 0.01 (value in cm)
- o Type for Description: Elevation 2001 in meters
- o Select: Show
- o Select all default values in the Display Options – Raster Map window.

- Browse through the map and look at the elevation values
- Add Map layers, such as **roads**, **waterbodies** and **administration**

To make the raster map **SubsRate**, in which the subsidence rate in cm per year is given, we have to interpolate the point map Benchmarks. For this, we follow basically the same interpolation procedure as for the map Eleva01 (see above).

We also use **Georef_Subsidence** (same area as eleva01). The only difference is, that the data to be interpolated are stored in a table benchmarks, and not in a map. The second difference is the limiting distance; this is set to 15.000 meter, to overcome the wide spacing of the benchmark point locations.

- In the ILWIS Menu Bar select: Operations > Interpolation > Point Interpolation > Moving Average. In the Moving Average window Select or type:
  - o Point Map: **benchmarks**

    Select: Subs-cmyr (remark: to select click the small box with a + in it front of the map benchmarks)
  - o Weight Function: ⦿ Linear Decrease
  - o Weight Exponent: default value
  - o Limiting Distance: 15.000 (value in meters)
  - o Output raster Map: **SubsRate** (value in cm/year)
  - o Georeference: **Georef_Subsidence** (30 m pixels)
  - o Value Range: default values
  - o Precision: 0.01 (value in cm)
  - o Type for Description: Subsidence rate in cm/year
  - o Select: Show
  - o Select all default values in the Display Options – Raster Map window.
- Browse through the map and look at the subsidence values in cm/year
- Add Map layers, such as **roads**, **waterways** and **administration**

6. Modelling future relative sea level rise

The scenarios in this exercise will produce maps with estimations of the relative sea level rises for the years 2010, 2019 and 2070. This means the sea level relative to the elevations of the land, taking into account land subsidence and enhanced sea level rise.

Scenario	**2010**	**2019**	**2070**
Low (cm)	3	6	15
Medium (cm)	**9**	**13**	**45**
High (cm)	15	25	90

The prediction from the study by the Asian Development Bank (1994) is taken as a basis for the absolute Enhanced Sea Level Rise scenarios in Semarang.

For the exercise, the medium values for the years 2010, 2019 and 2070 have been selected in the calculations of future land subsidence relative to enhanced sea level rise. This means a rise of 9 cm in 2010, of 13 cm in 2019 and 45 cm in 2070.

The calculation for the DTM for the year **t1** (=2010, 2019 or 2070), starting at the year **t0** (=2001) is (H. Sutanta, 2002):

$$ELEVA_{t1} = ELEVA_{t0} - (SLR_{t1} + (SUBSRATE * t_1 - t_0))$$

Where:

$ELEVA_{t0}$ = elevation at the initial condition (file: Eleva01)

$ELEVA_{t1}$ = elevation at the year to be estimated (file: **Eleva10, Eleva19**, **Eleva70**)

SLR_{t1} = sea level rise at the year to be estimated (2010, 2019 and 2070)

$SUBRATE$ = map of the rate of land subsidence (file: **SubsRate**)

In ILWIS, the necessary calculations based on the above formula, can be carried out using Map Calculations, to be typed in the Command Line. The equations are the following:

$$\textbf{Eleva10} = \textbf{Eleva01} - (\textbf{0.09} + \textbf{9xSubsRate/100})$$

$$\textbf{Eleva19} = \textbf{Eleva01} - (\textbf{0.13} + \textbf{18xSubsRate/100})$$

$$\textbf{Eleva70} = \textbf{Eleva01} - (\textbf{0.45} + \textbf{69xSubsRate/100})$$

Remark: the values *SubsRate* are divided by 100, to make units in meters in stead of cm.

- To make the map Eleva10, the following Map Calculation has to be performed (type in the Command Line):

  Eleva10 = Eleva01 –(0.09+9*SubsRate/100)

  Accept the defaults in the Raster Map Definition window and select: Show.
- Make with Map Calculation also the maps: **Eleva19** and **Eleva70**
- Check the result and add map layers such as **Administration**.

  As you will see did the interpolation of the points not stop at the coastline itself. To overcome this, you have to combine the resulting maps with a mask of only the land area of 2001. This is the map **SubsMask**, of which the coastline is digitized from the Landsat ETM image of 2001.
- Display the map: **SubsMask**
- To 'take out" or mask only the land area of the created elevation maps of the years 2010, 2019 and 2070, perform the following Map Calculation:

  ElevaMask10 = iff(SubsMask="Land", Eleva10,0)

  Meaning: Create a map with the name ElevaMask10 only for the areas which are "land" in the map SubsMask. Make the Sea: 0
- Accept the defaults in the Raster Map Definition window.
- Create the same way as above the maps **ElevaMask19** and **ElevaMask70**.
- Check the results. Add data layers of your own choice.

To get a better idea, on how badly the land has subsided in 2010, 2019 and 2070 compared to 2001, we display the topographical map of 1992 and browse with Pixel Info through the map, with the elevations of the three future years displayed in the Pixel Info window.

- Display topomap **Topo_1993** (or satellite image of 2001)
- Open Pixel Info from the Standard Toolbar
- Add the maps **Eleva01**, **ElevaMask10**, **ElevaMask19**, **ElevaMask70**, **SubsRate** to the Pixel Information window by selecting: File > Add Map.
- Analyze the results.

7. Display of the result data

The final step is to slice the ElevaMask 10, ..19, ..70 maps in such a way, that the subsided is represented in steps with clear and nice color.

For this, there is already made a domain with the steps elevation and a color look-up table with the same name. The output maps will be given the names: **Elevation 2010**, **Elevation 2019** and **Elevation 2070**.

- Select: Slicing from the Operations List (left side of window). Type or select in the Slicing window:
  - Raster Map: **Elevamask10**
  - Output Raster Map: **Elevation2010**
  - Domain: Elevation
  - Description: Elevation Map 2010
  - Select: Show
- Accept the default values in the Raster Map Definition window and Check / analyze the resulting map
- Make the same way maps **Elevation2019** and **Elevation2070**

Session 3.C Task 12

Monitoring the change of the Solo River delta , East Java, Indonesia

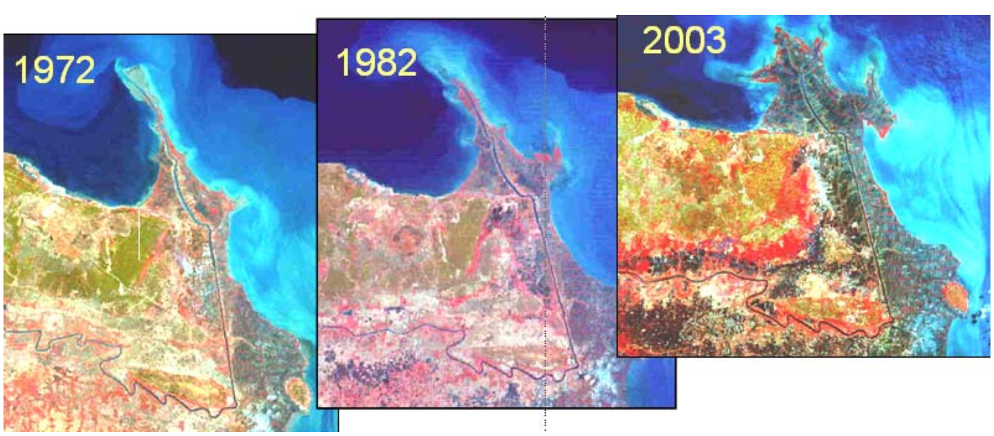
with multi-temporal satellite images & historic topographical map

Expected time:	1.5 hour
Data:	Data file: 3**.C Task 12: MonitoringSoloDelta**
After this exercise you will be able to:	
	- display multi-temporal and multi-resolution coastal images of a delta environment
	- analyze processes leading to changes in surface area;
	- quantify the changes of surface area using multi-temporal satellite data and an old topographical map;

1. Introduction

The Solo River delta in Indonesia is one of the largest on the island of Java, situated at the Northern coast. The delta can be characterized as a highly mud dominated and rapidly prograding single finder delta system. The east monsoon generated coastal currents and waves cause the mouth to be deflected eastward. The delta system consists of one major straight channel with pronounced natural levees and a few river outlets. The size of the drainage basin of the Solo River covers 16.000 km^2 and the total length of the river is 550 km.

The river flow regime is highly influenced by the monsoons. Most discharge takes place during the wet season (December – March). The mean annual discharge is 1350 m^3/sec (max 4000 m^3/sec – min. 80 m^3 sec.). The suspended sediment concentrations may vary from > 5000 mg/l (wet season) to less than 50 mg/l in the dry season. Almost 95 % of the suspended matter has a grain size < 50 microns.



2. Exploring the input data

In the data catalog you see the icons of the available input data of this case study.

Name	Type	Meaning
Solo_Topomap_1883	Raster	Scanned topographical map of 1883
Solo_MSS_1972	Raster	Landsat MSS image. Acquisition date: 27-09-1972
Solo_MSS_1982	Raster	Landsat MSS image. Acquisition date: 11-09-1982
Solo_ETM_2002	Raster	Landsat ETM image. Acquisition date: 23-08-2002
Solo_Aster_2003	Raster	Aster VNIR image. Acquisition date: 22-09-2003
Polygon maps of the coastline:		
Solo_Coastline_1883	Polygon	Digitized coastline from topographical map of 1883
Solo_Coastline_1972	Polygon	Digitized coastline from Landsat MSS image of 1972
Solo_Coastline_1982	Polygon	Digitized coastline from Landsat MSS image of 1982
Solo_Coastline_2002	Polygon	Digitized coastline from Landsat ETM image of 2002
Solo_Coastline_2003	Polygon	Digitized coastline from Aster VNIR image of 2003

3. Display and analysis of the individual satellite images

Display of the satellite images of the Solo River delta.

- Display the satellite images in color composites. Do this in screen windows with the different images next to each other.
- Analyze the images; try to recognize the coastline, the rivers(s) etc. Analyze the differences in respect to land and water characteristics, suspended materials in the sea and river water.
- Answer *Question 1.*

Question 1.

Which five or six terrain classes do you recognize? Give them a name:

1. ………………………………………………………………………………………..
2. ………………………………………………………………………………………..
3. ………………………………………………………………………………………...
4. ………………………………………………………………………………………...
5. …………………………………………………………………………………………
6. ………………………………………………………………………………………….

- Display a color composite of the most recent satellite image together with the 1883 topographical map in screen windows next to each other
- Answer *Question 3 a*
- Display the segment file of the 1883 coastline on top of the most recent satellite image
- Answer *Question 3 b*
- Calculate the surface area of the land for each year we have polygon maps available
- Answer *Question 3 c*

4. Change analysis of the Solo River delta

Analyze the change of the Solo River delta using the data from different years.

Question 2.

Which trends do you see in respect to the delta development?

……….

……….

……….

Question 3.

Calculate the surface area of the land for each year from which we have the data

Year	**Surface area (km^2)**
1883	
1972	
1982	
2002	
2003	

Exercise 3E: Earthquake hazard assessment

Expected time: 6 hours
Data: data from subdirectory:Riskcity exercise/exercise03E/data
Objectives: After this exercise you will be able to:

- Evaluate the earthquake catalog, with respect to the location, magnitude and depth of earthquakes
- Display earthquakes according to magnitude and depth
- Develop relations between depth, and magnitude
- Define the distance of the epicenters with respect to RiskCity
- Evaluate the completeness of the earthquake record.
- Estimation of PGA in rock in RiskCity for the various earthquakes in the catalog.
- Estimation of PGA in rock in RiskCity for the various earthquakes in the catalog.
- Application of various attenuation functions and evaluate their difference.
- Select a scenario earthquake, for which PGA values in rock are calculated
- Use the surficial geological information in order to define ranges of soil amplification
- Generate a PGA map for the city
- Convert the PGA to MMI
- Calculate the natural frequency of the soil in RiskCity
- Relate this with the natural frequency of buildings
- Make a zonation for different building altitudes

Introduction

A frequently used method for assessing and mapping earthquake hazards is seismic hazard zonation. It is the division of an area in smaller areas that have the same hazard level. Two types of seismic hazard zonation exist: the general method of macrozonation (mapping hazard on a small scale) and the detailed method of microzonation (on a large scale). The latter one allows for local geological and site conditions to be taken into account. Macrozonation is usually only based on earthquake recurrence and expected magnitude, and does not take local conditions into account.

This exercise deals with the use of GIS for seismic hazard assessment at a large scale, using two different methods:

- A simple method, followed by the RADIUS methodology, in which **Peak Ground Acceleration** is calculated for a scenario earthquake, and the amplification of soil is treated by simple multiplication values. This method gives only a very general approximation of the hazard
- A second method in which we will look more to **earthquake spectra**, and calculate the natural frequency of the soil, which is used to delineate areas which will experience large ground amplifications at specific frequencies which correspond to natural frequencies of certain building types.

In a real seismic hazard microzonation project the second method should be extended by calculating the response spectra for different soil columns, using strong motion records, and detailed soil column descriptions and properties. This would require a considerable amount of time and input data, and is not feasible within this case study. Here we will not be dealing in detail with the geological conditions of the RiskCity area. For this exercise it is important to know that the center of RiskCity has been filled in by lake-, river-, terrace and talus deposits. The valley is surrounded by steep mountains.

Exploring the input data

In the data catalog you see the icons of the available input data for this introduction to the case study. The following input data gives an overview of the thematic data and how they are derived.

Name	Type	Meaning
Image data		
Country_Anglyph	Raster image	An anaglyph image of the country in which RiskCity is located, made from DRTM data.
Geological data		
Geology_country	Polygon map	A geological map of the country in which RiskCity is located. This is linked to an attribute table with geological information
Faults_country	Segment map	A map with the main fault zones of the country
Seismic_zones	Polygon map	Seismo-tectonic zones, where a similar type of earthquakes can occur and which are used as earthquake source zones. Having their own magnitude-frequency relationship.
Earthquakes		
Earthquakes_countrty	Point map	A point map linked with a table containing information on the location, time, depth and magnitude of earthquakes in Honduras over the period: 1973-2008
Local data for RiskCity		
City_Centre	Point map	Location of the city center of RiskCity
Soildepth	Raster map	Flood extend map for a 100-year return period, obtained through modeling with HEC-RAs hydrological software
Lithology	Polygon map	Lithological map of RickCity
Altitude_dif	Raster map	Altitude of buildings

The exercise is made up of the following sections:

- Part 1: Evaluating the earthquake catalog & calculating magnitude-frequency relationships.
- Part 2: Estimation of PGA in rock in RiskCity for the various earthquakes in the catalog.
- Part 3: Generating PGA maps for RiskCity
- Optional exercise: Earthquake microzonation using overburden thickness

Part 1: Evaluating the earthquake catalog & calculating magnitude-frequency relationships.

Expected time: 2 hours

Objectives:

- Evaluate the earthquake catalog, with respect to the location, magnitude and depth of earthquakes
- Display earthquakes according to magnitude and depth
- Develop relations between depth, and magnitude
- Define the distance of the epicenters with respect to RiskCity
- Evaluate the completeness of the earthquake record.
- Estimation of PGA in rock in RiskCity for the various earthquakes in the catalog.

Look at the geological context

First we will start by having a look at the general structure of the country. We have an anaglyph image of the entire country (obtained from SERVIR on: http://www.servir.net/index.php?option=com_content&task=view&id=46). We also have geological map which was obtained from the USGS website. And we have a map with the main fault systems in the region. This was obtained from the following publication, which is also good as background reading for this exercise:

Cáceres, D. and Kulhánek, O. (2000) Seismic Hazard of Honduras. Natural Hazards 22: 49–69, 2000.

☞

- Open the anaglyph image **Country_Anaglyp**
- Add the layer **Geology_country**. Display boundaries only, and show with white lines with thickness 1.
- Add also the point map **City_centre**
- Open Pixel Information and add the map **Geology_country**.
- Use the red-green glasses to view the terrain and consult the geological information with you mouse while moving over the map.
- Also add the fault map **Faults_country**. See the relationship between the topography and the faults. Some have very clear topographic expressions.

Display the earthquakes according to their magnitude.

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- Overlay the point map **Earthquakes_country**.
- In the dialog box press OK.

As you can see all earthquakes are indicated with the same symbol size.

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- Double click a point in the map. The information on this particular earthquake will appear in the Window, called Attributes.
- Drag the size of the window so that you read all information. Try this for several other earthquakes.
- What do the various attributes mean?

You can also display the catalog according to the earthquake magnitude. We will use the column Magnitude for that.

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- Right click on the name of the map (**Earthquakes_country**) in the *Layer Management* pane (left part of the map) or in the map itself, and select *Display options*. The display options dialog box opens again.
- Select *Attribute*, and select the Attribute **Magnitude**.
- Click on *Symbol*. The Symbol dialog box opens.
- Change the line colour to red
- Select the option *stretch*. Enter the values to stretch from between 4 and 8.0. Use Size (pt) between 1 and 20. Press OK twice

Now you see that the earthquakes are displayed with different sizes according to their magnitude.

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- Experiment some more with these options, e.g. display the earthquakes according to their:
- Magnitude: show only those higher than Magnitude 5 (Tip: you can either use Symbols and stretch between 5 and 8, or you can create a new column in the table that only shows the Eq's above 5 and display these).
- Year: show the ones after 1990.
- Show the earthquakes according to their depth
- Close the point map **Earthquakes_country**.

It is sometimes better to evaluate the information in the table, and not in the map.

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- Open the table **Earthquakes_country**.
- Click on the graph icon. Select the column **Year** for the X-axis and **Magnitude** as Y-axis.

- Why is 1988 so different from the rest?
- Display also the depth against the magnitude.
- Experiment some more with these graphs.
- Close the graph windows.

Defining the distance of the epicenters to RiskCity

One of the aspects which is important to know for defining the potential Peak Ground Acceleration of the earthquakes is the distance of the historic earthquakes to RiskCity. In order to evaluate that we will make a distance map from the city center of RiskCity, and calculate for each earthquake in the catalog, how far away it is from the city.

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- Rasterize the point map **City_center**. Use the georeference: **Country** and use a pointsize 20.
- The map that is made will contain 20 by 20 pixels with the city center and the rest is undefined.
- Run the distance program on the raster map **City center**. Name the output map: **Distance** . Use a precision of 1.
- Display the Earthquake catalog on top of the distance map. Now you can read for each earthquake how far it is to RiskCity.
- Close the map window.

Open a point map as a table: it is possible to open a point map as a table, as it is basically a list of coordinates, each with an identifier. This allows us to make special calculations. What we calculate here is the distance from each point to the RiskCity by taking the distance value from the map Distance for each point. We do that using the command: **Mapvalue.**
It read from the map distance, using the coordinate information. The result is divided by 1000 to convert from meters to kilometers.

The next step is that we are going to read in the distance values of the earthquakes to RiskCity for each earthquake in the catalog. We do this using a special feature of ILWIS.

☞

- Right click on the point map **Earthquakes_country**, and select *Open as table*. Make sure to select the command line option in the *view* menu
- In the command line, type:

  Distance=(mapvalue(distance,coordinate))/1000

- Make sure to use a precision of 1 (we want to know the distance with 1 kilometer accuracy only). As you can see many earthquakes in the catalog are located outside of the country and they do not have a distance.
- Close the pointmap table and open the table **Earthquakes_country**. Join the column distance from the point map in the table
- Make a plot of **Distance** against **Magnitude**. What can you conclude?

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k

Estimate Log N (M) = a- b M relation

In this exercise you can also use the earthquake catalog in order to estimate the Log N (M) = a – b M relation. N(M) is the number of earthquakes occurring within a region in a given time period with magnitude (M) greater or equal to M. a and b are constants to be determined.

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- Open the table **Earthquakes_country**. Order the table according to the column **Magnitude**, in ascending order (by selecting Columns, Sort) from the menu. You will see that there are a lot of records that do not have a magnitude recorded. We can't use them in the analysis.

We will now classify the Magnitudes into classes. Since the Magnitude is a value column and we want to classify them into a class domain, we will use a class/group domain for that. The domain/group is called **Magnitude_class**.

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- Open the domain **Magnitude_class** and look at the classification method used.
- Classify the magnitudes using the group domain **Magnitude_class**. You can do that using the formula:

  Magn_class = CLFY(magnitude, Magnitude_class)
- We will now count how many earthquakes there are in each class. Use Column, Aggregate. Select the column **Magn_class**, select the aggregation: **Count**, select group by **Magn_class**. Select output table: **Magnitude_class**, and output column: **number**.
- Close the table **Earthquakes_country**, and open the table **Magnitude_class** that you have just made.

How many records do not have a magnitude ?
What is the total number of records in the table?
For the calculation we only want to work with the records that have a magnitude.

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- Open the table **Magnitude_Class**. Manually change the value in the record that has no magnitude (No_data) to 0. You might first have to break the dependency of the column.
- Add a column Magnitude (value, with 1 decimal) and give for each class the maximum Magnitude.
- Since we want to calculate the cumulative from high to low and not reverse, we need to make a column **Order**, by which we can later order the table. **Order:=9.0-Magnitude**
- Sort the table (Column, Sort) by the column Order, so that it is ordered from high to low magnitude.

- Now calculate the cumulative number of earthquakes that have a certain Magnitude or larger. Use *Column*, *Cumulative*, select the column **Number**, and order by the column: **Order**. Name the output column: **N**
- You can see now the number of earthquakes that have a certain magnitude or higher. Calculate log N:

  LogN = log(N)
- Display the column **Magnitude** as X-Axis and **LogN** as Y-Axis. Calculate the Least square fit using a polynomial function with 2 terms.
- What can you conclude about the a and b values? And what about the fit of the curve?
- You can improve it by making a new column that only displays the LogN for Magnitudes > 4.5 , plot them and calculate the least square fit.
- What is the LogN – Magnitude relationship ?
- Close the map and table windows.

NOTE: You can get a better graph if you omit the low magnitudes.
You can also do the magnitude frequency analysis directly in a spreadsheet, as was explained in the exercise related to the Guide book.

	number	Magnitude	order *>	N	logN
7.5_to_8.0	5	8.0	1.0	5	0.6990
7.0_to_7.5	3	7.5	1.5	8	0.9031
6.5_to_7.0	16	7.0	2.0	24	1.3802
6.0_to_6.5	25	6.5	2.5	49	1.6902
5.5_to_6.0	69	6.0	3.0	118	2.0719
5.0_to_5.5	183	5.5	3.5	301	2.4786
4.5_to_5.0	768	5.0	4.0	1069	3.0290
4.0_to_4.5	1118	4.5	4.5	2187	3.3398
3.5_to_4.0	363	4.0	5.0	2550	3.4065
3.0_to_3.5	67	3.5	5.5	2617	3.4178
2.5_to_3.0	36	3.0	6.0	2653	3.4237
2.0_to_2.5	10	2.5	6.5	2663	3.4254
< 2.0	2	2.0	7.0	2665	3.4257
NO_data	0	?	?	0	?
Min	0	2.0	1.0	0	0.6990
Max	1118	8.0	7.0	2665	3.4257
Avg	190	5.0	4.0	1208	2.5147
StD	341	1.9	1.9	1246	1.0448
Sum	2665	65.0	52.0	16909	32.6909

Figure: resulting table of Magnitude-frequency calculation.

For advanced ILWIS users

The Magnitude frequency calculation that we have just calculated is based on the earthquake catalog for the entire country. In a real earthquake hazard study it is required to subdivide the areas into a number of seismotectonic zones, and calculate Magnitude-frequency relations for each of the zones.
The zones are indicated in the paper cited earlier, and are also available as a polygon map **Seismic_zones**.

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- Extract the earthquakes from the **Earthquakes_country** that are falling within a zone. Make a separate file of these.
- Use the method described above to make separate Magnitude-Frequency relationship for the various zones.

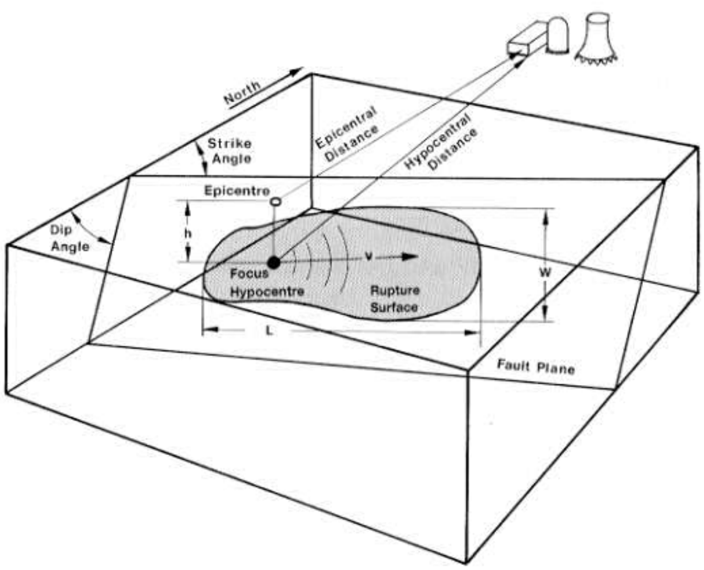
Once this part is finished we now have information on the magnitude-frequency relationships for the various seismo-tectonic zones. The next step is to estimate the PGA using attenuation curves.

Part 2: Estimation of PGA in rock in RiskCity for the various earthquakes in the catalog.

Expected time: 2 hours
Objectives:

- Estimation of PGA in rock in RiskCity for the various earthquakes in the catalog.
- Application of various attenuation functions and evaluate their difference.

Now that we know for the earthquake events in the catalog the distance to RiskCity, as well as the magnitude and the depth (only for those earthquakes for which this information is available), we can make an estimation of the Peak Ground Acceleration in rock in RiskCity as a result of these events. Input parameters for the scenario earthquake are location, depth, magnitude and occurrence time (hour during the day or night when the event strikes) (see figure below)



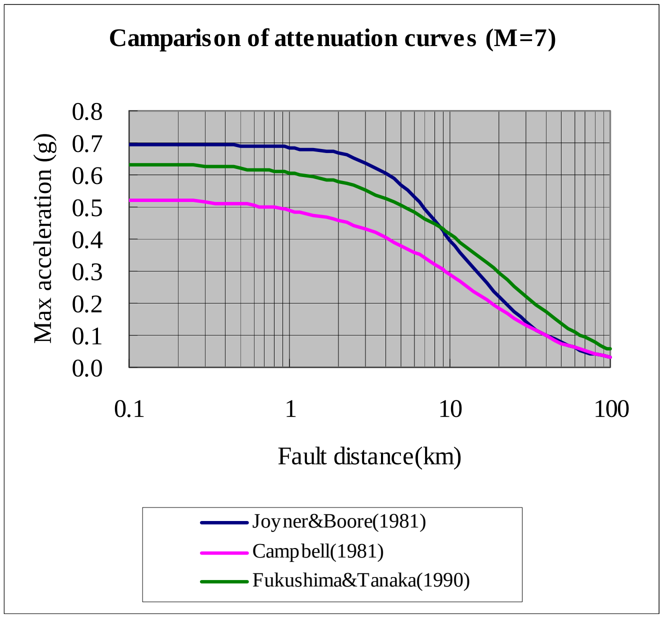


Figure: left: indication of main terms used in the earthquake analysis. Right: several examples of attenuation function, relating distance to fault with the PGA.

The relation between PGA, epicentral or hypocentral distance and Magnitude can be estimated using an **attenuation function**. An attenuation function gives the relations between Peak Ground Acceleration, and a number of factors related to the distance of the site to the earthquake, the depth of the earthquake and sometimes also the presence of rock or soil. Attenuation functions are derived by statistically analyzing a large number of strong motion records from different stations located at different distances, for the same earthquake events. The type of earthquake is very important (e.g. shallow or deep earthquakes) and the structural setting (different functions for subduction earthquakes, strike slip faults, and shallow earthquakes).

In the RADIUS method, PGA can be calculated using one of three attenuation formulas: Joyner & Boore (1981), Campbell (1981) or Fukushima & Tanaka (1990). See table below for functions.

Table 3 --- Attenuation Equations

AttnID	Source	Attenuation Equation
1	Joyner & Boore - 1981	PGA=10^(0.249*M-Log(D)-0.00255*D-1.02, D=(E^2+7.3^2)^0.5
2	Campbell - 1981	PGA=0.0185*EXP(1.28*M)*D^(-1.75), D=E+0.147*EXP(0.732*M)
3	Fukushima & Tanaka - 1990	PGA=(10^(0.41*M - LOG10 (R + 0.032 * 10^(0.41*M)) - 0.0034*R + 1.30))/980
	Note:	E-----Epicentral distance R----Hypocentral distance

The MMI will be calculated by the formula:

log(PGA*980)=0.30*MMI+0.014

or MMI=1/0.3*(log10(PGA*980)-0.014)

by Trifunac & Brady (1975). PGA unit is G.

For the study area there are also other attenuation curves proposed by Cáceres, D. and Kulhánek (2000). The first attenuation relation was derived by Climent et. al. (1994) from strong motion records of El Salvador, Nicaragua and Costa Rica with some additional records from Guerrero, Mexico:

$$\ln PGA = -1.687 + 0.553*M - 0.537*\ln R - 0.00302*R + 0.327*S$$

where **M** is the moment magnitude, **R** is the hypocentral distance (km) and **S** is a site coefficient (zero for rock sites and 1 for soil sites). The error is normally distributed with zero mean and standard deviation is around 0.6.
A second attenuation relationship is due to McGuire (1976) for the west coast of the United States:

$$PGA = 472 \times 10^{0:28M}(R + 25)^{-1:3I} ; \sigma_{(\log PGA)} = 0:222$$

The error term is normally distributed and σ is the standard deviation of the regression with zero mean.
The third attenuation relationship is by Schnabel and Seed (1973) for the northwestern United States (Table I). Finally, the fourth attenuation relationship is due to Boore et al. (1997), for shallow earthquakes in western North America:

$$\ln(PGA) = -1.08 + 1.036(M - 6) - 0.032(M - 6)^2 - 0.798 \ln \sqrt{(R^2 + 8.41^)} + 0.429\,\sigma ;$$
$$\ln(PGA) = 0.06$$

In this exercise we will use the function of Joyner & Boore – 1981. This formula is:

PGA=10^(0.249*M-Log(D)-0.00255*D-1.02)
D=(E^2+7.3^2)^0.5

E = Epicentral distance, M = Earthquake Magnitude

The distance was already calculated in the previous exercise.

☞

- Open the table **Earthquakes_country**. Join with the Point map **Earthquakes_country**, and read in the column **Distance**.
- Calculate a new column D with the formula in the command line:

  D=(distance^2+7.3^2)^0.5
- (Use a precision of 0.001 and 3 decimals. Adjust these values in the calculation window before accepting)
- Then calculate PGA using the formula:

  PGA=10^(0.249*Magnitude-Log(D)-0.00255*D-1.02)
- (Use a precision of 0.001 and 3 decimals. Adjust these values in the calculation window before accepting)
- Make a graph and display the distance against PGA.
- Also display the PGA values for the earthquake events in the map, and add the map Distance to it.

Questions:

- What can you conclude about the PGA values that can be expected based on the earthquake catalog?
- Are these values realistic?
- What can be concluded about the completeness of the catalog.

Now we will also try to calculate the attenutation curve based on the function given by Climent (See above)

☞

- Calculate the hypocentral distance using the formula:

  R:=SQRT((Depth^2)+(Distance^2))
- (Use a precision of 0.001 and 3 decimals. Adjust these values in the calculation window before accepting)
- Calculate now the attenuation function of Climent:

  LNPGA:= -1.687 + (0.553*Magnitude) - (0.537* ln(R)) - (0.00302*R) + (0.327*0)
- (Use a precision of 0.001 and 3 decimals. Adjust these values in the calculation window before accepting)
- Then calculate PGA using the formula:

  PGA_Climent:=EXP(LNPGA)
- (Use a precision of 0.001 and 3 decimals. Adjust these values in the calculation window before accepting)
- Make a graph and display the distance against PGA. Compare these values with the previous attenuation function of Joyner and Boore. What can you conclude?

Advanced exercise. For experienced ILWIS users:

- Calculate the hypocentral distance based on the epicentral distance and the depth. Name it: R
- Try to implement also the other attenuation functions indicated above.
- Compare the differences.

Part 3: Generating PGA maps for RiskCity

Expected time: 2 hours
Objectives:
- Select a scenario earthquake, for which PGA values in rock are calculated
- Use the surficial geological information in order to define ranges of soil amplification
- Generate a PGA map for the city
- Convert the PGA to MMI

Apart from the incomplete earthquake catalog we can also use another source of information, namely the results of the Global Seismic Hazard Assessment Program. The Global Seismic Hazard Assessment Program (GSHAP) was launched in 1992 by the International Lithosphere Program (ILP) with the support of the International Council of Scientific Unions (ICSU), and endorsed as a demonstration program in the framework of the United Nations International Decade for Natural Disaster Reduction (UN/IDNDR). In order to mitigate the risk associated to the recurrence of earthquakes, the GSHAP promotes a regionally coordinated, homogeneous approach to seismic hazard evaluation; the ultimate benefits are improved national and regional assessments of seismic hazards, to be used by national decision makers and engineers for land use planning and improved building design and construction. Regional reports, GSHAP yearly reports, summaries and maps of seismicity, source zones and seismic hazard are on the GSHAP homepage on http://seismo.ethz.ch/GSHAP/. Also we can use the information provided by the following study:

Cáceres, D. and Kulhánek, O. (2000) Seismic Hazard of Honduras. Natural Hazards 22: 49–69, 2000.

Based on this work we are using the following PGA values for RiskCity:

Return period	PGA g)
100 years	0.2 g
475 years	0.4 g

In this exercise we will calculate with a scenario earthquake with a magnitude of 7.7 occurring at a distance of 80 kilometers from the city at a depth of 30 kilometers.

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- Calculate the corresponding PGA value for this scenario, using the following formulae:
  - **D=(distance^2+7.3^2)^0.5**
  - **PGA=10^(0.249*M-Log(D)-0.00255*D-1.02)**

Soil Amplification

Soil amplification is estimated by the results from the previous steps, combined with a simple map with soil types. For each soil type a general amplification value from the table below will be used (values are according the the RADIUS method). You may also decide to adapt these values, after discussion.

Table --- Soil Type

Code	Description	Amplification Factor
0	Unknown	1.00
1	Hard Rock	0.55
2	Soft Rock	0.70
3	Medium Soil	1.00
4	Soft Soil	1.30

Soil information can be obtained from the Geological map (called Geological units).

☞

- Rasterize the map **Lithology**. Use the georeference **Somewhere**.
- Create an attribute table for the map, and add a column for the amplification values.
- Determine for each lithological unit what will be the amplification value from the table above
- Reclassify the geological units with the amplification factors, and name the map: **Amplification_factor**
- Multiply the amplification map with the PGA value that you obtained from the previous step. Call the map: **PGA**

Note:

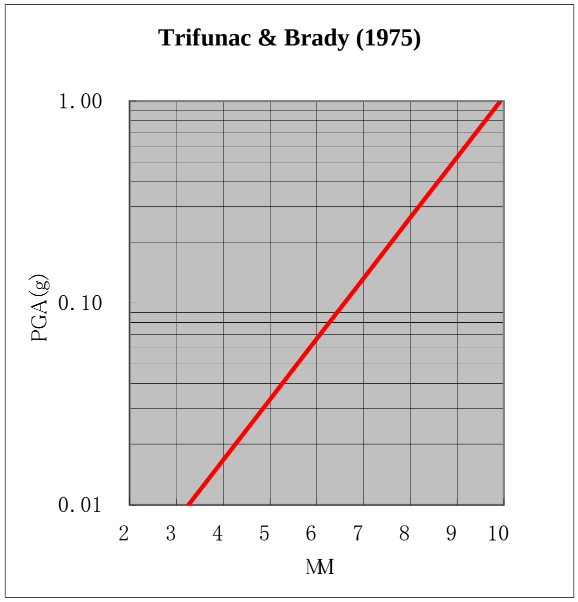
It should be mentioned here that this method is a simplification, and has severe drawbacks:

- Earthquake acceleration should not be presented as a single PGA value, because the natural frequency for buildings with different number of floors, should be related to accelerations in these specific frequencies, in order to be able to cause building resonance. As a rule of thumb, the frequency for building resonance can be evaluated with the formula: f = 10/N (where N = number of floors). Therefore response spectra should be used in stead of single PGA values.
- The amplification factors in the table are just a rough indication. Apart from the type of material, it is the soil depth which plays a very important role in amplification.

Converting PGA to MMI

In order to convert the Peak Ground Acceleration values to Modified Mercalli Intensity, the general relation of Trifunac & Brady (1975) is used:

MMI=1/0.3*(log10(PGA*980)-0.014)



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- Create a formula in Mapcalc (using the command line) for the PGA to MMI conversion and apply this for the map **PGA** calculated earlier. Name the output map: **MMI**
- Classify the **MMI** map in classes of 1 unit (e.g. from 0.5 - 1.5 will be class 1, etc).

Optional exercise: Earthquake microzonation using overburden thickness

Expected time: 2 hours

Objectives:

- Calculate the natural frequency of the soil in Riskcity
- Relate this with the natural frequency of buildings
- Make a zonation for different building altitudes

A very important factor in the response of the subsurface to an earthquake is the (soft) soil or overburden thickness. Soft soil sediments have a certain natural frequency which depend mainly on their internal (stiffness and strength) properties and thickness. Large ground motion at the surface is often a result of the fact that the soft soil start to resonate at their natural frequency under influence of an earthquake.

This exercise demonstrates how soil or overburden thickness can be used to delineate areas which will experience large ground amplifications at specific frequencies which correspond to natural frequencies of certain building types. In this manner a seismic microzonation map can be made for different building types, mainly based on the overburden thickness map.

Calculation of surface response and seismic hazard

Calculate the characteristic site periods of the overburden.

This step will evaluate the characteristic site periods on the basis of the soil thickness map and different assumed overburden properties.

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- Read the theory boxes below
- Calculate using MapCalc the *characteristic site period* of the overburden thickness map (**Soildepth**) for 2 different soil conditions on the basis of Equation 3:

$$f_0 = \frac{V_s}{4H}$$

- Calculate a raster map T250 with the characteristic site period for an average shear wave velocity (Vs) of 250 m/s (soft soil).
- Calculate a raster map T500 with the characteristic site period for an average shear wave velocity (V3) of 500 m/s (stiff soil)
- Contemplate what the difference of these different site period maps are in terms of hazard for different building types, i.e. high rise buildings vs. low rise buildings?

Theory

Soft ground effects

As the seismic wave travels from its source to the surface, the first part of its path is in rock. The last part, usually not greater than several tens of meters, is traveled through the soils overlying the bedrock. It was recognized as early as 350 BC by the Greek scientist Aristotle that soft ground shakes more than hard rock in an earthquake.
The intensity increments caused by this effects can sometimes be as large as 2 to 3 degrees in on the Mercalli intensity scale (Bard, 1994). Because large urbanised areas often are located along or near fertile ground, usually of alluvial or volcanic origin, this type of site effect is of great importance in earthquake hazard assessment worldwide.

Amplification on soft soils

The fundamental phenomenon responsible for the amplification of motion in soft sediments is the entrapment of body waves in the soft materials. This is caused by the impedance contrast that exists between soft sediments and bedrock. The impedance of a material is defined as:

$$I = V_s \cdot \gamma \qquad [1]$$

Where:
I = Impedance, in kgm-2s-1
V_s = Shear wave velocity, in m/s
γ = Mass density, in kg/m^3

Shear wave velocity is a very important soil parameter in earthquake engineering. Intuitively, one can already understand that a very strong or rigid soil (or a soil with a high shear wave velocity) behaves differently under vibration by an earthquake. The wave velocity is dependent on the soil's maximum shear modulus. Shear modulus can be determined under laboratory conditions and several theoretical and empirical relationships exist between shear wave velocity and shear modulus.

$$G_{\max} = \gamma \cdot V_s^{\,2} \qquad [2]$$

Where:
γ = Mass density (kg/m^3)
V_s = Shear wave velocity (m/s)

The contrast in impedance determines the amount of wave energy that is reflected when a seismic wave passes a layer boundary where the material properties change. This is shown by Zoeppritz' equation (Drijkoningen, 2000):

$$R = \frac{I_2 - I_1}{I_2 + I_1}$$

[3]

in which *R* is the reflection coefficient

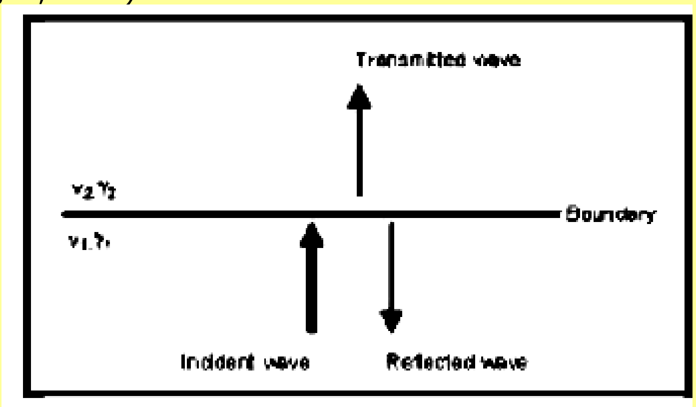

Figure Reflected and transmitted energy at layer boundary (Adapted from Drijkoningen, 2000)

Using some standard values for rock (γ=2700 kgm^{-3}, V_s=1000 ms^{-1}) and soil (γ=1750 kgm^{-3}, V_s= 1000 ms^{-1}), it can be concluded that for a wave passing through a boundary between soft soils and bedrock roughly 50% of the wave energy is reflected. At the surface, all of the energy is reflected because in air the shear wave velocity V_s is zero.

Upon entrapment, interference of the waves will start to occur. Apart from the initial wave, the reflected waves too become sources of motion. When looking at a horizontally layered structure, the problem simplifies to a one-dimensional one, incorporating only the trapping of body waves that travel up and down in the soft surface layers. When lateral discontinuities occur within the structure, the surface waves are influenced as well, making the situation very complex.

Trapped waves interfere, causing amplification of motion and resonance patterns. Resonance occurs when wave peaks coincide, resulting in a addition of amplitudes and a larger amplitude for the motion caused by these waves. Resonance does not occur at one specific frequency, but at several, resulting in site- and material specific resonance patterns. The mathematics behind this are explained below (from: Kramer, 1996):

The resonance spectrum for a uniform damped soil on rigid rock will look like the one in Figure below.

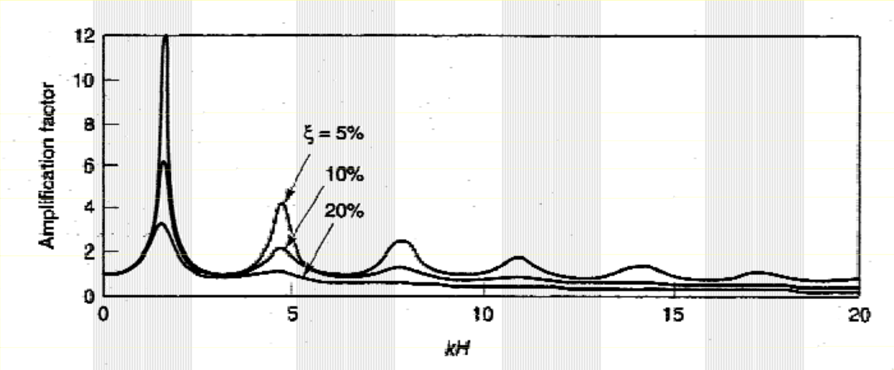

Figure Resonance spectrum for uniform damped soil on rigid rock (From Kramer, 1996).

While amplitude varies with damping, natural frequencies do not. The natural frequencies of a soil deposit are given by:

$$f_0 = \frac{V_s}{4H} \qquad \text{(fundamental)} \qquad [3]$$

$$f_n = (2 \cdot n + 1) \cdot f_0 \qquad \text{(harmonics)} \qquad [4]$$

With:

f_0, f_n = frequency for the first and n-th peak, in Hz

Vs = shear wave velocity, in ms-1

H = thickness of the soft soil layer, in m

As can be seen in Figure 4.3.2, amplification peaks quickly decrease in size due to damping. Because of this, the most important amplification occurs at the fundamental frequency. The fundamental frequency or the associated *characteristic site period* provides already a very useful indication of the frequency or period of vibration at which the most important amplification can be expected.

Surface motion

Upon arrival at the surface, the seismic waves cause a vibrating motion of this surface. The most important aspect of this motion is the acceleration. When a structure is subjected to a certain acceleration, this will result in a force acting on that structure. The physics behind this can be explained in a very simplified form by stating Newton's second law of motion:

$$F = m \cdot a \qquad [5]$$

Where:

F = Force, in Newton
m = Mass of the object, in kg
a = Acceleration to which the object is subjected, in m/s^2

Since the mass of the object is invariable, the force exerted on it is directly proportional to the acceleration, making this the most important parameter in a microzonation study.

Besides the acceleration, the frequency at which it occurs is another property of surface motion that is of great importance in causing structural damage. Every object has its own natural frequency (f_N, mainly determined by its stiffness (k) and mass (M). A relationship is given in the equation below:

$$f_N = \frac{1}{2\pi}\sqrt{\frac{k}{M}} \qquad [6]$$

Generally, a high building is less stiff (more flexible) than a smaller building and a high building is obviously heavier than a small building. Intuitively, but also considering the previous equation, one can see that taller buildings generally have lower natural frequencies than a small buildings.

In order to determine the exact typical frequency of an object is a very complex issue, and therefore the International Conference of Building Officials have issued a number of rules of thumb for estimating it. The most commonly used one, though originally designed for moment frames and not for concrete and masonry buildings, is:

$T = 0.1 \cdot N$ or $f_N = \frac{10}{N}$ (Day, 2001) [7]

in which N stands for the number of storeys of the building, and T and f_N denote period in seconds and natural frequency in Hertz, respectively.

Response spectra analysis

As mentioned, the frequency at which a certain acceleration takes place is a very important factor in the analysis of surface motion. In order to obtain a good idea on seismic hazard caused by surface motion, the surface response can be plotted against frequency, producing a graph as shown in **Error! Reference source not found.**.

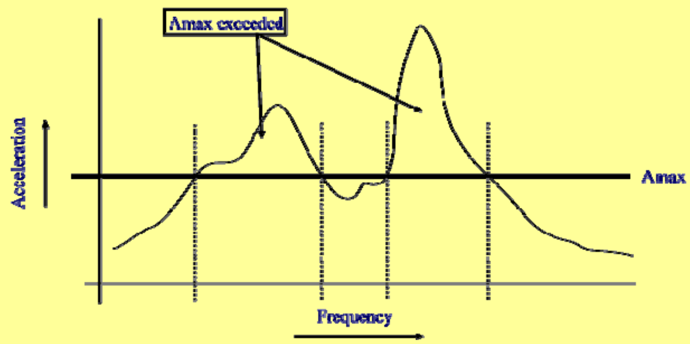

Figure. Frequency dependency of spectral acceleration combined with maximum sustainable acceleration of a building.

As can be seen in the figure, collapse risk of a building capable of sustaining accelerations up to A_{max} depends on the frequency at which shaking takes place. The response spectrum being such an important factor, it usually is the key element in any microzonation study.

Classification of characteristic site period into hazard zonation map

If the natural period of a building corresponds to the natural period of the overburden at that site, there is a potential hazard that this building will experience large damage. This will due to the large ground accelerations as a results of soil resonance.

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- On the basis of equation 7, and the altitude map of the city (**Altitude_dif**) calculate a map with the natural frequencies of the buildings. Name the map: **Building_freq**.
- Make a class domain (Building class) on the basis of this table
- Re-classify the maps T250 and T500 (use: *Slicing*) into raster maps T250_class and T500_class, respectively. Compare them with the building_freq map. In which areas resonance might be expected?

Table 1

Building class	N_{max}	Description	Natural period (s)	Natural frequency (Hz)
I	1	Single storey buildings		
II	2	Single family houses		
III	5	Offices, apartment buildings		
IV	10	Shopping malls, hospital		
V	>10	High rise buildings		

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- Compare the two classified maps. Is this what you expected? What are your conclusions?
- What type of additional information would you need in order to make a risk assessment on the basis of this hazard zonation?

References

- Bard, P. 1994. Local effects of strong ground motion: Basic physical phenomena and estimation methods for microzoning studies. Laboratoire Central de Ponts-et-Chausees and Observatoire de Grenoble.
- Day, R.W. 2001. Geotechnical Earthquake Engineering Handbook. McGraw-Hill, 700 pp.
- Kramer, S.L. 1996. Geotechnical Earthquake Engineering. Prentice Hall, Upper Saddle River, New Yersey 07458. 653 pp.

Exercise 3. Flood hazard assessment using 2D flood propagation model outputs

Expected time: 3 hours
Data: data from Subdirectory: /Exercise 3 Hazard assessment/Flood hazard
Objectives: This exercise aims at showing how to extract flood parameters through the simulation of diferent return periods flood events. Flood depth, velocity, and rising time will be extracted for each simulated return period event using SOBEK 1D-2D flood propagation model.

Background information: River morphology and landforms

River geomorphology consists in complex landforms, produced by rivers erosion/sedimentation, that vary from the source to the mouth. The overall river environment can be divided into three main sections (Fig. 1).

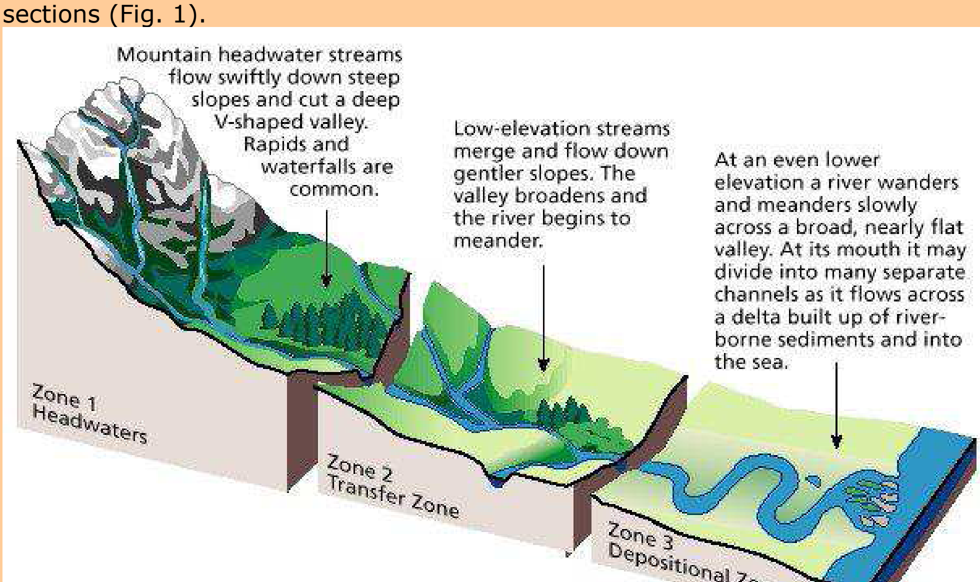

Fig. 1: longitudinal river sections

Starting from the source, the Headwaters represent the younger stage of the river: here the stream flows in upstream areas with high internal relief; the regime is torrential: very high flow velocity due to the high slope gradient, low discharges or even waterless in dry seasons and high discharges picks in rainy seasons. Due to the high flow velocity, the dominating pattern is the straight channel following the valley bottom. The river erosion is dominating on the deposition and it is stronger during high discharges periods; the river creates with its activity steep V-shaped valleys and when the slope changes abruptly at the exit of the mountain chains, the river widen into streams and form the so called alluvial fans, concave deposition bodies formed by coarse sediments (gravels and coarse sand).
The Depositional Zone next to the mouth represents the terminal stage of the river path: the river widely meanders in downstream lowland flat areas; the discharges are higher and more constant in the course of the year. The floodable areas next to the water course are close to the elevation of the river or even lower if backswamps systems have been created; the flood prone region is identified as floodplain. Part of the floodplain can be protected by artificial or natural levees. The deposition is dominant, and it increases during flood events. When the river overflow the bankfull conditions the water spreads onto large areas in the floodplain, where it deposits the sediment load, which is mainly suspended silt and clay. The bed load (sand – fine sand) is deposited right next to the river and it forms the natural levees along the main course. The compaction of the clay material in the floodplain produces a relative subsidence on those areas that can become lower than the river channel. The flow characteristics are: low flow velocity, high suspended load, and high deposition rates especially during flood events. The position and the width of the meander slowly changes during the periods of normal discharge, where erosion and deposition take place simultaneously.

Transfer Zone represents the transition section from upstream to downstream areas. The channel pattern can be straight (characteristic of the upstream area) meandering (present in the downstream areas), or braided. This pattern consists of a series of secondary channels meeting and re-dividing each others. Braided channels have steeper gradients than meandering rivers but more gentle than straight channels; the channels remain stable during the normal flow while they change shape and direction during flood events.

Background information: Flood definitions and classifications

- A flood is a natural event for rivers and streams. Excess of water from snowmelt, rainfall, or storm surge accumulates and overflows onto the banks and adjacent floodplains. Floodplains are lowlands, adjacent to rivers, lakes (and oceans) that are subject to recurring floods (FEMA, 2001).
- A flood is a high stream flow that overtops 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 damage and loss of life.
- Flood is a natural and recurring event for a river or stream.

The term flood includes different events; the primary differences among flood types are established considering the triggering factors and the morphological characteristics of the affected areas, which drive the duration and the intensity of the flood events.

Riverine Floods are the result of intense and/or persistent rain for several days or even weeks over large areas. The riverine floods occur in level land with a very low internal relief (transition–deposition zone), where the river shows a braided or, more frequently, meandering pattern; such flood prone areas are identified as floodplains. The flood depth varies according to the morphology of the area. The flood extent can be as wide as the floodplain during extremely severe events. The flow velocity is generally low and it rapidly decreases moving away from the main channel. The water rising rate is slow and the flood duration last from days to weeks, especially if backswamps are present in the floodplain, or if the water overflowed the levees systems. Weather predictions and boundary conditions (upstream-downstream catchments conditions and tributaries contributions) are important in riverine flood early warning.

Flash Floods are mostly local events and scattered in time and space. They are the result of intense rainfall over small upstream areas within a short period of time (usually less than 6 hours) causing water to rise and fall quite rapidly. They affect mainly areas with moderate to high slope gradient. Flash floods are extremely dangerous for their sudden nature; the flow velocity is high and the water level rises very rapidly. The sediment load is abundant and it can include from fine sediments to gravels and blocks, due to the high transport capacity of the water body, increasing the destructive power of the flash flood. The flood duration is short and the early warning systems are based on precipitations predictions.

…

Figure xxx : Opening screen of SOBEK.

Post processing of flood modeling

Hydraulic simulation software, for instance SOBEK, can be used to analyze the flow of water in greater detail. Especially 2D flood models can be used to characterize flood events over complex topography, such as in an urban environment. In this exercise we will work with the data that is generated by hydraulic simulation software, for instance SOBEK.

The output data of the model consists of a series of water depth and flow velocity maps at different time steps. In this case the maps are generated at one hour intervals. The model also creates a set of maps that summarize the simulation; these include a **maximum water depth** map (representing the highest water depth value that was reached at some point during the simulation), a **maximum flow velocity map** (representing the highest flow velocity value that was reached at some point during the simulation), two maps that indicate **the time at which the maximum water depth and the maximum flow velocity** were reached and a map that shows the time at which a pixel **started being inundated**.

This exercise consists of two parts: Part 1 is a classical flood hazard assessment. Here we will combine the maximum water depth maps of flood scenarios with different return periods into a map giving the annual probability of inundation. Part 2 focusses on one single event and is a demonstration how the flood simulation results can be used to calculate derivative maps that characterize the flood event in a more meaningful way.

PART 1: Flood hazard map

Data:

File name	Meaning
Max_h_5y Max_h_10y Max_h_20y Max_h_50y Max_h_100y Max_h_200y	Maximum water depth, flood return period = 5 years Maximum water depth, flood return period = 10 years Maximum water depth, flood return period = 20 years Maximum water depth, flood return period = 50 years Maximum water depth, flood return period = 100 years Maximum water depth, flood return period = 200 years
Building_map_segments	Vector map with the building blocks.
DEM10 Building_map_segments	Georeference (10m) Domain and representation of the vector map

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- Open the maps **max_h_5y** and **max_h_200y** and check the content of the file. Both maps contain the water depth in meters.

Question 1:
Which map shows the greatest flood extent and water depths; Why?

- Close both maps.

Hazard is defined as the probability that an event of a certain magnitude occurs in a given area within a specified period of time. If we want to calculate the annual probability, that is the chance that a flood of a certain magnitude occurs in the coming year, we have to divide 1 by the return period.

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- Fill in the following table:

Map	Return Period	Annual Probability
Max_h_5y	5 Year	
Max_h_10y	10 years	
Max_h_20y	20 years	
Max_h_50y	50 years	
Max_h_100y	100 years	
Max_h_200y	200 years	

- Create the map with the annual probability for the flood with the 5 year return period by typing the following statement in the command-line:

Prob_5y:=iff(max_h_5y>0, xxx, 0)

Where xxx is the annual probability you calculated in the table.

Question 2:
What is the meaning of this ILWIS statement?

- Repeat this for the other 5 maps and create the maps Prob_10y, Prob_20y, Prob_50y, Prob_100y and Prob_200y.

We now have 6 maps with the annual probability. To combine the maps into an integrated hazard maps we have to follow a stepwise approach.

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- Type the following statement in the command line:

Hazard_a:=max(prob_5y,prob_10y,prob_20y)

followed by <enter>; Have a look at the intermediate map.

- Then type:

Hazard_b:=max(prob_50y,prob_100y,prob_200y)

- Combine both maps, by typing in the command line:

Hazard:=max(hazard_a,hazard_b)

- Have a look at the result
- Close all maps.

To combine this map with other data-layers, for instance topographical data, it is useful to transform the raster format hazard map into vector format.

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Question 3a:
What is the current domain of the hazard map?

Question 3b:
Why is it not possible to transform maps with such a domain to vector format?

In order to make the conversion to vector format we have to classify the hazard map. In ILWIS this is called "slicing". The first step is to create a domain to define the class boundaries; then we "slice" the hazard map.

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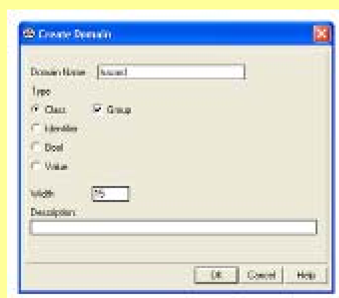
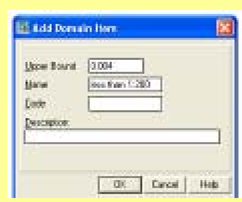


- Go to the "*file*" pull-down menu on the ILWIS main page and select "*create*" and then "*domain*".
- Give the new domain the name "`hazard`"
- Make sure the tick-box "*group*" checked
- Click <*OK*>
  The *create domain group hazard* window is opened
- Use the <insert> key of your key-board open the "add domain item" window.
- Type for Upper Bound: `0.004` and for Name: "`less than 1/200`". Click <OK>.
- Add the following class boundaries:



Upper Boundary	Name	Color
0.004	Less than 1/200	
0.009	1/200	
0.019	1/100	
0.049	1/50	
0.099	1/20	
0.19	1/10	
1	1/5	

- After the class boundary is added, close the "domain group" window.
- In the ILWIS catalogue window open the class representation "hazard" and chance the color scheme as indicated in the table.
- Right-click on the map "`hazard`" and select *image processing* and then *slicing*.
- Give the new map the name: `hazard_cla`
- Select for Domain: "`hazard`"
- Click <*OK*>.
- Open the new map and add the segment map "`building_map_segments`"
- Save the view as "`hazard`".
- Right-click on the map `hazard_cla` and select "*Vectorize*" and then "*raster to polygon*"
- Accept the defaults and name the output map `hazard_cla`.
- Click <show> to have a look at the result.

PART 2: Indicator maps

Data:

Name	Type	Meaning
RiskCity_DTM **Manning_10**	raster	Digital Elevation Model Surface roughness map: buildings have n=1, streets n=0.03, parks and other features n=0.1.
import **slicing** **classify** **rising** **impulse** **duration** **sediment**	Script	Imports SOBEK asci-files in ILWIS, replaces no_value data with zero-values and adds a standard georeference to all maps. Classifies the maximum maps Classifies the hourly maps to create map lists Calculates the speed of rising of the water level in m/h Calculate the maximum impulse in m^2/s Estimates the flood duration Estimates the relative sedimentation / scouring potential of the flood
Building_map_segment	vector	Contains the building blocks of RiskCity
Building_map_segment **Duration** **Maxc** **Maxh** **Maxi** **Maxr** **Sediment** **ttf**	Domain / representation	 Group domain to classify the duration map Group domain to classify the maximum flow velocity map and the hourly flow velocities maps Idem for waterdepth Idem for impulse Idem for rising of the water level Idem for sediment estimates Idem for the flood propagation (time to flooding)
DEM10	georeference	Standard georeference for all raster maps
 DM1MAXD0.ASC **DM1MAXC0.ASC** **DM1TMAXC.ASC** **DM1TMAXD.ASC** **DM1TWT00.ASC**	Asci maps	SOBEK output (summary maps) Map contains the maximum water depth during the scenario Map contains the maximum flow velocity during the scenario Map contains the time at which the maximum flow velocity was reached. Map contains the time at which the maximum water depth was reached Map contains the time at which a pixel is flooded for the first time.
DM1C0000.asc **DM1C0001.asc** **DM1C0002.asc** **DM1C………….** **…….** **DM1C0048.asc** **DM1D0000.asc** **DM1D0001.asc** **DM1D0002.asc** **DM1D………….** **…….** **DM1D0048.asc**	Asci maps	SOBEK output at hourly intervals DM1C is velocity maps DM1D is water depth

The output data of the model consists of a series of maps, which represent flood depth and flow velocity at different time steps. They are in ASCII format.

The aim of this exercise is to derive several indicator maps that may be used to characterize the complexity of flood events. We need to carry out the following steps:

- Import the files in ILWIS;
- Change the georeference;
- Classify the map in a limited number of classes;
- Create the indicator maps.

Importing the SOBEK output files in ILWIS

The first step in the analysis is the import of the datafiles in ILWIS. We will do one file manually, and after that use a script to import the rest.

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- Open the asci file **Dm1d030.asc** in a texteditor (notepad) and check the content of the file (it contains water depth in meters). Close it again
- From the file menu select *Import / Maps*.
- Select the option *ArcInfo.ASC or .NAS (Non-compressed ASCII raster)*
- Import the asci-file **DM1d0030.asc** and give it the ILWIS file name **d30**
- Open the map **d30** (play with the stretch to get a better result on the screen) and check the result.

It would be possible to import all maps like this; however, it would take a lot of time. Therefore we have made a script called **Import** that will do the import in one time. The script is given below, with a description of the activities in italics.

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- Run the script file Import by typing the following statement in the command line: `run import`. **This will take some time.**
- Have a look at some of the resulting maps.

You can see that the maps have a larger pixel size than the other maps in the dataset (10 meters instead of 1 meter) and that they cover a different area. This was done to reduce the calculation time in the SOBEK model.

Script	Description
rem import waterdepth files import arcinfonas(dm1d0000.asc, h000x) import arcinfonas(dm1d0001.asc, h001x) …… …… import arcinfonas(dm1d0047.asc, h047x) import arcinfonas(dm1d0048.asc, h048x)	*Import files the hourly waterdepth ASCI maps using the ArcInfo NAS import option for ASCII files. An ILWIS file with the name h000x is created.*
rem import flow velocity files import arcinfonas(dm1c0000.asc, c000x) import arcinfonas(dm1c0001.asc, c001x) …… …… import arcinfonas(dm1c0047.asc, c047x) import arcinfonas(dm1c0048.asc, c048x)	*Idem for the hourly flow velocity maps*
rem georeferencing setgrf c*.mpr dem10.grf setgrf h*.mpr dem10.grf	*All imported files get the same georeference dem_10m.grf*
del -force h*.grf del -force c*.grf	*The other georeference files are deleted*
rem ongedfinieerd wordt 0 h000:=ifundef(h000x,0,h000x) h001:=ifundef(h001x,0,h001x) …. ….. h047:=ifundef(h047x,0,h047x) h048:=ifundef(h048x,0,h048x)	*The undefined values in all the map are replaced by zero- values*
c000:=ifundef(c000x,0,c000x) c001:=ifundef(c001x,0,c001x) ….. ….. c047:=ifundef(c047x,0,c047x) c048:=ifundef(c048x,0,c048x)	*Idem for the velocity files.*
del -force h???x.mpr del -force c???x.mpr	*All intermediate maps are deleted*
import arcinfonas(dm1maxd0.asc, max_hx) import arcinfonas(dm1maxc0.asc, max_cx) import arcinfonas(dm1twt00.asc, ttfx) import arcinfonas(dm1tmaxc.asc, tmax_cx) import arcinfonas(dm1tmaxd.asc, tmax_hx)	*The summary maps are imported*
setgrf max_hx.mpr dem10.grf setgrf max_cx.mpr dem10.grf setgrf ttf.mpr dem10.grf setgrf tmax_cx.mpr dem10.grf setgrf tmax_hx.mpr dem10.grf	*The summary maps get the georeference*
max_h:=ifundef(max_hx,0,max_hx) max_c:=ifundef(max_cx,0,max_cx) tmax_h:=ifundef(tmax_hx,0,tmax_hx) tmax_c:=ifundef(tmax_cx,0,tmax_cx) ttf:=ifundef(ttfx,999,ttfx)	*Undefined values are replaced by zero-values*
del -force max_hx.mpr del -force max_cx.mpr del -force tmax_hx.mpr del -force tmax_cx.mpr del -force ttfx.mpr	*All intermediate maps are deleted*
del -force max_hx.grf del -force max_cx.grf del -force tmax_hx.grf del -force tmax_cx.grf del -force ttfx.grf	*All georeferences are deleted*

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- Open the maps **RiskCity_DTM** and **manning_10**; what information do these map contain?
- Open the map **max_h**. (apply a stretch of 0 – 10 in the display communication window)
- Display the segment map **Buildings_map_segments** on top of it, so you can study the map together with the topographical information.
- Do the same with the maps:
  - **max_c** (apply a stretch of 0 – 2)
  - **ttf** (strectch 0 – 15),
  - **t_maxh** (stretch 10 – 15)
  - **t_maxc** (stretch (5 – 25)

Question:
What are the units of these 5 maps?

Calculating flood parameter maps

A lot of important information for hazard and risk assessment is contained within the time series of maps with water depth and flow velocity. To analyze this data an aggregation procedure has been developed to create seven parameter maps that describe the different aspects of the flood event. These parameter maps are (see Figure xxx):

- Maximum water depth
- Maximum flow velocity
- Flood propagation characteristics (also Time to Flooding)
- Maximum impulse
- Maximum rising of the water level
- Duration
- Sedimentation

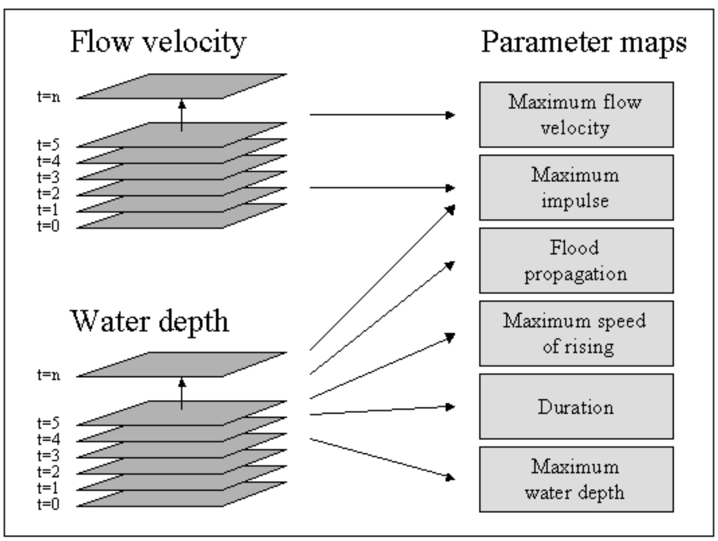

Figure xxx. Transformation of the model output maps into flood hazard parameter maps.

The first three maps are already calculated by SOBEK; These maps are **max_h**, **max_c** and **ttf**.

1 Maximum water depth (unit: m);
This map shows the maximum depth that occurred during the inundation. The rationale behind this parameter map is that areas with deep water are more dangerous to people and potentially more damaging to objects like houses and cars. It identifies areas where the second floor of houses, or even the third or fourth floor, is not a safe refuge. The maximum water depth map also serves as a possible means for model calibration. Maximum water depth is one of the few flood parameters that can easily be retrieved after a flood event because of wetting marks in and on structures.

2 Maximum flow velocity (unit: m/s);
This map shows the maximum flow velocity that occurred during the inundation. The rationale behind this parameter is that velocity is a component of the floodwater that can sweep people off their feet and make cars float away. This map shows where preferential flow paths may develop that could be dangerous for children, adults and cars.

3 Flood propagation characteristics (unit: h);
This map shows how the flood propagates through the area. After each time interval the flooded area is identified and compared with the situation at the previous time interval. It records the time at which a cell is inundated for the first time. The rationale behind this parameter map is that it shows how much time it takes for the first floodwater to reach a certain location and thus how much warning time people have to prepare themselves. Areas that are flooded quickly are potentially more dangerous than areas further away.

The ILWIS script "**slicing**" classifies these three maps.

☞

- Run the script "**slicing**"
- Open the three created classified maps
  - maxh_cla
  - maxc_cla
  - ttf_cla

4 Maximum impulse (unit: m^2/s);
This map shows the maximum impulse that occurred during the inundation. The impulse is calculated at each time step by multiplying water depth and flow velocity. For each pixel this value represents the amount of movement of the water mass (per pixel the mass only depends on the water depth, since the surface area of the pixel and volume weight of water are constant). The rationale behind this parameter is that flow velocity alone does not suffice to estimate the amount of potential damage or danger to humans and cars to be swept away. Shallow water with a high flow velocity does not have a lot of kinetic energy or momentum and neither has deep, but practically still-standing water. Deep, fast flowing water however is potentially dangerous for people and vehicles and is potentially damaging to objects like houses and crops. Especially in urban

environments this parameter shows that streets become preferential flow paths for water.

☞

- Run the script "**impulse**"
- Open the classified map **maxi_cla**

5 Maximum rising of the water level (unit: m/h);
This map shows the maximum speed at which the water level rose at some point during the inundation. It is calculated by taking the difference between two successive water depth maps, divided by the time interval between the two maps. The result is an increase in water depth per hour. The rationale behind this parameter map is that a quick rising of the water level is potentially dangerous for people who may not have sufficient time to seek higher ground or elevated structures.

☞

- Run the script "**rising**"
- Open the classified map **maxr_cla**

The parameters **water depth**, **flow velocity**, **impulse and rising of the water level** fluctuate with time. In ILWIS it is possible to display these mapseries as an animation. But before that is possible the maps in the mapseries must be classified first, else they cannot be included in a map list. The script "classify" does exactly this.

☞

- Run the script "**classify**"
- Create a map list (*file* menu, *create*, *map list*)
- Name it "velocity"
- Move all the *c---_cla* maps to the right-hand side window (use the <Ctrl> key to make multiple selections)
- When all the c---_cla files are moved, click <OK>
- In the ILWIS catalogue window go to the *view* menu and select "*customize catalogue*". Check the tick-box "*hide objects that are member of an object collection*". Click <OK>
- Open the map-list "**velocity**"
- Click on the "open as slide show" icon  in the top map-list window, accept the default settings and click <OK>.
- Click <OK>
- The animation with the flow velocity will start.
- Create map lists for **depth**, **impulse** and **rising** and add the maps *h---_cla*, *i---_cla* and *r---_cla* respectively.
- Display each map series as an animation.

6 Duration (unit: h).

This map estimates the time the floodwater remains at a certain location. It is based on several assumptions regarding the drainage of the floodwater from the flooded area. For instance in the studies presented in this book it is assumed that there is free drainage at the lowest point of the inundated area through a "canal" of a certain width (1 or more pixels wide). It also requires a sufficiently long simulation run that includes the descending limb of the flood wave. The rate of water level change is calculated as dh/dt, where dh is the difference between the maximum water depth and the water depth at the end of the simulation and dt is the difference between the time at the end of the simulation and the time the maximum water depth is reached. The duration is estimated by extrapolating this rate of change until the moment of a water depth of zero is reached - see Figure xxx9.

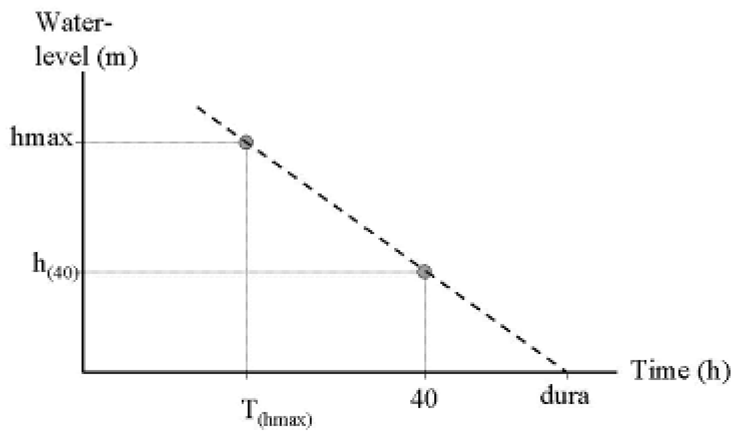

Figure xxx. Estimation of the parameter "duration".

The rationale behind this parameter is that it gives a first, rough impression of how long the floodwater will stay in the area. This is the minimum time period that people have to be relocated, that businesses and industries are closed and that transportation in and through the area might be impossible or hindered. It is a strong parameter to assess the economic and social impact of the flood on the people living and working in the area. It is also an important parameter to estimate agricultural damage because many crops, like fruit bearing trees and vineyards can withstand inundation of their stems for a short time (usually some days), but if the period becomes too long the roots will starve from oxygen depletion and the trees will die.

☞

- Run the script "**duration**"
- Open the classified map **duration_cla**

Question:
What is the estimated duration of this flood event? What is the time unit?

7 Estimation of scouring and sedimentation

The estimation of the sedimentation and scouring is based on the Rouse number that gives the ratio of downward (falling) velocity of a particle to the shear velocity (turbulence acting to keep particles suspended). The method applied here was suggested by Kleinhans (2002).

$$Z = \frac{W_s}{\kappa u^*} - 1 \qquad 7.1$$

Where:
☐ = Rouse number [-]
☐ = Kármàn constant (=0.4) [-]
u* = Shear velocity [m/s]
Ws = Downwards velocity for a particle of certain grain size [m/s].

This criterion is calculated at the hourly time steps, for sediment particles with a diameter of 210 ☐m. When Z > 0, sedimentation is possible because the downward velocities are larger than the upward directed velocities. The particles present in the water will experience a net downward movement and may sediment on the surface. When Z < 0, then the upward directed velocities are higher than the downward velocities which means there is potential for uplifting of particles (scouring) and available particles will remain in suspension. The downward velocity Ws of a particle with a diameter between 100 and 1000 ☐m (fine sand) is given by:

$$W_s = 10\,\frac{\nu}{d}\left(\sqrt{1 + \frac{(0.01(s_p - s_w)/s_w\, g\, d^3}{\nu^2}} - 1\right) \qquad 7.2$$

Where:
☐ = viscosity of water = 1.2 * 10-6 [m2/s]
sp = density of quartz = 1.65 * 103 [kg/m3]
sw = density of water = 1 * 103 [kg/m3]
d = grain size diameter = (in this study) 210 * 10-6 [m]
g = gravity acceleration = 9.81 [m/s2]

Since all parameters in formula 7.2 are constant, Ws is approximately 0,01 m/s for a particle with a diameter 0f 210 ☐m. The shear velocity is given by:

$$u^* = \frac{\kappa\ U}{\ln\left(\frac{0.37\,h}{3.97\ 10^6\ n^6}\right)} \qquad 7.3$$

Where:
U = flow velocity [m/s]
h = water depth [m]
n = Manning's roughness coefficient

The flow velocity and water depth are computed by the model, whereas the spatial distribution of Manning's coefficient is one of the known boundary

conditions. All parameters are known at hourly time-steps. The final sedimentation / scouring gives the accumulated hourly values of the dimensionless parameter Z to identify areas where sedimentation or scouring are dominant. In this procedure, positive and negative values can cancel each other out: the higher the value, the more potential for sedimentation; the lower the value the more potential for scouring. Zero means no net sedimentation or scouring. To estimate the availability of sediment, three additional assumptions were made:
the sediment-load of water flowing into the area decreases inversely with time (high at the start, then decreasing with time);
the sediment is distributed uniformly in the floodwater and is never zero - the sediment fluxes are proportional to the water fluxes;
sedimentation and scouring occurs only in the first 150 hours of the flood (the time period for which this parameter map was calculated).

This approach does not yield estimates for sedimentation and scouring in terms of deposition or scouring depth, but provides an indication where and to what degree sedimentation and scouring can be expected.

☞

- Run the script "**sediment**"
- Open the classified map **sediment_cla**

Question:
The maps show areas of potential scouring and deposition. What does that mean?

Deliverables: 7 maps: **maxh_cla**
maxc_cla
maxi_cla
maxr_cla
duration_cla
ttf_cla
sediment_cla

☞

- Open each the first of the seven above mentioned maps.
- Add to it the vector map **buildings_map_segment**
- Under the "*file*" menu in the map-window select "*create layout*"
- Give a name to the map-view (e.g. `maxh` for the first).
- For scale use 1:5000 and click <OK>.
- Click on the map to make it active
- In the lay-out window under the "*insert*" menu, select *legend*.
- Select the appropriate map legend. Click <OK>
- Make sure that the tick-box transparent is not checked.
- Click <OK>
- If you want you may add additional map attributes such as scale, north arrow, etc. to the map.
- Under the *file* menu in the lay-out window you select "*export to bitmap*"
- Give an appropriate name and reduce the resolution to 40 or 50 dpi (make sure the result is still readable.
- Repeat this for all seven maps.
- Paste all seven maps in a MS-Word or MS-Powerpoint file.
- Create also a layout of the `hazard_cla` map you created in part 1 and add it to the document.
- This document must be submitted.

Exercise 3F2: Flood hazard monitoring using multi- temporal SPOT-XS imagery

In this exercise you will use multi temporal satellite images to evaluate the flood problem in the confluence area of the Ganges and Jahmuna rivers in Bangladesh, Southwest of the capital of Dhaka. In this area river dynamics are impressive. Rivers change their course for kilometers within years.

You will evaluate the areas covered by water during three periods:

- During the dry season, using a SPOT image from 9-1-1987,
- During a moderately severe flood, using a SPOT image from 7-11-1987,
- During a severe flood, using a SPOT image from 10-10-1988.

Introduction

Bangladesh probably is the most affected country by natural catastrophes, especially floods, in the world. Approximately 40 percent of the country is subjected to regular flooding. It contains more than 250 perennial rivers, of which 56 originate outside of the country, in Tibet, India, Bhutan and Nepal. Ninety percent of the river discharge from the main rivers, the Ganges, the Brahmaputra and the Meghna originates from other countries.

The primary cause of flooding in Bangladesh is directly or indirectly related to rainfall in the catchment areas of the three major river systems. The rainfall, together with snow-melt from the Himalayas generates enormous quantities of runoff to be discharged through Bangladesh into the Bay of Bengal.

Moderately strong semidiurnal tides are prevailing in the Bay of Bengal. Due to the extreme flat topography of the country (half the country lies below the eight meter contour line), the tidal influence reaches very far into the country. During the monsoon, recession of the floodwater is delayed due to the tidal effect. Cyclonic sea flooding occurs when due to the friction of the wind on the surface of the sea a storm surge moves inland.

From 1960-81 Bangladesh has suffered 63 disasters with the loss of 655.000 lives. Of these events, 37 were tropical cyclones, which killed 386.200 people. The last major floods were in 1987 and 1988 and a cyclone in 1990, killing about 140.000 inhabitants on the Bay of Bengal coast.

The evaluation of the flooding hazard is an international effort, as rainfall and river discharge monitoring in the entire catchment of the major rivers is required, as well as monitoring of sea levels and warning systems for tropical cyclones. For flood stage mapping and river dynamics determination, digital image processing and analysis of sequential SPOT images using GIS can be of large use. The study area covers the confluence of the rivers Meghan and Ganges, south east of the capital of Dhaka.

With the images from the three dates you can evaluate two things:

- Monitoring the extend of inundations,
- Monitoring river dynamics.

First a method has to be used for discriminating water surfaces from the other land cover types present in the images.

Selection of a single band in which water can be differentiated

All images are multi spectral SPOT-XS images, with a spatial resolution of 20 meters, consisting of three bands:

- Band 1: spectral resolution 0.5-0.6 µm: green portion of the visible spectrum.
- Band 2: spectral resolution 0.6-0.7 µm: red portion of the visible spectrum.
- Band 3: spectral resolution 0.8-0.9 µm: near infrared portion of the spectrum.

This method can be applied when individual bands are selected in which water has a specific reflectance that does not spectrally overlap with other cover classes. In this exercise SPOT XS imagery is used and the reflectance curves for some cover types are given in figure 2.1.

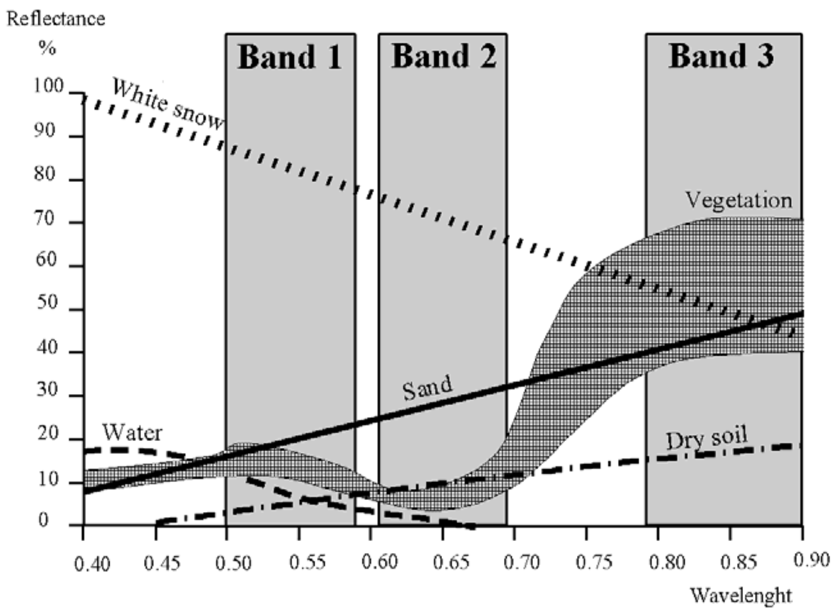

Figure 1: Reflectance curves for some cover types, and the spectral resolution of the three SPOT XS bands

Band ratio’s

Another method is the use of band ratios, which are combinations of the individual bands. This method has the advantage that if spectral reflectances of cover types in one band are similar, the ratio of two bands can be used to differentiate them.

Table 1: Relative reflectance for different land cover types for the 3 SPOT XS bands

Cover type	Band1	Band3	Band ratio 3/1
Water	Moderate	Low	Low-moderate
Clouds	High	High	Moderate
Shadow	Low	Low	Moderate
Vegetation	Moderate	High	Moderate-high
Bare soil	High	High	Moderate

The table shows that water has the same range of reflectance if compared to vegetation in band 1 and shadow in band 3. Using a band ratio water can be better separated. On the other hand clouds, shadow and bare soils are harder to distinguish. It therefore depends on the type of research which method to use.

Flood stage mapping

Before the band ratios are made, it is important to get a good idea of the individual images. First band 1 of the image from the moderate severe flood will be displayed.

☞

- Display the image Mfl87_1w by double-clicking the map icon. Deselect the check box stretch in the Display Options dialog box. Click OK. The map will be displayed. Note the overall gray, or low contrast, throughout the whole image. You can find out the DN (digital number) value of each pixel by clicking on a pixel within the image.
- Close the map window.
- Double-click the histogram of the map Mfl87_1w. The histogram is shown in a table window. Observe the values in the table (scroll down to see the values). Display the histogram in a graph by selecting Options and Show Graph. Select Image value for the X-axis and Npix for the Y-axis in the Graph dialog box. Click OK, and again click OK in the Edit Graph window. Now the histogram is displayed as a line.

The horizontal axis of the histogram may be interpreted as if it is a gray scale, with 256 different shades of gray. A reflectance value of zero is displayed in black, a reflectance value of 255 is displayed in white, and all values in between in various shades of gray. The vertical axis shows how many pixels in the image have that value.

Notice that practically all pixels have a DN value between 20 and 50. Only the white spots in the image, which are actually clouds, may have higher DN values. That is why the image is mostly dark gray. To increase the contrast in the image, we will need to change the display so that all the colors of the palette are used, ranging from black to white.

☞

- Close the graph window.
- Scroll down the table and write down the DN values for which the cumulative percentage (column Npcumpct) = 1 and to 99. Close the table window.
- Double-click the raster map Mfl87_1w again, but now select the check box stretch in the Display Options dialog box, and enter the values you have just written down, as the minimum and maximum values. Click OK. The image is now displayed with much more variation in gray tone.

The easiest way to improve the visibility of an image is by using the option stretch. When this is used, the minimum value in the image is displayed with the lowest color in the gray representation (black) and the maximum is displayed with the highest color (white). If we use the stretch option in the display of the map, the actual image values are not changed. Only the way in which they are represented changes.

If we want to actually create a map with DN values between 0 and 255 we have to use a Stretch operation, which will produce another image. In ILWIS two possibilities exist for stretching an image: linear stretching, and histogram equalization. The most commonly used method is the linear stretch. The principle of linear stretching is shown in the figure below. IN represents the original image values; OUT the corresponding image values after stretching.

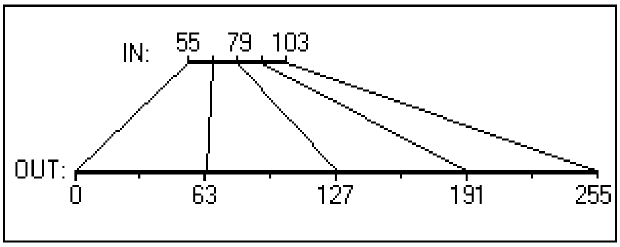

Figure 2: Principle of the linear stretching technique

☞

- Close the map window.
- From the Operations menu in the Main window, select Image Processing, Stretch. The Stretch dialog box is opened. Select the image Mfl87_1w as input map. Use the Linear Stretch option, and a percentage value of 1%. Enter Mfl87_1s as the output image, and click on Show and OK. After calculation the Display Options dialog box is opened. Click OK. The image is shown. It will look the same as the previously displayed image, except when you now click on the values in the map, you will see that they are really in the range of 0 to 255.
- From the File menu of the Main window, select Open Pixel Information. Drag-and-drop the maps Mfl87_1w and Mfl87_1s into the pixel information window. Move the mouse pointer over the image and observe the different values before and after stretching.
- Compare the histograms before and after stretching.
- Close the map window and the pixel information window.

Creating a false color composite

The first step is to evaluate the pixel values for different cover types. This will be done using a color composite from the moderate flood.

☞

- From the Operations menu, select Visualization, Color Composite

  Enter for the Name of red band: Ml87_3w

  Enter for the Name of green band: Mfl87_2w

  Enter for the Name of blue band: Mfl87_1w

  Name of output image: Mfl87fcc.

  Switch off 24 bits.

  Select Linear Stretching and a percentage of 1.00 for all three input bands.
- Click Show and OK. After calculating the map the Display Options dialog box is opened. Click on OK. The false color composite is displayed. See results

In this image you can see more clearly the different land cover units. As you can see water is shown in blue green colors, vegetation in red colors, clouds and bare soils (e.g. sand bars) in white, and shadows in black. Now you will evaluate how these classes are shown in the three individual bands.

☞

- Open the pixel information window and add the maps Mfl87_1w,. Mfl87_2w and Mfl87_3w to it. If you move the mouse pointer through the image you see the values of three input bands.
- Zoom in on certain parts of the map with water, vegetation, clouds, shadows and bare soil. Note in the table below the DN values per band of the given land cover types.
- Calculate the band ratio 3/1 using the ILWIS pocket line calculator. For example, if you want to calculate 34/45, you type ?34/45↵ on the command line of the Main window. Select at least 5 pixels per cover class.

Table 2: Fill in the DN values for the indicated bands and cover types. Also calculate the ratio 3/1

Cover type	Band 1	Band2	Band3	Band3/Band1
Water				
Water				
Water				
Water				
Water				
Vegetation				
Vegetation				
Vegetation				
Vegetation				
Vegetation				
Clouds				
Clouds				
Clouds				
Clouds				
Clouds				
Shadow				
Shadow				
Shadow				
Shadow				
Shadow				
Bare soils				
Bare soils				
Bare soils				
Bare soils				
Bare soils				

As you can see from the results we cannot differentiate the water from vegetation in band 1. In band 3 we can differentiate the two, but then shadows will also have a low reflectance.

That is why, if we take the ratio of band 3 and band 1, we can differentiate the water.

☞

- Close the map window and the pixel information window.

Computation of Band ratio's

Now you will calculate the ratio of bands 3 and 1.

☞

- Type the following formula on the command line:

  Brmfl=Mfl87_3w/Mfl87_1w↵

- The Raster map definition dialog box is opened. Click the Create domain button. The Create Domain dialog box is opened.

  Type Ratio for the domain name. Select the domain type Value. Click OK. The Domain Editor is opened.

- Enter 0 for Min, 10 for Max and 0.01 for the Precision. Click OK. You are back in the Raster Map Definition dialog box. Change also here the value range to 0 and 10. Click OK.
- Double-click the map Brmfl. Make sure the representation Gray is selected in the Display Options dialog box. Accept the defaults and click OK. See results
- The map Brmfl is shown in gray tones. Read the values in the map and see if you can now differentiate between the water and the rest. Also consult the histogram for this. Find the critical value that limits water from land.

To find out the limiting value for differentiating land and water, it is helpful to create a representation, with two colors (blue and green). All pixels with values below the limit will be displayed in blue (water), and those with higher values in green (land). When you change the limit, the display changes as well, and you can evaluate if all the water pixels are classified as water. This way you can interactively find out the best value for differentiating land and water.

☞

- When you have an idea about the boundary value, double-click the New Repr item in the Operations-list. The Create Representation dialog box is opened. Enter Ratio for the Representation name, and select the domain Ratio. Click OK. The Representation Editor is opened.
- In the Edit menu of the Representation Editor, select Insert Limit. Enter the critical value that differentiates between land and water (for example 0.5), and select the color blue. Click OK.
- Activate the map window, and press the right mouse button while the mouse pointer is on the image. Select map Brmfl from the context-sensitive menu. The Display Options dialog box is opened again.
- Select the representation Ratio and click OK. Now the map Brmfl is redisplayed, according to the representation Ratio.
- Activate the Representation Editor again. Change the color of the limit 10 to Green. Double-click on the word "stretch" between the limits until it changes to "upper".

☞

- Press the Redraw button in the map window. Now the map is shown in two colors: blue (water) or green (land). Evaluate if the limit 0.5 is correct for differentiating water and land. If not change the limit in the Representation Editor, and press the Redraw button again in the map window.

When you are sure about the value for differentiating land and water, you can use the Slicing operation, to change the ratio image into a class map. For the Slicing operation, a group domain is required.

☞

- Create a domain Mfl (you do this by selecting he menu items File, Create, Create Domain from the Main window). The domain should be class and group. Press OK. Now you can enter the boundary values and the names of the classes. Select Edit, Add Item and fill in the value that you found earlier as the boundary value, and Watermfl as the name. Press OK. Add another class: Landmfl with as boundary value the maximum value in the map. Close the Domain Editor.
- Now use the Slicing operation (by selecting the menu items Operations, Image processing, Slicing from the Main window). Use Brmfl as input map, Mfl as domain, and Mfl as output map.
- Display the map Mfl, and compare it with the image Brmfl.

Now you have a class map, indicating the flooded area during the moderate flood of 1987.

☞

- Follow the same procedure for the images of the other two dates: 9-1-1987 (dry season by making a band ratio map Brdry, a domain dry , with the classes Waterdry, and Landdry and a final map dry) and 10-10-1988 (severe flood: by making a band ratio map Brfl, a domain fl with the classes Waterfl, and Landfl and a final map Fl). See results
- Create a false color composite using the three bands from 10-10-1988. Name the resulting map Fl88fcc. See results

☞

- Display the image Fl88fcc and the maps Dry, Mfl, Fl all together on the screen. Compare them.
- Close the map window.

Combining the three water level maps

You now have three maps which show the difference in land/water for three periods: the dry season of 1987, the moderately severe flood of 1987, and the severe flood of 1988. These maps will be combined into one final map, using the Crossing operation.

☞

- Cross the maps Dry and Mfl, create a cross map and a cross table, both called Drymfl.
- Cross the maps Drymfl and Fl, create a cross map and a cross table,

both with the name Final.

- Convert the domain Final from Identifier to Class, by pressing the Convert to Classes button in the Properties dialog box. See results
- Create a representation Final.
- Create annotations for the map Final and store the result as a map view.
- Calculate the percentage of the different classes of the output map.

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Alexander, D. (1993). *Natural disasters*. UCL Press Ltd., University College London. 632 pp.

Asaduzaman, A.T.M. (1994). *A geomorphologic approach to flood hazard assessment and zonation in Bangladesh, using Remote Sensing and a geographic information system*. MSc thesis, ITC, Department of Earth Resources Surveys. Enschede. 85 pp.

Maathuis, B.H.P (1993). *Flooding Bangladesh: ITC Demo*. CZM Toolbox, tools and applications for Coastal Zone Managment, World Coast Conference 1993, pp. 15-18 (+demo diskette).

Exercise 3L1. Landslide susceptibility assessment using statistical method

Expected time:	3 hours
Data:	data from subdirectory:Riskcity_exercise/exercise03L1/data
Objectives:	This exercise shows you how carry out a basic bivariate statistical landslide susceptibility assessment, using a limited number of factor maps, and only one landslide type. The method used is the information value method, one of the simplest methods which can be easily implemented in GIS. The use of scripts is also demonstrated. The output map is validated using the success rate method.

Some background information:

In this exercise we will generate a landslide susceptibility map, using a basic, but useful, statistical method, called hazard index method. This method is based upon the following formula:

$$W_i = \ln\left(\frac{\text{Densclas}}{\text{Densmap}}\right) = \ln\left(\frac{\dfrac{\text{Area(Si)}}{\text{Area(Ni)}}}{\dfrac{\sum \text{Area(Si)}}{\sum \text{Area(Ni)}}}\right)$$

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.

The method is based on map crossing of a landslide map with a certain parameter map. The map crossing results in a cross table, which can be used to calculate the density of landslides per parameter class. A standardization of these density values can be obtained by relating them to the overall density in the entire area. The relation can be done by division or by subtraction. In this exercise the landslide density per class is divided by the landslide density in the entire map. The natural logarithm is used to give negative weights when the landslide density is lower than normal, and positive when it is higher than normal. By combining two or more maps of weight-values a hazard map can be created. The hazard map value is obtained by simply adding the separate weight-values. We are only using two factor maps in this exercise: Lithology and Slope, as the aim is to learn the procedure. In reality many possible factor maps should be evaluated.

Statistical landslide assessment:

There are two main types of statistical landslide susceptibility assessment: multi-variate and bivariate methods. Both require a landslide map which should contain only 1 type of landslides. Each landslide type or failure mechanism has its own combination of causal factors. The aim is to be able to separate the various types as best as possible. Also you should only use the scarp areas, and not the accumulation areas, because there the factors are considerably different.

Input data

In this exercise we will use the landslide inventory map Landslide_ID, which we have used in the previous exercises and a number of factor maps, listed in the table below.

Name	Type	Meaning
Factor data		
Slope_cl	Raster	Slope class map
Aspect_cl	Raster	Slope direction map (with classes)
Lithology	Raster	Lithological map
Soildepth	Raster	Soildepth map
Landuse	Raster	Landuse map
River_dis	Raster	Distance from rivers
Road_dis	Raster	Distance from roads
Landslide data		
Landslide_ID	Raster map	Points within each of the interpreted landslides with associated attribute table
Landslide_ID	Table	Attribute table with information on the landslides in the area.
Other data		
Building_map_segments	Segment map	Boundary lines of the buildings in the area.
High_res_image	Raster	High resolution image of the study area.

Landslide susceptibility versus hazard:
A landslide susceptibility map indicates the relative susceptibility of the terrain for the occurrence of landslides. It only has a spatial component. A landslide hazard map also contains information on the temporal probability of occurrence. Most so-called landslide hazard maps are in fact only landslide susceptibility maps, as it is very difficult to obtain sufficient temporal landslide information for a temporal probability assessment.

DFDX filter:
It calculates the first derivative in x-direction (df/dx) per pixel. The values in the matrix are:
1 -8 0 8 -1
Gain factor = 1/12 = 0.0833333
DFDY filter:
It calculates the first derivative in y-direction (df/dy) per pixel.

In this exercise the method for landslide susceptibility assessment is made by using only one factor map: **Slope_cl** (slope class map). The landslides are stored in the map **Landslide_ID**, which contains information on several attributes.

☞

- Open the map **High_res_image** and overlay the **landslide_ID** map. Also open several of the factor maps and check their contents.

Along side the landslide map you also have two parameter maps: Lithology (geological units) and Slope (slope angles).

For experienced ILWIS users:

Creating slope and aspect maps.

☞ For those interested in the procedure for the generation of slope class and slope aspect maps, you can follow the following procedure :

- Create a DTM by interpolation of the contours (*Operations / Interpolation / Contour interpolation*).
- To calculate height differences in X-direction: start the Filter operation, select the Digital Elevation Model as the input map and select linear filter dfdx. Call the output map for example DX. Do the same for the y direction, using filter dfdy. Name output: DY.
- Calculate the slope in degrees using the formula in MapCalc:

SLOPEDEG = RADDEG(ATAN(HYP(DX,DY)/ PIXSIZE(DEM)))

- Calculate the aspect in degree using the following formula:

ASPECTD = RADDEG(ATAN2(DX,DY) + PI)

- The map **Slope** still needs to be classified into classes (*File/Create/ Domain*). Make a class (don't forget to indicate the option *group*) domain **Slopecl** , and add the slope classes you want to differentiate. E.g. you can make classes of 10 degree each.
- Select from the main window: *Operations / Image Processing /Slicing*. Select the raster map Slope, and the domain **Slopecl**. Name the output map **Slopecl**. Same procedure for Aspect.

Conditional statements:
IFF(a, b, c)
If a is true, then return b, else return c.
IFF returns:
if a=true, b is returned;
if a=false, c is returned;
if a=undefined, undefined is returned.
The amount of nested IFF statements is unlimited
When the definition symbol = is used, a dependent output map or dependent output column is created;
When the assignment symbol := is used, the dependency link is immediately broken after the output map/column has been calculated

MapCalc and TabCalc:
The same type of formulas can be used on columns in tables (called Table Calculation or TabCalc) and also on maps in the command line to the main window (called Map Calculation or MapCalc).

Undefined values:
These are indicated by a question mark (?). They either indicate missing values, unknown values, values outside the value range, or the area outside the study area.

So far you have only been looking at the content of the maps. You will now start with the actual analysis. A statistical analysis should be done using landslides with same characteristics. That is why we will separate the fossil landslides from the recent ones. We do that using a map calculation formula.

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- Open the table **Landslide_ID**.
- We are going to use only the class **S** (scarp) and the activities A (=Active) and R(=Reactivated). We make now a column in the table in which these will have a value 1 and the rest a value of 0. Type the following formula on the command line in the table:

Active1:=iff(((Activity="a")or(Activity="r"))and(Part="s"),1,0)

- Meaning: if the columns **Activity** has the class a (active) or r (reactivated) and the column **Part** is s (scarp), then the result is 1 otherwise 0. How many landslide fulfill this criteria?
- Close the table. We will now make an attribute map. Select *Operations / Raster Operations / Attribute map*. Select the Raster map: **Landslide_ID**, Table: **Landslide_ID**, Attribute: **Active1**. Name the output map as: **Active1.** Check the resulting map.
- We still need to change the undefined values in the map to 0 values. Type the following command line in the Main Window:

  Active:=iff(isundef(Active1),0,Active1)
- Meaning: iff the map Active1 is undefined, then we change it into 0 , otherwise we keep the same values.

Note: if you are not interested in learning the exact procedure on how the information value method can be calculated, you can simply skip this part of the exercise and go to the part dealing with the use of a script which will automate this procedure.

Step 1: Crossing the parameter maps with the landslide map

The landslide occurrence map, showing only the recent landslides (Active) can be crossed with the parameter maps. In this case the map **Slope_cl** is selected as example. First the map crossings between the occurrence map and the two parameter maps have to be carried out.

Map crossing:
The Cross operation performs an overlay of two raster maps. Pixels on the same positions in both maps are compared; the occurring combinations of class names, identifiers or values of pixels in the first input map and those of pixels in the second input map are stored. These combinations give an output cross map and a cross table. The cross table includes the combinations of input values, classes or IDs, the number of pixels that occur for each combination and the area for each combination.

☞

- Select from the main ILWIS menu the options: *Operations, Raster operations, Cross*.
- Select the map **Slope_cl** as the first map, the map **Active** as the second map, and call the output table **Actslope**. (Ignoring the undefined values has no effects, as both maps don't have undefined values). Deselect the box Output map.Click Show and OK. Now the crossing of the two maps takes place.
- Have a look at the resulting cross table. As you can see this table contains the combinations of the classes from the map **Slope_cl** and the two types from the map **Active**. Close the table.

Now the amount of pixels with different landslide activities in each slope class, has been calculated, the landslide densities can be calculated.

Step 2: Calculating landslide densities

After crossing the maps, the next step is to calculate density values. The cross-table includes the columns that will be calculated during this exercise. Each of the calculation steps is indicated below.

☞

- Make sure that the cross-table **Actslope** is opened.

  Step 2.1: In this table create a column in which only the active landslide are indicated by typing the following formula on the command line of the table window:

  AreaAct=iff(Active=1,area,0)↵

  You do this in order to calculate for each slope class the area with only active landslides.
- **Step 2.2:** Calculate the total area in each slope class.
  Select from the table menu: Columns, Aggregation.
  Select the column: **Area**. Select the function Sum. Select group by column **Slope_cl**. Deselect the box Output Table, and enter the output column **Areasloptot**. Press OK. Select a precision of 1.0.
- **Step 2.3**: Calculate the area with active landslides in each slope class.
  Again select from the table menu: Column, Aggregation.
  Select the column: **AreaAct**, Select the function Sum, select Group by column **Slope_cl**. Deselect the box Output Table, and enter the output column: **Areaslopeact**. Press OK. Select a precision of 1.0.
- **Step 2.4:** calculate the total area in the map.
  Again select from the table menu: Columns, Aggregation.
  Select the column: **Area**. Select the function Sum. Deselect the box group by. Deselect the box Output table, and enter the output column: **Areamaptot**. Press OK. Select a precision of 1.0.
- **Step 2.5:** The next step is to calculate the total area with landslides in the map. Again select from the table menu: Columns, Aggregation.
  Select the column: **AreaAct**. Select the function Sum. Deselect the box group by. Deselect the box Output Table, and enter the output column: **Areamapact**. Press OK. Select a precision of 1.0.
- **Step 2.6:** Calculate the landslide density per slope class
  Type:

  Densclas=Areaslopeact/Areasloptot↵

  Select a precision of 0.0001.
- **Step 2.7:** Calculate the landslide density for the entire map.
  Type:

  Densmap=Areamapact/Areamaptot↵

  Select a precision of 0.0001 and decimal: 4.

Hint: If Denclas and Densmap are not in 4 decimals then use property dialog box to change the decimal

The result will look like below:

	Slope_cl	Active	NPix	Area	AreaAct	Areasloptot	Areaslopeact	Areamaptot	Areamapact	Densclas	Densmap
0 - 5 * 0	0 - 5	0	4169438	4169438	0	4173424	3986	14000000	213446	0.0010	0.0152
0 - 5 * 1	0 - 5	1	3986	3986	3986	4173424	3986	14000000	213446	0.0010	0.0152
5 - 10 * 0	5 - 10	0	2718437	2718437	0	2723958	5521	14000000	213446	0.0020	0.0152
5 - 10 * 1	5 - 10	1	5521	5521	5521	2723958	5521	14000000	213446	0.0020	0.0152
10 - 15 * 0	10 - 15	0	1941860	1941860	0	1952714	10854	14000000	213446	0.0056	0.0152
10 - 15 * 1	10 - 15	1	10854	10854	10854	1952714	10854	14000000	213446	0.0056	0.0152
15 - 20 * 0	15 - 20	0	1488289	1488289	0	1502075	13786	14000000	213446	0.0092	0.0152
15 - 20 * 1	15 - 20	1	13786	13786	13786	1502075	13786	14000000	213446	0.0092	0.0152
20 - 25 * 0	20 - 25	0	1062314	1062314	0	1086549	24235	14000000	213446	0.0223	0.0152
20 - 25 * 1	20 - 25	1	24235	24235	24235	1086549	24235	14000000	213446	0.0223	0.0152
25 - 30 * 0	25 - 30	0	826051	826051	0	854335	28284	14000000	213446	0.0331	0.0152
25 - 30 * 1	25 - 30	1	28284	28284	28284	854335	28284	14000000	213446	0.0331	0.0152
40 - 50 * 0	40 - 50	0	407252	407252	0	450340	43088	14000000	213446	0.0957	0.0152
40 - 50 * 1	40 - 50	1	43088	43088	43088	450340	43088	14000000	213446	0.0957	0.0152
30 - 40 * 0	30 - 40	0	1017888	1017888	0	1073296	55408	14000000	213446	0.0516	0.0152
30 - 40 * 1	30 - 40	1	55408	55408	55408	1073296	55408	14000000	213446	0.0516	0.0152
50 - 60 * 0	50 - 60	0	125097	125097	0	147443	22346	14000000	213446	0.1516	0.0152
50 - 60 * 1	50 - 60	1	22346	22346	22346	147443	22346	14000000	213446	0.1516	0.0152
60 - 90 * 0	60 - 90	0	29928	29928	0	35866	5938	14000000	213446	0.1656	0.0152
60 - 90 * 1	60 - 90	1	5938	5938	5938	35866	5938	14000000	213446	0.1656	0.0152

Now you have calculated all the required densities for the map **Slope._cl**

Step 3: Calculating weight values

The final weight-values are calculated by taking the natural logarithm of the density in the class, divided by the density in the map. With this calculation we find that the density in the entire map = 213446 / 14000000 = 0.0152

Previously the calculation was done on the cross-table for the maps **Slope_cl** and **Active**. As you could see from the table above, this results in many redundant values, since you only want to calculate the densities and the weights for each slope class. The result should look like table below instead, where each slope class occupies only one record. That is why you will work now with the attribute table connected to the map **Slopecl** and use table joining combined with aggregation to obtain the data from the cross table.

	Areasloptot	Areaslopact	Densclas	Weight
0 - 5	4173424	3986	0.0010	-2.7213
5 - 10	2723958	5521	0.0020	-2.0281
10 - 15	1952714	10854	0.0056	-0.9985
15 - 20	1502075	13786	0.0092	-0.5021
20 - 25	1086549	24235	0.0223	0.3833
25 - 30	854335	28284	0.0331	0.7782
30 - 40	1073296	55408	0.0516	1.2222
40 - 50	450340	43088	0.0957	1.8399
50 - 60	147443	22346	0.1516	2.3000
60 - 90	35866	5938	0.1656	2.3883

☞

- Create a table **Slope_cl** for the domain **Slope_cl**. This table contains no additional columns, except the column with the domain. Repeat the procedure from above, but now with table joining.
- **Step 1:** Calculate the total area in each slope class.
  Select Columns, Join. Select table **Actslope**. Select column: Area. Select function Sum. Select group by column: **Slopecl**. Select output column **Areasloptot**. Press OK.
- **Step 2:** Calculate the area with active landslides in each slope class.
  Select Columns, Join. Select table: **Actslope**. Select column **Areaact**. Select function Sum. Select group by column **Slopecl**. Select output column **Areaslopact**. Press OK.
- **Step 3:** With both columns, you can calculate the landslide density in each slope class with the formula:

  Densclas:=Areaslopact/Areasloptot↵

  Select a precision of 0.0001.
- If you look at the result, some classes have a density of 0. This should be

adjusted, since the calculation of the weights is not possible. To adjust type the following formula:

Dclas:=iff(Densclas=0,0.0001,Densclas)↵

- The final weight can now be calculated with the formula:

  Weight:=ln(Dclas/0.0152)↵

- Check the resulting weights in the table. Which slope classes have the most important relation with landslides?
- Close the table.

Step 4: Creating the weight maps

The weights from the table can now be used to renumber the maps.

☞

- Select from the main ILWIS menu: Operations, Raster operations, Attribute map. Select raster map **Slope_cl,** table **Slope_cl**. Select attribute **Weight**. Select output raster map **Wslope_cl**. Press OK.
- Display the resulting map **Wslope_cl**. Stretch between -2.5 and +2.5
- Use the same procedure the other parameter map **Lithology**. Name table as **Lithology_cl** with domain **lithology**. The resulting map should be called: **WLithology**.
- The weights for the two maps can be added with the formula:

  Weight1=Wslope_cl+WLithology↵

- Display the map **Weight1** and use the pixel information window in order to read the information from the maps **Slope_cl, Wslopecl, Lithology, WLithology** and **Weight1**.

Step 5: Use of scripts (to calculate for all factor maps)

You can automate the calculation procedure by using a script, which contains the formulas for the ILWIS operations. Parameters can be used in the form of %1 - %9. You can make a script by copying the statement which is shown on the command line when executing an operation, and pasting it into a script file. Table calculation formulas need the word TABCALC in front. For more information on scripts, consult the ILWIS Help, or the ILWIS User's Guide

Script:
A script is a sequenced list of ILWIS commands and expressions. By creating a script, you can build a complete GIS or Remote Sensing analysis for your own research discipline. Each line in a script is a statement that is executed via the ILWIS command line of the Main window. Via a script, you can for instance handle some necessary object management (e.g. copy or delete), display of objects (open or show), and the creation and calculation of data objects. All map and table calculations, and all ILWIS expressions to perform operations may be used. Furthermore, you can call other scripts and start other Windows applications from within a script.

☞

- The script that is given on the next page can be used to automate the analysis. Select *File/Create/Script*, and copy the text in the script window. Save the script as **Weights**
- Then close the script and run the script on the command line:

  Run weights Slope_cl

- Similarly you can also run the script for other parameter maps that you consider important for landslide occurrence. Such as Lithology, or landuse or distance from the river etc.

  Run weights aspect_cl
  Run weights Landuse
  Run weight River_dis
  Run weight Lithology
  Etc..

Parameters in scripts: A script can use parameters. Parameters in a script replace (parts of) object names, operations, etc. Parameters in scripts work as DOS replaceable parameters in DOS batch files, and must be written on the Script Tab in the script editor as %1, %2, %3, up to %9.

```
//script for Information value method
// required parameters: %1 = name of the factor map, which should be a class
map

del active%1.* -force
del %1w.* -force

//calculation in cross table
Active%1.tbt := TableCross(%1,active,IgnoreUndefs)
Calc Active%1.tbt

//Calculate the area of landslides in the crosstable only for the combinations with
landslides
Tabcalc Active%1 AAct:=iff(active=1,Area,0)

//create an attribute table
crtbl %1w %1

//calculate the total area of landslides within each class of the factor map
Tabcalc %1w Areaclassact:= ColumnJoinSum(Active%1.tbt,AAct,%1,1)

//calculate the total area of the class of the factor map
Tabcalc %1w Areaclasstot:= ColumnJoinSum(Active%1.tbt,Area,%1,1)

//calculate the total area of landslides in the map
Tabcalc %1w Areaslidetot:= ColumnJoinSum(Active%1.tbt,AAct,,1)

//calculate the total area of the map
Tabcalc %1w Areamaptot:= ColumnJoinSum(Active%1.tbt,Area,,1)

//calculate the density of landslides in the class
Tabcalc %1w dclass { vr=::0.000001}:=Areaclassact/Areaclasstot

//correcting for those areas that have no landslides
Tabcalc %1w densclass { vr=::0.000001}:= iff((isundef(dclass))or(dclass=0),
0.000001, dclass)

//calculate the density of landslides in the map
Tabcalc %1w densmap { vr=::0.000001}:=Areaslidetot/Areamaptot

//calculate the weight
Tabcalc %1w weight:=ln(densclass/densmap)

//generating the weight map
active%1:= MapAttribute(%1,%1w.tbt.weight)

Show active%1.mpr
```

After running the script you can check the weights in the attribute table to evaluate whether the parameter map is a useful tool for landslide prediction. You might also have to combine different parameters, into new more meaningful ones. This is an iterative process.

Step 6: Combining the weights in a final susceptibility map

After running the script for all the factor maps, and after selecting which maps you want to use in the creation of the final map, you can add up the weights into a final weight map.

☞

- In the command line calculate the following equation to add up the weight maps:

Weight:=activeaspect_cl+activeslope_cl+activelihtology+activelanduse+activeriver_dis

The map Weight has many values, and cannot be presented as it is as a qualitative hazard (susceptibility) map. In order to do so we first need to classify this map in a small number of units.

☞

- Calculate the histogram of the map **Weight** and select the boundary values for three classes: Low hazard, Moderate hazard, and High hazard.
- Create a new domain: **Susceptibility**. By selecting: File, Create, Create domain. The domain should be a Class and tick on Group. Now enter the names and the boundary values of the different classes in the domain. When you are ready, close the domain.
- The last step is using the program slicing. Select: Operations, Image processing, slicing. Select raster map: **Weight**. Select output raster map: hazard. Select domain: **Susceptibility**. Press show and OK.
- Evaluate the output map with Pixel information. If necessary adjust the boundary values of the domain hazard and run slicing again, until you are satisfied with the result

☞ **For experienced ILWIS users:**

- It is also important to include the areas occupied by old landslides in the hazard map. You can do this with a map calculation formula. Design the procedure and formula's yourself. Give it the name **Final**

Step 7: Calculating success rate.

The "predictive power" of the resulting weight maps can be tested by analysing their success rate and prediction rate. The success rate is calculated by ordering the pixels of a susceptibility map in a number of classes, from high to low values, based on the frequency information from the histogram. After that an overlay is made with the landslide inventory map, and the joint frequency is calculated. The success rate indicates how much percentage of all landslides occurs in the pixels with the highest values in the different combination maps. For example, 50 percent of all landslides are predicted by 10 percent of the pixels with the highest value in the map.

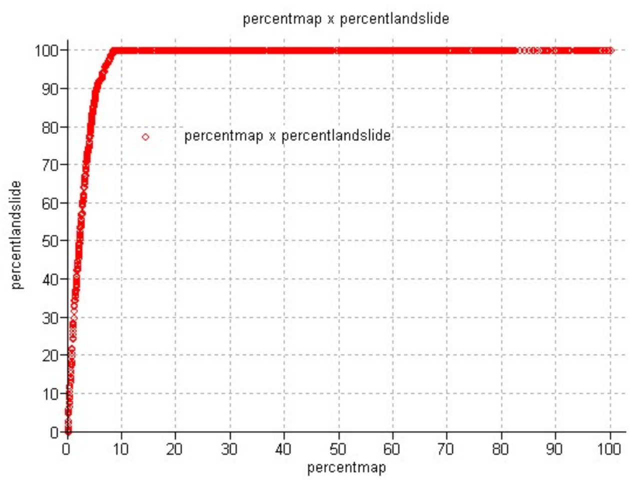
☞

- Create a script for the calculation of the success rate, using the example script below. Call it: **success**
- Run the success rate script as follows:

  Run success weight

- After running the script, open the table **Activeweight**. Open the Display in a graph the column **percentmap** on the X-axis and the column **percentlandslide** on the Y-axis. Evaluate the results and decide on the best boundary values for dividing the map in high, moderate and low susceptibility.
- Use these boundaries to classify the weight map again.

```
//script for success rate calculation
// one parameter %1 = weight map resulting from the statistical analysis

del active%1.* -force

// Cross Final with Map: active
Active%1.tbt := TableCross(%1,active,IgnoreUndefs)

//In the cross table, calculate
tabcalc Active%1 npixact:=iff(active=1,npix,0)
tabcalc Active%1 Npcumactive = ColumnCumulative(npixact)
tabcalc Active%1 totalslide = ColumnAggregateSum(npixact,,1)
tabcalc Active%1 totalarea = ColumnAggregateSum(npix,,1)
tabcalc Active%1 percentage:=100*(Npcumactive / totalslide)
tabcalc Active%1 Percentlandslide:=100-percentage
tabcalc Active%1 Npixcumul:= cum(NPix)
tabcalc Active%1 reverse = totalarea -npixcumul
tabcalc Active%1 percentmap = 100*(reverse/totalarea)
// after this display a graph with Percentlandslide az y-axis and Percentmap as x-axis
```



Some final remarks:

- The method was only done using a limited number of parameter maps, just to show the procedure. In reality many more parameter are used. The method is also used to differentiate the parameters according to their importance.
- The analysis should actually be done for different landslide types separately, as they will all have different combinations of causal factors.
- The Hazard index method is a useful, but simple method. Many more methods exist for landslide hazard assessment, which might be more appropriate, given the objectives of the study, the size of the area, and the available input data.

☞ **For experienced ILWIS users:**

- There is also another script in the directory which can be used for calculating a more complicated method: Weights of Evidence. You can try that as well if you like.

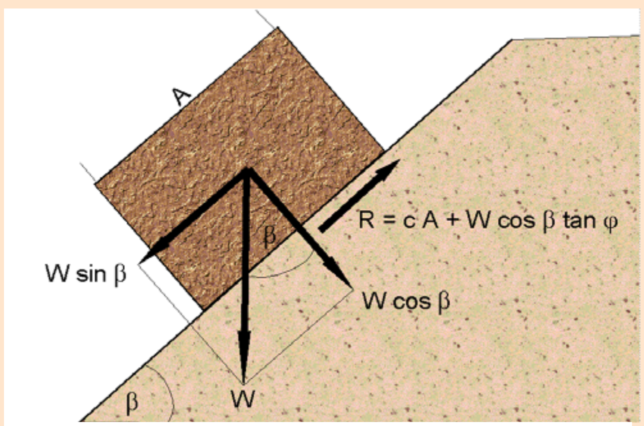
```
rem ILWIS Script for Weights of Evidence
//The parameter %1 refers to the name of the factor map. It should be less than 7 characters long.
// Make sure that each map has a domain with the same name

//FIRST WE WILL DELETE EXISTING RESULT FILES
// the crosstable s%1.tbt
//The attribute table %1.tbt
// and we make a new attribute table

del s%1.*
del w%1.*
del %1.tbt
crtbl %1 %1

//NOW WE CROSS THE FACTOR MAP WITH THE ACTIVITY MAP
// The landslide map should be called ACTIVE and should have either 0 or 1 values. 1 values mean
landslides.
// The cross table is called s%1

s%1=TableCross(%1.mpr,active.mpr,IgnoreUndefs)
calc s%1.tbt

//Now we calculate one column in the cross table to indicate only the pixels with landslides.

Tabcalc s%1 npixact=iff(active=1,NPix,0)

//NOW WE USE AGGREGATION FUNCTION, WITH OR WITHOUT A KEY TO CALCULATE:
//NCLASS = number of pixels in the class. We sum the values from columns Npix and group them by %1
//nslclass = number of pixels with landslides in the class.We sum the values from columns Npixact and
group them by %1
//nmap = number of pixels with landslides in the map. We sum the values from columns Npix and don't
group them
//nslide = number of pixels with landslide in the map. We sum the values from columns Npixact and don't
group them
//THE RESULTS ARE NOT STORED IN THE CROSS TABLE S%1 BUT IN THE ATTRIBUTE TABLE %1

Tabcalc s%1 %1.nclass = ColumnJoinSum(s%1.tbt,Npix,%1,1)
Tabcalc s%1 %1.nslclass = ColumnJoinSum(s%1.tbt,Npixact,%1,1)
Tabcalc s%1 %1.nmap = ColumnJoinSum(s%1.tbt,Npix,,1)
Tabcalc s%1 %1.nslide = ColumnJoinSum(s%1.tbt,Npixact,,1)

//NOW WE CALCULATE THE FOUR VALUES NPIX1 - NPIX4 AS INDICATED IN THE EXERCISE BOOK. THIS IS
DONE IN THE ATTRIBUTE TABLE
// We correct for the situation when Npix1 - Npix3 might be 0 pixels, and change it into 1 pixel

Tabcalc %1 npix1 =IFF((nslclass>0),nslclass,1)
Tabcalc %1 npix2 = IFF((nslide-nslclass)=0,1,nslide-nslclass)
Tabcalc %1 npix3 = IFF((nclass-nslclass)=0,1,nclass-nslclass)
Tabcalc %1 npix4 = nmap-nslide-nclass+nslclass

//NOW WE CALCULATE THE WEIGHTS IN THE ATTRIBUTE TABLE
Tabcalc %1 wplus {dom=value.dom; vr=-10:10:0.00001} =
LN((npix1/(npix1+npix2))/(npix3/(npix3+npix4)))
Tabcalc %1 wminus {dom=value.dom; vr=-10:10:0.000001}  =
LN((npix2/(npix1+npix2))/(npix4/(npix3+npix4)))

//NOW WE CALCULATE THE CONTRAST FACTOR
Tabcalc %1 Cw = wplus-wminus

//NOW WE CALCULATE THE FINAL WEIGHT
//The final weight is the sum of the positive weight and the negative weights of the other classes
Tabcalc %1 WminSum=aggsum(wminus)
Tabcalc %1 Wmap=wplus+Wminsum-Wminus

//NOW WE MAKE AN ATTRIBUTE MAP OF THE FINAL WEIGHTS
w%1.mpr = MapAttribute(%1,%1.Wmap)
calc w%1.mpr
```

Exercise 3L2. Deterministic landslide hazard assessment

Expected time:	3 hours
Data:	data from subdirectory:Riskcity exercises/exercise03L2/data
Objectives:	This exercise shows you how to carry out a basic slope stability analysis using the infinite slope model. This will calculate the stability of each pixel for different scenarios of the relation groundwater depth / failure surface depth.

Some background information:

The final aim of large scale landslide hazard analysis (scales larger than 1:10,000) is to create quantitative hazard maps. The hazard degree can be expressed by the *Safety Factor*, which is the ratio between the forces that make the slope fail and those that prevent the slope from failing. F-values larger than 1 indicate stable conditions, and F-values smaller than 1 unstable. At F=1 the slope is at the point of failure.



$$F = \frac{c\,A + W \cos\beta \tan\phi}{W \sin\beta}$$

in which:

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 (°)

According to the formula:

F < 1 unstable slope conditions,

F = 1 slope is at the point of failure,

F > 1 stable slope conditions

Some background information:

Many different models exist for the calculation of Safety Factors. Here we will use one of the simplest models, the so-called ***infinite slope model***. This one dimensional model describes the slope stability of slopes with an infinitely large failure plane. It can be used in a GIS, as the calculation can be done on a pixel basis. The pixels in the parameter maps can be considered as homogeneous units. The effect of the neighboring pixels is not considered, and the model can be used to calculate the stability of each individual pixel, resulting in a hazard map of safety factors. The safety factor is calculated according the following formula (Brunsden and Prior, 1979) :

$$F = \frac{c' + (\gamma - m\gamma_w)\, z \cos^2\beta \tan\phi'}{\gamma z \sin\beta \cos\beta}$$

in which:

c' = effective cohesion (Pa= N/m^2).

γ = unit weight of soil (N/m^3).

m = z_w/z (dimensionless).

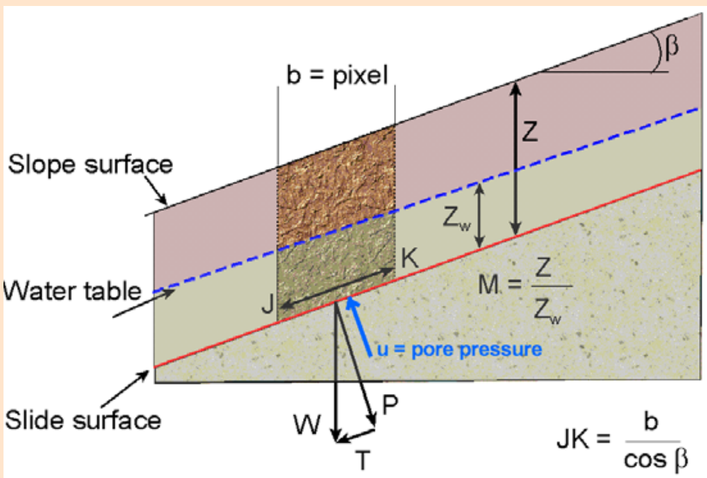
γ_w = unit weight of water (N/m^3).

z = depth of failure surface below the surface (m).

z_w = height of watertable above failure surface (m).

β = slope surface inclination (°).

ϕ' = effective angle of shearing resistance (°).



The infinite slope model can be used on profiles as well as on pixels. The entire analysis requires first the preparation of the data base. The parts on groundwater modelling and the modelling of seismic acceleration are not shown here. For more information see Van Westen (1993). In this exercise only the calculation of average safety factors will be done for different scenarios. These average safety factor maps could be used in the creation of failure probability maps.

Visualization of the input data

In this exercise the slope stability analysis is made by using only two parameter maps: **Soildepth** (thickness of soil) and **Slope_map** (slope angles in degrees).

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- Open the maps **Soildepth** and **Slope_map** and check the values in the maps. Click OK in the Display Options dialog box. The map is displayed.

We assume that:

the depth of the possible failure plane is taken at the contact of the soil and the underlying weathered rock material.

All soils have the same values for Cohesion, friction angle and unit weight.

In the first part of the exercise we will calculate the stability of the soil cover using only one single value of cohesion, friction angle and bulk density. The consequence of this is that safety factors will not be calculated for the entire area, but only for the areas where there is soil overlying the bed rock.

Besides soil depth which is assumed to be the same as the depth to the failure surface, and the slope of the terrain, we also need to know the other parameters of the infinite slope formula. From laboratory analysis the following average values are known:

M:

Zw/Z = Depth to groundwater / Depth to failure surface

c' = effective cohesion (Pa= N/m^2) = 11000 Pa

γ_w = unit weight of water (N/m^3) = 10000 N/m^3

z = depth of failure surface below the surface (m) = map **Soildepth**

β = slope surface inclination (°) = map **Slope_map**

ϕ' = effective angle of shearing resistance (°) = 32 °

tan(ϕ') = tangent of the effective angle of shearing resistance = 0.625

The only unknown parameter yet is the depth of the water table. In the formula this is expressed as the value m, which is the relation between the depth of the water table and the depth of the failure surface.

Sine and Cosine

The ILWIS functions for sine and cosine only work with input values in radians, while our map Slope_map is in degrees. Therefore we need to convert to slope map from degrees to radians first.

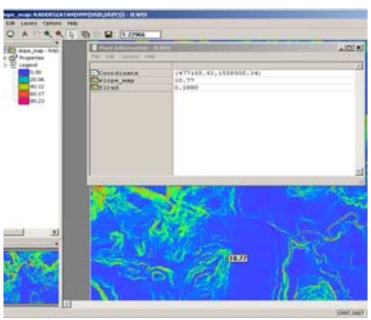
Preparation of the data

Before you can start with the analysis, you need to reorganize the map **Slope_map**. In the calculation we need three parameters that are derived from the slope:

sin(slope) = the sine of the slope

cos(slope) = the cosine of the slope

cos2(slope) = cos(slope)*cos(slope)



The ILWIS functions for sine and cosine only work with input values in radians, while our map Slope is in degrees. Therefore we need to convert to slope map from degrees to radians first. ILWIS has the function Degrad for that:

Degrad(Slope) degrees to radians function: slope*2π/360

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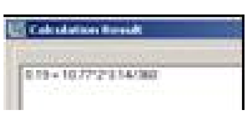
- Type the following formula on the command line:

  Slrad:=degrad(Slope_map)↵

  Accept the default minimum, maximum and precision.

- Open the result map and compare the values of the map **Slrad** with those of the map **Slope_map**. With the pixel information click in some points of the map and read the values in degree and in radians. For example: you can type in the command line of ILWIS the following formula:

  ?10.77*2*3.14/360



Now you have the slope in radians, and you can calculate the sine and cosine. You will calculate individual maps for these so that the Safety factor formula (formula 6.1) can be calculated easier.

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- Type the following formula on the command line:

  Si:=sin(Slrad)↵

  (with this formula you calculate the sine of the slope).

  Accept the default minimum (-1), maximum (+1) and give a precision of 0.001.

- Open the result map and compare the values of the map Si with those of the map Slrad. Calculate it with the pocket line calculator or the Windows calculator for some pixels, using the formula given above.
- Type the following formula on the command line:

  Co:=cos(Slrad)↵

  (with this formula you calculate the cosine of the slope).

  Accept the default minimum (-1), maximum (+1) and give a precision of 0.001.

- Open the result map and compare the values of the map Co with those of the map Slrad. Check it for some pixels, using the formula given above.
- Type the following formula on the command line:

  Co2=sq(Co)↵

  (with this formula you calculate the square of the cosine, using the ILWIS function Sq()).

  Accept the default minimum, maximum and precision

- Check your results again.

Now all necessary parameters for the formula are known, except for the parameter *m* related to the groundwater depth.

Creating a function for the infinite slope formula

In the following sections you will use the infinite slope formula extensively for different scenarios, and different input data. To avoid that you have to retype the formula each time, it is better to create a user-defined function for it.

Functions

Besides many internal pre-programmed functions, ILWIS gives the user an opportunity to create new functions. Especially when you need to execute certain calculations which require a lot of typing work several times, user-defined functions may be time saving. A user-defined function is an expression which may contain any combination of operators, functions, maps and table columns

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- Double-click New Function in the operations list. The Create function dialog box is opened.
- Type for the Function Name: Fs

  Type for the expression:

  (Cohesion+(Gamma-M*Gammaw)*Z*Co2*Tanphi)/(Gamma*Z*Si*Co)

  Type the Description: Safety factor.

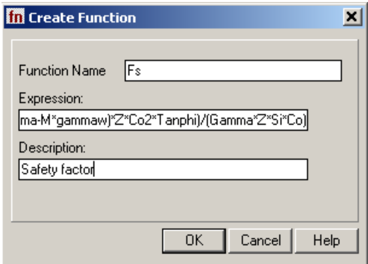
- Click OK. The Edit Function dialog box is opened. Click OK.

In this dialog box you can edit the expression of the function. Now the expression is:

```
Function fs(Value Cohesion,Value Gamma,Value M,Value Gammaw,Value Z,Value
Co2,Value Tanphi,Value Si,Value Co) : Value
Begin
Return (Cohesion +(Gamma-M*Gammaw)*Z*Co2*Tanphi) /(Gamma*Z*Si*Co)
End;
```

As you can see the function contains the following variables (listed in the first line):

- Value Cohesion: the value for the effective cohesion.
- Value gamma: the value for the unit weight of soil.
- Value m: the value for the relation z_w/w.
- Value gammaw: the value for the unit weight of water.
- Value z: the value for the depth of failure surface below the surface.
- Value co2: the value for the square of the cosine of the slope.
- Value tanphi: the value for the tangent of the effective angle of shearing resistance.
- Value si: the value for the sine of the slope.
- Value co: the value for the cosine of the slope.



However, a number of these variables are fixed. You will use them for all calculations: The fixed variables are: Value Cohesion (10000 Pa), Value Gammaw (10000 N/m^3), Value Z (raster map **Soildepth**), Value Co2 (raster map **Co2**), Value Tanphi (**0.625**), Value Si (raster map **Si**), and Value Co (raster map **Co**).

So you can simplify the function considerably, so that it looks like:

```
Function fs(Value Gamma,Value M) : Value
Begin
Return(10000+((Gamma-m*10000)*Soildepth*Co2*0.625))
/(Gamma* Soildepth *Si*Co)
End;
```

As you can see there are only two variables: Value Gamma and Value M.

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- Edit the Function until it is the same as above. Click OK.

Calculating Safety Factors for groundwater scenarios

Now that the function is created, you can start to calculate safety factor maps for different scenarios. In the first part you will calculate the safety factors for different scenarios where only rainfall is the triggering factor. You will not yet look at the influence of an earthquake.

Dry condition

You will first calculate the safety factor for the soils under the assumption that the soil is completely dry. In that case the parameter m is equal to zero.

Remember the other parameter that were given on the previous page:

c' =	Effective cohesion (Pa= N/m2)	= 11000 Pa
γ =	Unit weight of soil (N/m3)	= 11000 N/m3
γw =	Unit weight of water (N/m3)	= 10000 N/m3
z =	Depth of failure surface below the surface (m)	= map **Soildepth**
m =	Relation zw/z (dimensionless)	= 0
β =	Slope surface inclination (°)	= map **Slope_map**
ϕ' =	Effective angle of shearing resistance (°)	= 32 °
tan(ϕ') =	Tangent of the effective angle of shearing resistance	= 0.625
sin(β) =	Sine of slope angle	= map **Si**
cos (β) =	Cosine of slope angle	= map **Co**
cos2(β) =	Square of the cosine of slope angle	= map **Co2**

Now you can start with the actual calculation of the average safety factor map representing the situation under dry conditions. The two variables for the function *fs* are **11000 (Value Gamma)** and **0 (Value M)**.

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- Type the following formula on the command line:

  Fdry:=fs(11000,0)↵

- Make sure the georeference **Somewhere** is used. Use a minimum of 0, a maximum of 100, and a precision of 0.1.
- Open the result map and compare the values of the map **Fdry** with those of the input maps. Calculate the safety factor manually for some pixels with the Pocket line calculator or the Windows calculator, using the infinite slope formula

The resultant map (**Fdry**) will have some pixels with missing values indicated by a question mark (?). You can investigate these pixels and see that the values of the pixels cannot be calculated either because they lack soil or because they are flat areas. Both conditions indicate stability and thus can be safely grouped as stable.

As you can imagine a situation with a completely dry situation does not occur in a tropical region such as RiskCity, which receives quite a lot of rainfall each year. In any case the map **Fdry** gives the most stable situation. Let us see how much percent of the area is unstable under these conditions. In order to know that we will first classify the map **Fdry** into three classes:

Unstable = safety factor lower than 1

Critical = safety factor between 1 and 1.5

Stable = safety factor above 1.5

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- Create a new domain **Stabil** (type class, group) with the following three classes:

Boundary	Name
1	Unstable
1.5	Critical

100 Stable

- Use the Slicing operation to classify the map **Fdry** with the domain **Stabil** into the map **Fdryc**.
- Calculate a histogram of the map **Fdryc** and write down the percentages of the three classes in a table on a sheet of paper with the column name **Dry**. Later we will calculate the values for other situations.

The percentage of the pixels classified as unstable gives you an indication of the error, since the occurrence of unstable pixels under fully dry conditions is not possible.

Completely saturated condition

The next scenario that you will evaluate is a condition in which the slopes are completely saturated. This is also not a very realistic situation, but it will give us the most pessimistic estimation of slope stability, with only one triggering factor involved (rainfall leading to high perched watertables).

When we have a saturated soil, the *m* factor from the infinite slope formula is equal to 1. This means that the watertable is at the surface. There is also another parameter that will vary when the soil is completely saturated, which is γ:

c' =	Effective cohesion (Pa= N/m^2)	= 11000 Pa
γ =	Unit weight of soil (N/m^3)	= 16000 N/m^3
γ_w =	Unit weight of water (N/m^3)	= 10000 N/m^3
z =	Depth of failure surface below the surface (m)	= map **Soildepth**
m =	Relation z_w/z (dimensionless)	= 1
β =	Slope surface inclination (°)	= map **Slope_map**
ϕ' =	Effective angle of shearing resistance (°)	= 32 °
tan(ϕ') =	Tangent of the effective angle of shearing resistance	= 0.625
sin(β) =	Sine of slope angle	= map **Si**
cos (β) =	Cosine of slope angle	= map **Co**
$\cos^2(\beta)$ =	Square of the cosine of slope angle	= map **Co2**

The two variables for the function *fs* are **16000 (value gamma)** and **1 (value m).**

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- Type the following formula on the command line:

  Fsat:=fs(16000,1)↵

- Use a minimum of 0, a maximum of 100, and a precision of 0.1. Change the GeoReference to "**Somewhere**".
- Open the result map and compare the values of the map **Fsat** with the maps **Fdry** and the input map. Calculate the safety factor manually for some pixels with the ILWIS pocket line calculator or the Windows calculator for some pixels, using the formula given above.
- Use the Slicing operation (under image procession) to classify the map Fsat with the domain **Stabil** into the map **Fsatc**.
- Calculate a histogram of the map Fsatc and write down the percentages of the three classes in a table on a sheet of paper with the column name Sat. Compare them with the column **Dry**.

Now that we have calculated all scenarios, we can compare them. This can be done in a table.

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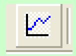
- Create a table from the domain **Stabil**.
- Go to Columns, Join and select Table histogram of **Fdryc**; use the column **Npixpct**. Give the name **Dry** to the output column. Accept the default values and click Ok.
- Also join the histogram file of the map **Fsatc.** Give the name **Sat**.
- Click the button Graph  in the main menu, Remove the tick mark in the X axis, Select **Dry** as Y axis and click OK. You will see a histogram of the percentage area under different stability classes in dry condition.
- In the Graph window itself, go to *Edit menu, Add Graph* and select and *from columns*. Select Y axis **Sat**. Now you will see the histograms of the percentage area under different stability classes in dry and saturated conditions side by side.
- Draw conclusions on the effect of the groundwater on the stability of the soils in the area.

Partially saturated condition

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- Now design some scenarios yourself where you use M values that vary between 0 and 1, and see the effect on the stability.
- Draw conclusions on the effect of the groundwater on the stability of the soils in the area.

For experienced ILWIS users

☞ **For experienced ILWIS users:**

Using different values for cohesion and friction angle

- It is also important to include different values for cohesion, friction angle and unit weight of soils for different soil or lithological types. You can do that by adding columns **Cohesion, FrictionAngle** and **Gamma** to the table **Lithology**.

☞ **For experienced ILWIS users:**

Include earthquake acceleration

- Iit is also possible to include earthquake acceleration in the equation for the factor of safety. You could try to make a function for that based on the formula given below, and test this out for a few scenarios of earthquake acceleration and M values.

$$F = \frac{c' + z(\gamma \cos^2 \beta - \rho a_h N \cos \beta \sin \beta - \gamma_w m \cos^2 \beta) \tan \varphi'}{z(\gamma \sin \beta \cos \beta + \rho a_h N \cos^2 \beta}$$

C′ = effective cohesion (Pa)
z = depth of failure surface below terrain surface
γ = unit weight of soil (Nm^{-3})
β = terrain suface inclination (degrees)
ρ = bulk density (kgm^{-3})
Ah = peak horizontal acceleration in rock (ms^{-2})
N = amplification of seismic acceleration in soil
γ_w = unit weight of water (Nm^{-3})
M = groundwater/soil thickness ration z_w/z
Z_w = height of the water table above failure surface (m)
φ′ = effective angle of shearing resistance (degrees)

Exercise 3V: Modelling erosion from pyroclastic flow deposits on Mount Pinatubo

Expected time:	4-5 hours
Data:	data from subdirectory: RiskCity exercise/exercise03V/data
Objectives:	This exercise deals with the evaluation of erosion from pyroclastic flow deposits on Mount Pinatubo, Philippines, which erupted in 1991 and produced an enormous deposit of hot ashes, up to 200 meters thick. In the years after the eruption, heavy rainfall in the area triggered large erosion and lead to a series of lahars. The data from this exercise was provided by Art Daag, from the Philippine Institute of Volcanology and Seismology (PHIVOLCS), who made his MSc study on this topic.

Background information

Mount Pinatubo is situated on the island of Luzon, about 80 km northeast of Manila, the capital of the Philippines. The volcano, with K-Ar datings of approximately 1.1 million years, and with youngest C^{14} dating of ±400 years BP, is the youngest volcano in the Zambales range and in the western Luzon volcanic arc.

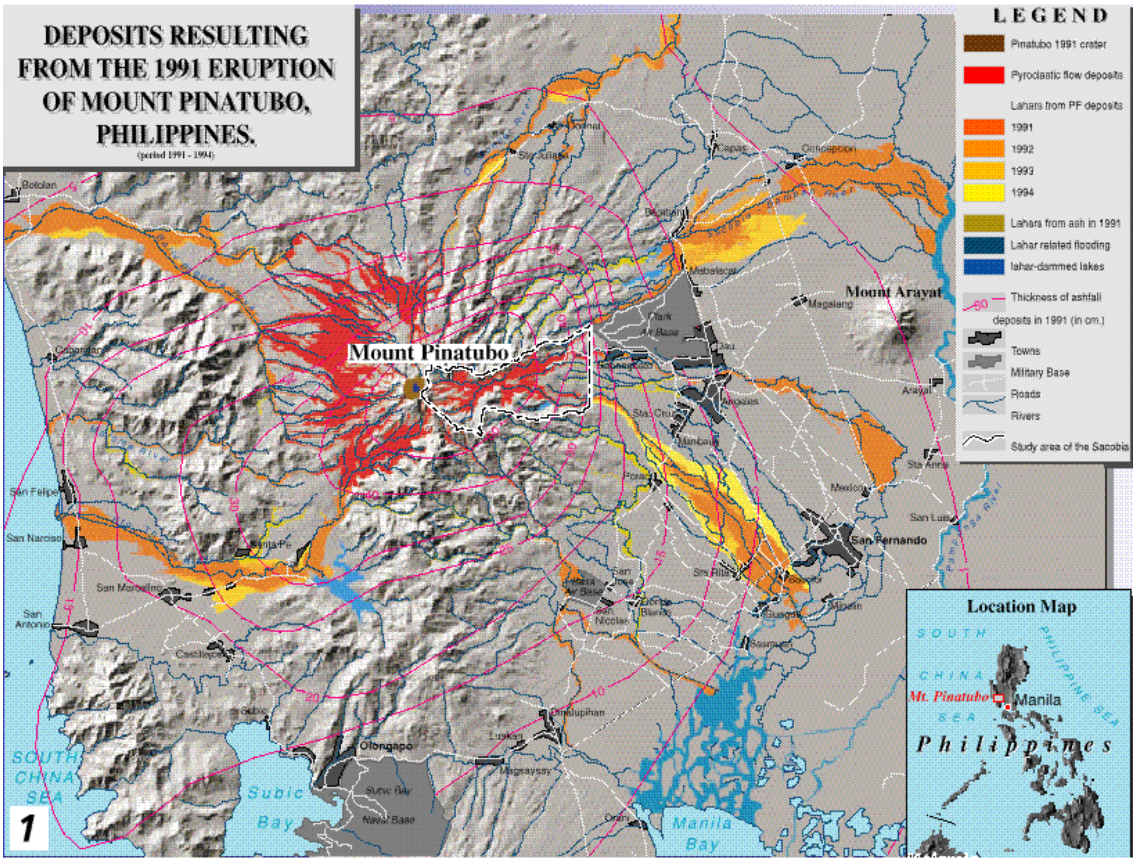

Figure 1: Overview of situation after the eruption of Mt Pinatubo

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- The map **View3d** gives an overview of the region around Mount Pinatubo. This figure was prepared from an extensive digital terrain model (DTM), derived from 16 1:50.000-scale topomaps.
- Display this map. Close it after you have seen it.

Mt. Pinatubo began spewing ash on June 3, 1991 at 0730H, and continued for 3 months until the end of August 1991. It peaked during the eruption of June 15 1991, propelling ash up to 30 km above the vent. Mount Pinatubo is located in a densely populated area, with major cities such as San Fernando, and Angeles. Before the eruption 2 large US military bases were present in the area (Clark Air Base, and Subic Bay Naval Base).

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- An overview of the area surrounding Mount Pinatubo, and the deposits resulting from the 1991 eruption, as well as the lahar deposits from 1991 till 1994, are shown in the map **Location**.
- Display this map. The legend can be found in the map Legend

The 1991 eruption had deposited about 6.83 km^3 of pyroclastic flows into the different watershed namely: O'Donell (0.6 km^3), Sacobia (1.78 km^3), Porac-Gumain (0.05 km^3), Marella-Sto. Thomas (1.3 km^3) and Balin-Baquero (3.1 km^3). The Sacobia watershed, which is the watershed analyzed in this study, starts at the eastern crater rim of the volcano (see map location) and extends downslope until reaching the lowland Candaba swamp (50 km east) and Manila bay (60 km southeast).

The rapid erosion or removal of the 1991 pyroclastic flow deposit is one of the major social and scientific concerns after the 1991 eruption of the Pinatubo Volcano because this generates life threatening and destructive lahars of enormous magnitude. This will continue to occur for several years. The lahars from Pinatubo resulted in losses of lives and damage to properties in areas surrounding the volcano. About 50,000 persons were left homeless and the indirect impacts such as flooding and isolation have affected more than 1.3 million people in 39 different towns and 4 large cities. About 1,000 square kilometers of prime agricultural lands are at risk. Lahars predominantly occur during the rainy season in the southwest monsoon period, which lasts from June till November. The average annual rainfall varies from 1946 millimeter in the East of Pinatubo, to 3900 millimeters in the West. Long duration and high intensity rainfall are associated with the occurrence of strong typhoons, which are responsible for the production of large magnitude of destructive lahars.

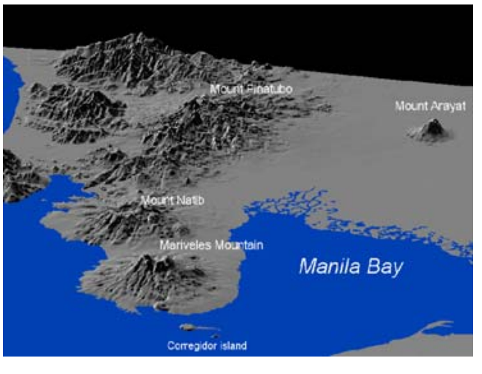

Figure 2: 3-D view of Mt Pinatubo

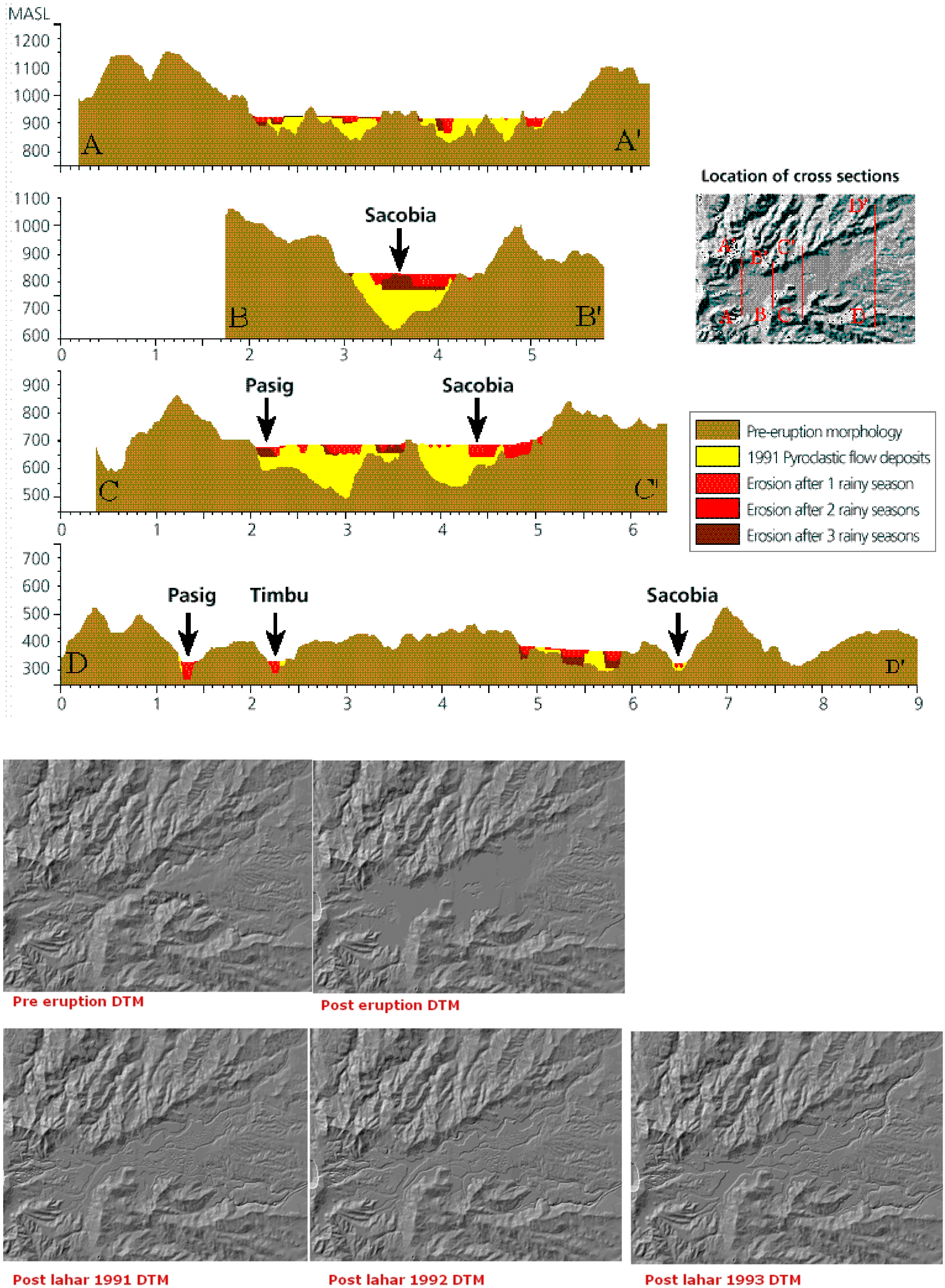

Figure 3: Above: cross sections showing the progressive rapid erosion of pyroclastic flow deposits. Below: the DEMs for different periods used in this exercise

Methodology

The main objective of this study was to evaluate the geomorphologic changes in the upper Sacobia catchment, where pyroclastic flows have been deposited. The following activities were undertaken during the investigation:

1. Elaboration of geomorphologic maps for the pre- and post-eruption situations, up till 1993. This was done in order to evaluate the changes in the catchment areas and their significance in producing lahars.

2. Creation of digital terrain models for each year, from which the thickness of pyroclastic flows, and the yearly eroded volume can be calculated.

The study of geomorphologic changes was based on the interpretation of both vertical and hand-held oblique aerial photos, video tapes, and satellite images taken at different time periods.

To calculate the volume of the 1991 pyroclastic flow deposits and the yearly eroded sediment volumes, a DTM overlaying technique using GIS was applied. For this procedure it was necessary to construct DTMs of several periods: i.e. the pre-eruption DTM; the post-plinian eruption DTM which renders the undisturbed deposits of the 1991 pyroclastic flows; a post-lahar 1991 DTM; a post-lahar 1992 DTM; and a post-lahar 1993 DTM.

Pre-eruption situation

The DTM of the pre-eruption situation is called **Dtmpre**. This DTM was generated in ILWIS using the following steps:

– Digitizing the contours (with contour interval of 50 m) from the 1:50.000 scale topographic map before the eruption.

– Interpolating the rasterized contour lines using the InterpolSeg operation in ILWIS.

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- Display the Digital terrain model **Dtmpre** by double clicking on the map icon. Change the representation to *Pseudo*. Press OK in the *Display Options* dialog box. The map will now be displayed in pseudo colors, which are stretched between the minimum value of 140 m and the maximum value of 1740.
- Move the cursor over the map and press the left mouse button to see the values in the map.
- Close the map window again.

A better way to see the DTM is to generate a so-called hill-shading image from it. A hill-shading image simulates the shadows created by the sun from the NE. Slopes directed to the northeast are shown in bright gray, and slopes directed to the southwest in dark gray.

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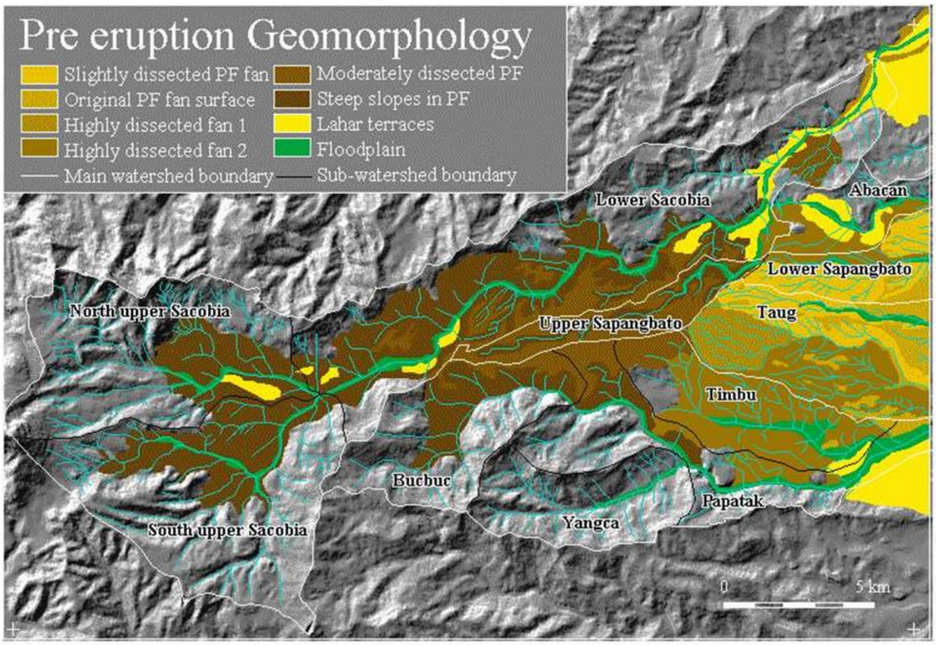
- Calculate a hillshading image of the map **Dtmpre** (by selecting *Operations, Image processing, Filter* from the main ILWIS menu). Select the filter name shadow. Name the output map Shadpre.
- Display this map in gray tones. Stretch the map between -500 and +500.
- Overlay the segment information from the polygon map **Catchpre** (use *Layer, Add layer, Polygon map*). Select *Info* and *Boundaries only*, and use a red color for the boundary lines.
- Overlay the segment information from the segment map **Drainpre**.

Accept the defaults; the drainage will be displayed in blue.

- When you move through the map and press the left mouse button, the name of the catchment will be displayed.



The pre-eruption river system in the study area consists of 2 major rivers namely: Sacobia, and Pasig. The largest watershed is the Sacobia river which is divided in the North Upper Sacobia (9.97 km2), South Upper Sacobia (11.73 km^2), and the Lower Sacobia (18.12 km^2) sub-catchments. The second largest watershed is Pasig, and it contains the following sub-catchments; Bucbuc (5.95 km^2), Yangca (4.55 km^2), Papatak (6.46 km^2), and Timbu (4.94 km^2). Other, small, catchments in the study area are Abacan (2.54 km^2), Taug (6.60 km^2), and Sapangbato (5.29 km^2). These sub-catchments are located in the distal part of the study area at about 12 km from the crater.

At least 6 major eruptive episodes have been identified throughout the modern history of Mount Pinatubo with repose periods of several centuries or millennia. The youngest eruption, before the 1991 event, was dated 400 ± 70 Before Present. The strongest eruption was dated to have occurred in the period between 30,390 ± 890 and 35,000 years B.P.

This calderagenic eruption produced an extensive pyroclastic flow-fan on the eastern side of the volcano which occupies an area 5 times larger than the 1991 pyroclastic flow deposits. The deposits resemble broad coalescing fans reaching up to about 20 km east of the volcano. They were subjected to a high degree of erosion as evidenced by the intricate patterns of deeply dissected gullies in the Lower Sapangbato, Taug and Timbu catchments. These resistant pyroclastic flow deposits partly serve as watershed divides of the Abacan, Sacobia and Pasig rivers.

The original pre-1991 pyroclastic flow level was severely eroded in the upstream section leaving deep valleys of about 200 meters. At altitudes between 500 to 200 m.a.s.l., in between Pasig and Sacobia rivers, this pyroclastic flow level can still be recognized, forming a large broad fan, in the upper Sapangbato catchment. The broad and extensive lahar deposits build the large alluvial fan landscape around the volcano which mantles the highly built-up areas and had formed fertile agricultural areas.

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- Save the contents of the map window in a map view called **Viewpre**. Close the map window.
- Rasterize the polygon map **Catchpre** using the georeference **Dtmpre**. This map you will used later in the analysis.

The situation shortly after the 1991 eruption

The DTM of the post-eruption situation is called **Dtmerp**.

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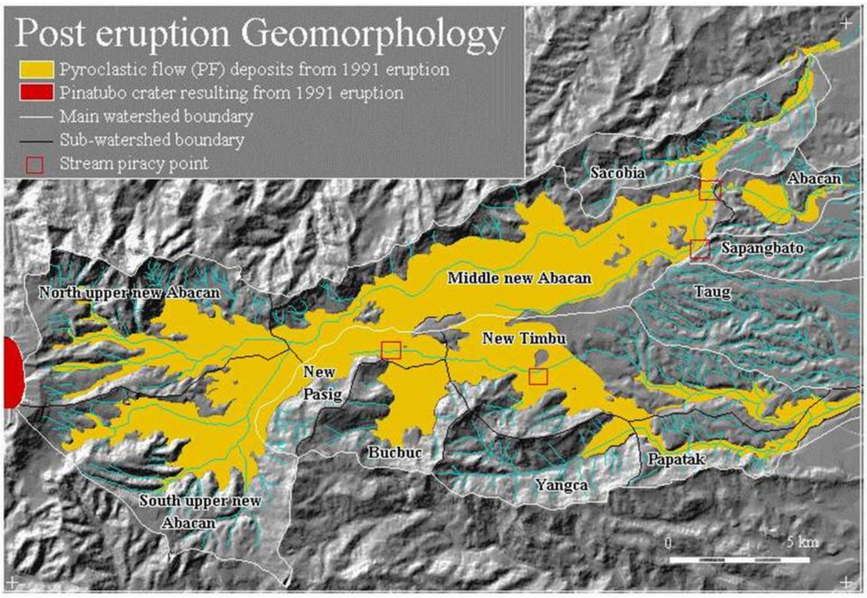
- Calculate a hillshading gray image of the map **Dtmerp** and display it on the screen.
- Overlay the segment (**boundary**) information from the polygon **Catcherp** and the segment **Drainerp**.
- Save the contents of the map window in a map view called **Viewerp**.
- Display both map views from the period before and after the eruption, and compare the results visually.

The new pyroclastic flow deposits covered about 24 km^2 and obliterated 3 major water divides leaving only the high hills, which form distinct "islands" in the middle of new and featureless flat pyroclastic flow deposits. The pre-eruption pyroclastic fan in the catchments of Sapangbato and Taug, which was not covered, acted as a wedge dividing the pyroclastic flow into two directions: North in to the lower catchment of the Abacan and Sacobia rivers, and South into the Pasig river.



One of the most significant effects of the deposition of the extensive pyroclastic flow deposits was the change in the hydrological situation. Since the pre-eruption river valleys were completely filled up, new streams developed on top of the pyroclastic flow level, with courses that were partly different from the pre-eruption situation. The most striking example is the covering of the drainage divide between the Sacobia and the Abacan rivers. Pyroclastic flow deposits overtopped this drainage divide by about 20 meters and were deposited in the upper reaches of the Abacan catchment. Therefore, during and directly after the eruption, lahars resulting from the passing of typhoon Yunya did not follow the pre-eruption river valley of Sacobia, but were drained through the Abacan river valley, causing destruction in the city of Angeles. The Upper Sapangbato catchment was also diverted towards the Abacan catchment.

Another crucial change in the hydrological situation took place in the Pasig river, where a section of the pre-eruption South upper Sacobia catchment was captured, thus extending the pre-eruption catchment of the Pasig river over the water divide. This was covered by 80 meters of pyroclastic flow deposits. Further downstream stream piracy took place in the headwaters of the Timbu creek, which captured the main Pasig river.

First you calculate the changes in the catchments that resulted from the accumulation of the pyroclastic flow deposits.

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- Rasterize the map **Catcherp** using the georeference **Dtmpre**.
- Cross the two raster maps **Catchpre** and **Catcherp**. Use the menu options *Operations, Raster operations, Cross*. The first map: **Catchpre**, the second map: **Catherp**. Output table: **Cerppre**. Click Show and OK.
- Have a look at the resulting cross table. You see the areas of the changes between the two periods, displayed in square meters. As you can see there are some combinations with undefined values. This is caused by the formation of the crater, which no longer forms part of the Sacobia catchment after the eruption.
- To convert these values to square kilometers, type the following command in the command line of the cross table:

  Areakm2=Area/1.0E+6↵
  (use a precision in the output column of 0.001).
- Fill in the values in table 1.
- Close all map and table windows.

Table 1: Changes of catchment sizes before and after the eruption. Fill in the table based on the results from the cross table

		After the eruption					
		Sacobia	Pasig	Abacan	Taug	Sapangbato	Total
Before	Sacobia						
	Pasig						
	Abacan						
	Taug						
	Sapangbato						
	Total						

Now that you know the changes in catchment areas after the eruption, you can also look at the volumes of pyroclastic flow materials that have been deposited in the different catchments. If you consider a cross section through one of the valleys in the area: the pre-eruption situation is given by the map **Dtmpre** (showing the pre-eruption topography). The topography after the eruption is given by the map **Dtmerp**.

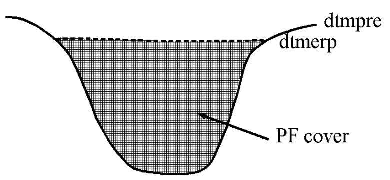

Figure: Schematic cross-section showing the situation after the eruption

You can subtract the two maps to find the pyroclastic flow (PF) thickness:

Pfthick=Dtmerp-Dtmpre.

The positive values in the resulting map indicate accumulation area. Negative values indicate where the crater has been formed

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- Type the following formula on the command line of the main window:

  Pfthick=iff(Dtmerp-Dtmpre>0,Dtmerp-Dtmpre,0)↵

  Make sure the output map has a precision of 1. Display this map in gray and read the values together with those of the input maps by clicking Pixel Information.
- Cross the catchment map after the eruption (**Catcherp**) with the map **Pfthick**. The output table is called **Pferp**.
- Open the cross-table **Pferp** and look at the columns. The column **Area** gives you the area occupied by pyroclastic flow deposits of a certain thickness. The thickness itself is given in the column **Pfthick**. To know the volume of pyroclastic flow deposits for each thickness you have to multiply the column Area with the thickness. Type the following formula on the command line in the table:

  Volerp=Area*Pfthick/1.0E+6↵

  The output values are then in million cubic meters. Use a precision of 0.0001.
- Create a new table (**Total**) with the domain **Catchm**. In this table you will aggregate the results. Open this table.
- Now the volumes from the cross table will be aggregated into this table. Type the following formula on the command line of the table:

  Volerp=aggsum(Pferp.Volerp,Pferp.Catcherp)

  This means, calculate the sum of the values in the column **Volerp** from the table **Pferp**, and use the column **Catcherp** as the column by which the grouping should be done. Note that this column **Catcherp** has the same domain (**Catchm**) as the table **Total**.
- Have a look at the result, and close table windows.

Now you know the volume of pyroclastic flow that was deposited in each of the catchments.

The situation after the first rainy season

The geomorphology of the Sacobia catchment changed dramatically during the first rainy season, following the 1991 eruption. Due to heavy rainfall, the original pyroclastic flow surface was eroded, resulting in a series of terrace levels with a high gully density, separated by deep valleys. Within a few months after the eruption, the main rivers had eroded into impressive gorges, up to about 35 meters.

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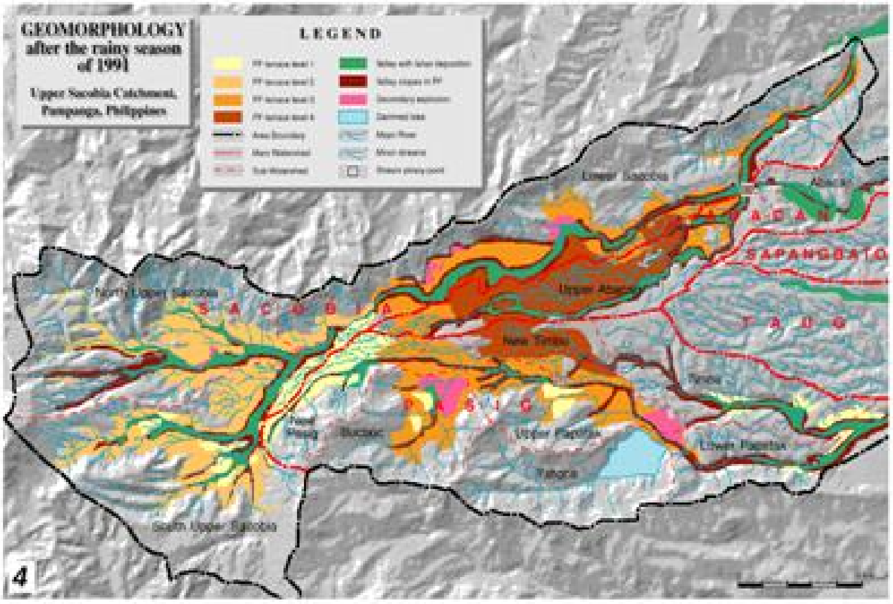
- Calculate a hillshading image of the map **Dtm91** and display it on the screen.
- Overlay the segment information from the polygon boundaries **Catch91** and segment Drain91. Save as map view View91.

- Compare the resulting map view with those of the previous exercises.

Due to the deposition of the pyroclastic flow and lahar materials the Yangca creek, which is a tributary of the Pasig river, was blocked, and a dammed lake started to develop.



Another serious geomorphologic feature is the presence of secondary explosions. Secondary explosions are phreatic explosions occurring in the pyroclastic flow deposits. These are produced when water comes into sudden contact with the hot in-situ pyroclastic flow deposits, producing expanding steam. The mechanisms for generating secondary explosions are not yet fully understood. However, they commonly occur simultaneously with heavy rains, although in some instances they can occur also during little or no rainfall. In these latter cases they may be related to groundwater flow within the pyroclastic flow material. Moderate to minor explosions can also occur more frequently due to large valley-side collapse of the newly exposed hot pyroclastic flow deposits produced during the passage of erosive lahars. Most of the secondary explosions in the Sacobia watershed result in deep semi-circular to oblate craters or crown features with a relatively flat base. The depth of secondary craters ranges from 20 to about 80 meters. One of the effects of secondary explosions may be the triggering of secondary pyroclastic flows. They can remobilize volumes of considerable thickness over large distances.

The most important secondary explosion after the rainy season of 1991, occurred on April 4, 1992 at the water divide between Sacobia and Abacan. The secondary explosions at the so-called Abacan gap produced 2-3 km of channel-confined secondary pyroclastic flow deposits and resulted in the recapture of the upper catchment by the Sacobia river causing large destructive lahars in 1992 in the downstream section which buried several villages and destroyed hundred of hectares of agricultural lands. The secondary pyroclastic flows completely buried the lahar retaining structures constructed along the Sacobia river which were recently built. Only a small area of the pyroclastic flow covered zone still drained towards the Abacan, but this section was captured later by the Sacobia as well. Due to the loss of connection with the pyroclastic flow deposits the Abacan river ceased to cause any serious lahar threats to the city of Angeles. The lahars were now flowing along the main courses of the Sacobia and the Pasig rivers, with the former being the most important, as it had the largest catchment area within the pyroclastic flow deposits. Another important stream capture took place by the Pasig river, which recaptured its old course, and reduced the lahar activity via the Timbu river.

You will first calculate the changes in the catchments that resulted from the accumulation of the pyroclastic flow deposits.

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- Rasterize the polygon **Catch91** using the georeference **Dtmpre**.
- Cross the two raster maps **Catcherp** and **Catch91**. Use the menu options: *Operations, Raster operations, Cross*. The first map: **Catcherp**, the second map: **Catch91**. Output table: **C91erp**. Click Show and OK.
- Have a look at the resulting cross table. You see the areas of the changes between the two periods, displayed in square meters.
- To convert these values to square kilometers, type the following command in the command line of the cross table:

  Areakm=Area/1.0E+6↵

  Use a precision in the output column of 0.001.
- Fill in the values in table 4.2
- Close table windows.

Table 2: Changes of catchment sizes after the first rainy season, and shortly after the eruption. Fill in the table based on the results from the cross table

		After first rainy season of 1991					
		Sacobia	Pasig	Abacan	Taug	Sapangbato	Total
After eruption	Sacobia						
	Pasig						
	Abacan						
	Taug						
	Sapangbato						
	Total						

Now that you know the changes in catchment areas, after the first rainy season, you can also look at the volumes of pyroclastic flow materials that still remain and the volumes that have been eroded.

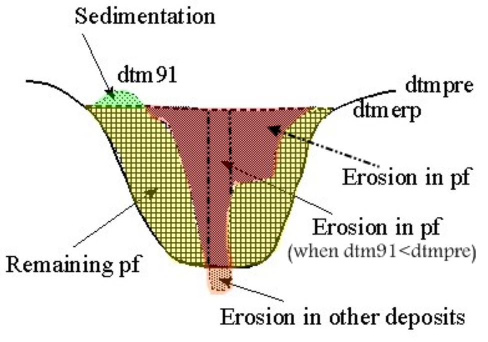

Figure3: Schematic cross-section showing the situation after the first rainy season following the eruption

Calculations are given below to derive the thickness of eroded materials:

Total erosion

Ero91=iff(Dtm91<Dtmerp,Dtmerp-Dtm91,0)

Erosion in PF deposits:

Eropf91= iff((Ero91>0)and(Dtm91>Dtmpre),Dtmerp-Dtm91,iff((Ero91>0)and(Dtm91<Dtmpre),Dtmerp-Dtmpre,0))

Erosion in other deposits:

Eroot91=iff((Ero91>0)and(Dtm91<Dtmpre),Dtmpre-Dtm91,0)

Sedimentation in 1991:

Sed91=iff(Dtm91>Dtmerp,Dtm91-Dtmerp,0)

Remaining PF material in 1991:

Pfth91=iff(Dtm91>Dtmerp,Dtmerp-Dtmpre, iff(Dtm91<Dtmpre,0,Dtm91-Dtmpre))

or

Pfth91=(Dtm91-Dtmpre)-Sed91

and use only the positive values.

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- Start by calculating the total erosion after the rainy season of 1991. Type the following formula on the command line:

  Ero91=iff(Dtm91<Dtmerp,Dtmerp-Dtm91,0)↵

  Make sure the output map has a precision of 1.

- Now calculate the erosion in PF deposits. Type the following command:

  Eropf91=iff((Ero91>0)and(Dtm91>Dtmpre),Dtmerp-Dtm91,iff((Ero91>0)and(Dtm91<Dtmpre),Dtmerp-Dtmpre,0))

  Make sure the output map has a precision of 1.

- The next map to calculate is the erosion in 1991 in other deposits. Type:

  Eroot91=iff((Ero91>0)and(Dtm91<Dtmpre),Dtmpre-Dtm91,0)↵

  Again, the precision should be 1.

- Now you calculate the thickness of the sedimentation in 1991. Type:

  Sed91=iff(Dtm91>Dtmerp,Dtm91-Dtmerp,0)↵

  Also here, the precision should be 1.

- Finally you can calculate the remaining thickness of PF deposits in 1991. Type:

  Pfth91:=iff(Dtm91>Dtmerp,Dtmerp-Dtmpre,iff(Dtm91<Dtmpre,0,Dtm91-Dtmpre))

  Precision should be 1.

- Have a look at the results, use the pixel information window and the ILWIS pocket line calculator to check them, and close all map and table windows.

Now the erosion and sedimentation maps for 1991 have been calculated. The next step is to cross these maps with the catchment map after the first rainy season (Catch91), and to aggregate the results in the table Total.

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- Cross the map **Catch91** with the map **Ero91**. Make a cross table: **Ero91**, and calculate the volume of erosion in million cubic meters, in a column called **Erosion91**. Open the table **Total** and calculate for each catchment the erosion by aggregating the values from the cross table.
- Cross the map **Catch91** with the map **Eropf91**. Make a cross table **Eropf91** and calculate the volume of erosion in PF in million cubic meters, in a column **Erosionpf91**. Calculate the values for each catchment in the table **Total**.
- Cross the maps **Cathc91** and **Eroor91**, and follow the same procedure.
- Cross the maps **Catch91** and **Sed91**, and follow the same procedure.
- Cross the maps **Catch91** and **Pfth91**, and follow the same procedure.

After finishing this, the table **Total** contains for each catchment how much was eroded and sedimented in 1991, and how much pyroclastic flow material is still remaining.

The situation after the second rainy season

After the second rainy season the valleys in the study area were widened and deepened considerably in relation to the year before. Most valleys established their course following the former deep pre-eruption valley axis where new pyroclastic flow deposits are thick. This may be due to the resistant pre-eruption pyroclastic flow terraces which are only mantled by less than 30m of new pyroclastic flows. Some of the gullies at Sacobia partly incised the pre-eruption deposits.

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- Calculate a hillshading image of the map **Dtm92** and display it on the screen.
- Overlay the segment information from the map **Catch92** and **Drain92**. Create a map view **View92**.
- Compare the result with the one from the previous year.

The area of the terraces rapidly diminished as a result of valley widening at the base of the terrace, gully widening, and secondary explosions. Isolated terraces began to form as a result of the erosion along several sides. In 1992, large secondary explosions occurred in both the Sacobia and Pasig catchments. The main explosion which occurred along the Sacobia river had an area of 0.3 km^2 and depth of 30 m. This is located in an area which has a circular low depression in the pre-eruption morphology, and which is likely a former site of pre-historic secondary explosions.

Several minor explosions from side wall collapse had occurred as a result of lateral erosion. The secondary explosion crater at the confluence of Bucbuc and Pasig and the large crater at the Sacobia river were not active in 1992. Their features are gradually diminishing as a result of gully side erosion.

The lake at the confluence of Yangca creek and Pasig river had again generated large lake-breakout related lahars. At the same time the lake was being filled by lahars spreading out from the Pasig river.

During the second rainy season only minor changes in drainage areas took place, resulting from stream captures. The only change took place at the Sacobia river, which captured the last 0.3 km^2 from the Abacan river in direct contact with pyroclastic flow deposits.

You can now calculate the changes in the catchments that resulted from the accumulation of the pyroclastic flow deposits

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- Rasterize the map **Catch92** using georeference **Dtmpre**.
- Cross the two raster maps Catch91 and Catch92. Follow the same procedure as used earlier to calculate the changes in catchment sizes (in square kilometers).
- Fill in the values in table 4.3.
- Close table windows.

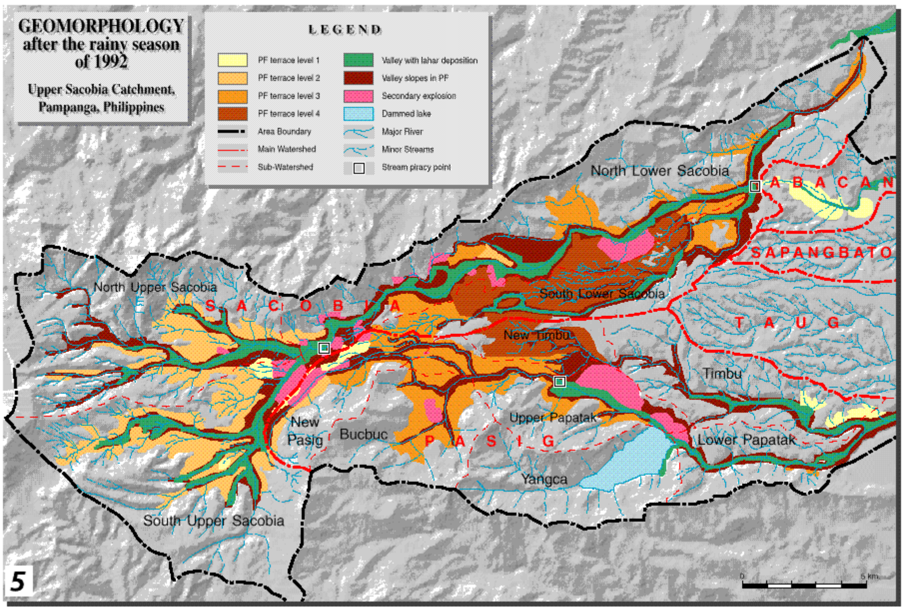

Table 3: Changes of catchment sizes between the first and second rainy season following the eruption. Fill in the table based on the results from the cross table

After first rainy season of 1991	After second rainy season of 1992					
	Sacobia	Pasig	Abacan	Taug	Sapangbato	Total
Sacobia						
Pasig						
Abacan						
Taug						
Sapangbato						
Total						

The exact calculations for obtaining the erosion and sedimentation, and the remaining PF volumes in 1992 are not given here anymore, but you are requested to formulate them yourself.

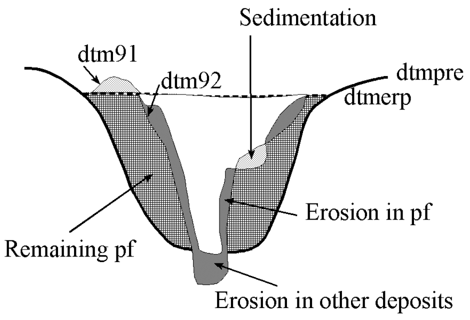

Figure 4: Schematic cross-section showing the situation after the second rainy season following the eruption

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- Design the formulas yourself and write them in the spaces below.
- Calculate the volumes for:
  - total erosion in 1992,
  - erosion in PF deposits in 1992,
  - erosion in other deposits in 1992,
  - sedimentation in 1992,
  - remaining PF volume in 1992.
- Store the results in the table Total.

Total erosion:
Ero92=
Erosion in PF deposits:
Eropf92=
Erosion in other deposits:
Eroot92=
Sedimentation in 1992:
Sed92:=
Remaining PF material in 1992:
Pfth92=

The situation after the third rainy season

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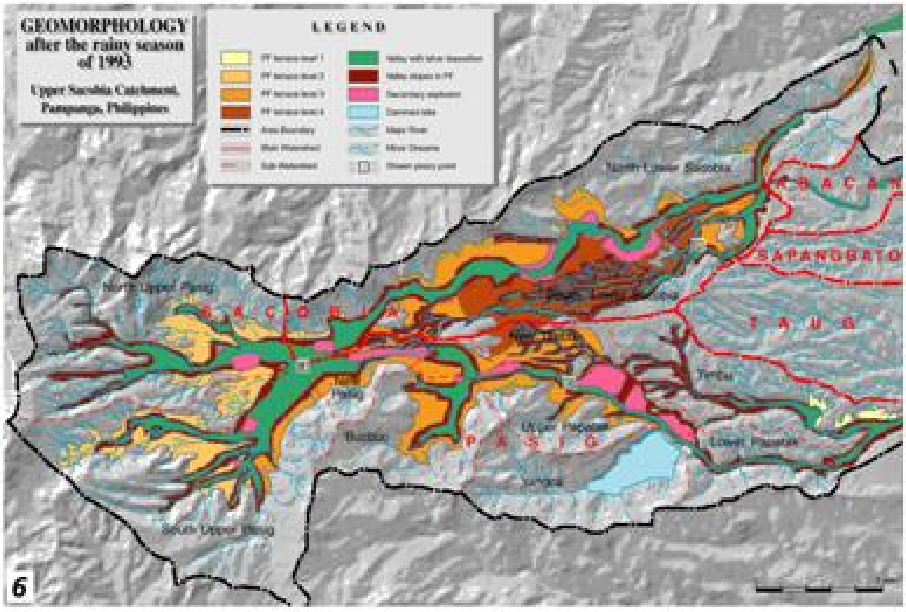
- Calculate a hillshading image of the map **Dtm93** and display it on the screen.
- Overlay the segment information from the maps **Catch93** and **Drain93**. Create a map view **View93**.
- Compare the result with that of the previous year.

Valleys have grown rapidly in the upper portion of the catchment near the confluence of the 2 large valleys. This massive erosion was triggered by a large secondary explosion which occurred on October 6, 1993, and as a result, a large secondary pyroclastic flow was directed towards the Pasig river. This event caused the capturing of the entire upper Sacobia catchment by the Pasig river, and brought a major shift in lahar delivery from the Sacobia to the Pasig river. From aerial reconnaissance, the secondary pyroclastic flows covered the major gullies both in Sacobia and Pasig catchments by at least 20 meters of hot secondary pyroclastic flow deposits. The event did not leave clear secondary craters due to the large subsequent erosion, but only broad flat valleys. The capture occurred during typhoon Kadiang. The relative timing of capture can be reconstructed by the change of lahar magnitude of both channels as measured by the acoustic sensors in the lahar monitoring stations.



As a result of the capture of the upper section of the Sacobia catchment, the erosion in the Pasig river increased dramatically. Rapid vertical and lateral erosion in the pyroclastic flow deposits, which were still hot, resulted in numerous secondary explosions along the Pasig river. At the lower part of Sacobia, the valleys were considerably incised into the pre-eruption deposits attaining a vertical valley wall of about 50-80 meters.

The upper pyroclastic flow level was by now completely eroded, and the second level remained only in the eastern part of the catchment. In the lower terrace levels erosion reached the underlying pre-1991 pyroclastic flow deposits in several places.

The capacity of the temporary lake to retain water had decreased considerably due to the deposition of lahars into the Yangca creek. No large lake-failure related lahar occurred during 1993, since the lahar dam at Yangca creek was much higher than the active channel. In 1994 however, the lahar dam failed, resulting in a major lahar in the downstream Pasig catchment.

Now you can calculate the changes in the catchments that resulted from the accumulation of the pyroclastic flow deposits.

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- Rasterize the map **Catch93** using the georeference **Dtmpre**.
- Cross the two raster maps **Catch92** and **Catch93**. Follow the same procedure as used earlier to calculate the changes in catchment sizes (in square kilometers).
- Fill in the values in table 4.
- Close all map and table windows.

Table 4: Changes of catchment sizes between the second and third rainy season following the eruption. Fill in the table based on the results from the cross table

		After third rainy season of 1993					
		Sacobia	Pasig	Abacan	Taug	Sapangbato	Total
After second rainy season of 1992	Sacobia						
	Pasig						
	Abacan						
	Taug						
	Sapangbato						
	Total						

The exact calculations for obtaining the erosion and sedimentation, and the remaining PF volumes in 1993 are not given here anymore. Again, you are requested to formulate them yourself.

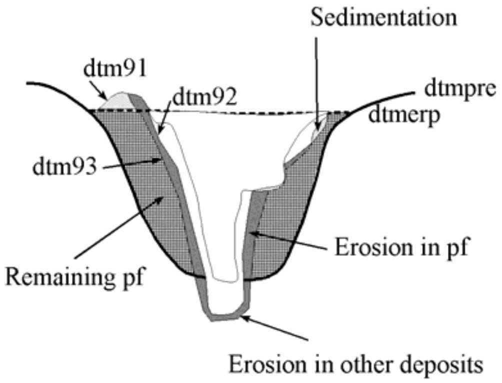

Figure 5: Schematic cross-section showing the situation after the third rainy season following the eruption

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- Design the formulas yourself and write them in the spaces above.
- Calculate the volumes for:
  - total erosion in 1993,
  - erosion in PF deposits in 1993,
  - erosion in other deposits in 1993,
  - sedimentation in 1993,
  - remaining PF volume in 1993.
- Store the results in the table Total.

Optional exercise:

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- Make a synthesis of the sediment changes and catchment changes for the investigated period.

References

Daag, A. and Van Westen, C.J. (1996). Cartographic modelling of erosion in pyroclastic flow deposits of Mount Pinatubo, Philippines. *ITC Journal* 1996-2: 110-124.

Pierson, T.C., Janda, R.J., Umbal, J.V. and Daag, A.S. (1992). *Immediate and Long Term Hazards from Lahars and Excess Sedimentation in Rivers Draining Mt. Pinatubo, Philippines*. United States Geological Water Survey Resources Investigation Report 92-4039. USGS Vancouber, Washington, 35pp.

Punongbayan, R.S., Tungol, N.M., Arboleda, R.A., DelosReyes, P.J., Isada, M., Martinez, M.L., Melosantos, M.L.P., Puertollano, J., Regalado, T.M., Solidum, R.U., Tubianosa, B.S., Umbal, J.V., Alfonso, R.A. and Remotique, C.T. (1993). *Impacts of the 1993 Lahars and Long-Term Lahar hazards and Risks Around Pinatubo Volcano*. Philippine Institute of Volcanology and Seismology (PHIVOLCS). PHIVOLCS publication, Quezon City, 72 pp.

Exercise 4a: Generating a database of elements at risk from scratch

Expected time:	3.5 hours
Data:	data from subdirectory:Riskcity_exercises/exercise04a/data
Objectives:	This exercise gives a method for the generation of a database for the elements at risk within RiskCity, focusing on buildings and population. In this exercise 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.

Risk assessment with GIS can be done on the basis of the following basic equation:
Risk = Hazard * Vulnerability * Amount of elements at risk

In this exercise we are limiting ourselves to only the upper row : buildings and population. This is due to the limited time for the exercises. Also because in practice they are considered first. However, a complete risk assessment should also evaluate the direct and indirect impacts of the other types of elements at risk.

The elements at risk that may be affected by hazardous events are numerous, and can be classified in many different ways. The table below provides an example of such a classification.

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, acuifers, flora, fauna, biodiversity.

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. The area within a mapping unit can be considered as more or less homogeneous, and the buildings have more or less the same urban land use, and the same building type. We do not carry out risk assessment for individual buildings because the hazard and vulnerability information is not detailed enough to do that at such a detailed level.

Depending on your interest in the topic you may select to either do Exercise 4a (creating a database by starting from scratch), or Exercise 4b (creating a database with available building footprint information). You can also decide to do both exercises, although that might perhaps take a bit too much time

Input data

The following table gives an overview of the thematic data and how they are derived.

Name	Type	Meaning
Image data		
High_res_image	Raster image	This represents a high resolution color image derived from an IKONOS image. It has been orthorectified, and the panchromatic band is fused with the color bands, and resampled to 1 meter.
Elements at risk		
Unit_boundaries	Segment map	A segment map of the boundaries of the mapping units (city blocks) that will be used as the basis for the creation of the polygon map.
Mapping_units_ points	Point map	A point map with a point in each mapping unit, with a unique identifier that can be used to polygonize the segment map **Unit_boundaries**.
Mapping_units	Polygon map and table	This map represents the mapping units used for elements at risk mapping, but now as polygons. Each of the mapping units has a unique identifier, so that in the accompanying table information can be stored for each unit. The units may be individual large building or plots with a specific landuse, although they are mostly grouping a number of buildings. In the accompanying table information is given on the number of buildings and number of people
Mapping_units_ population_estimate	Table	Intermediate results. A table containing the correct information on landuse and number of buildings, required for estimating the population per mapping unit.
Roads	Segment map	A segment map of the streets, roads and paths, made by digitizing from topographic maps.

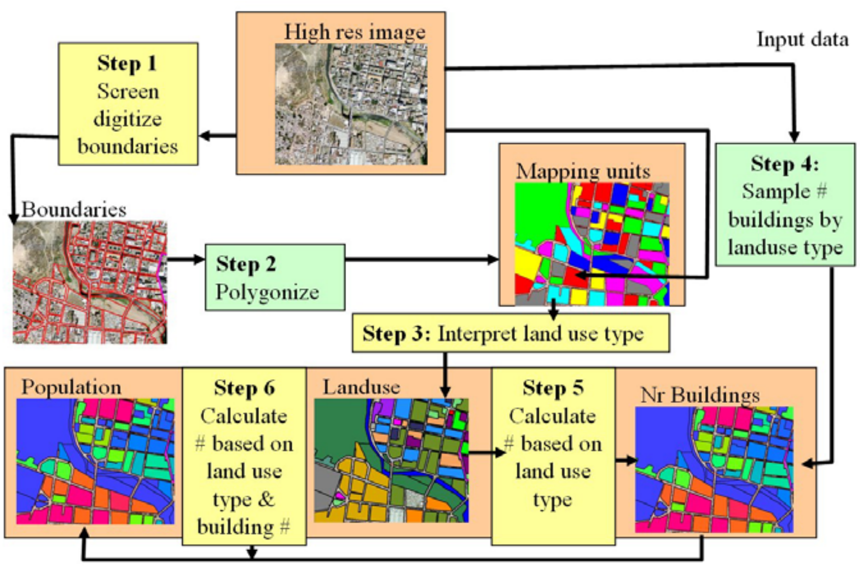

Figure: flowchart showing the procedure followed for the generation of an elements at risk database from scratch. The steps indicated in green are not part of this exercise.

The database generation is done using the procedure shown below. Central in the database is the map **Mapping_units**, derived from boundary lines that are screen digitized on top of the high resolution image. The attribute information linked to this map is related to **urban land use** (interpreted from the image), and the **number of buildings** (estimated from samples taken from the image),. The building information is used to estimate the population distribution.

In the figure a flowchart is given of the procedure that we will follow in this exercise. The steps indicated in yellow will be explained, and you can practice with these. The steps indicated in yellow are skipped, because they might take too much time.

Important: in order to be able to do every step individually we have provided the results of each step so that you can use that to do the next one. For step 1 and 3 you will only do a very smalll part. Given the large size of the area, digitizing the entire area and interpreting all mapping units for the landuse would simply take too much time.

In this case study we only take into account two types of elements at risk: buildings and population. Building information could be obtained from existing cadastral databases, and population data from census database. However, in many cities in developing countries such data are not available, or are restricted, or are not in a digital format. When these data are not available they should be collected. However, the generation of a building database in GIS is a very time-consuming procedure. When high-resolution data sets are available, such as in this exercise, we can use them for interpretation, and the basic mapping units can be digitized on the screen.

Step 1: Screen digitizing the mapping units

In this exercise we will show you a number of steps to generate an elements at risk

As mentioned earlier we base the risk study on so-called mapping units, which consists of a series of buildings, with more or less the same landuse pattern. In exercise we will centrate on the mapping of the basic units for the urban risk assessment. There are two files in the dataset that are most important for that:

- **Unit boundaries**: this contains the boundary lines of the mapping units that will be used as basic units for the elements at risk. It has been made through screen digitizing on the high-resolution image. The segments of the street pattern have been used as the basis for the screen digitizing.
- **Mapping_units**: These polygons represent the mapping units used for elements at risk mapping, but now as polygons. Each of the mapping units has a unique identifier, so that in the accompanying table information can be stored for each unit. The units may be individual large building or plots with a specific landuse, although they are mostly grouping a number of buildings.

We start with the actual screen digitizing the segment of the mapping units. It is possible to do that in three ways:

Watch Demo 9 for instructions

1. On top of the **High_res_image**. In this case you will not be able to see stereo, which is a disadvantage in the interpretation. However, you are able to see a lot of detail and the color also adds to it.
2. On top of a **color stereo image**. This is the best way, but you will need a screen stereoscope for that, so not possible now
3. On top of the anaglyph stereo image **Anaglyph**. You will need anaglyph glasses for the interpretation. The problem is that the lines will not exactly match with the features in the image.

Let us start by using option 1:

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- Open the raster image **High_res_image**.
- On the **Layer** Menu, go to **Add Layer** and select the **Unit_boundaries** segment map.
- Now you can view the segments of the different mapping units in the study area. As you can see the mapping units are mostly bounded by the streets.
- You can also see that there are two areas indicated by a thick line that do not yet have unit boundaries: one in the center of the city and one near the river. Zoom in on the part in the city center, indicated by the purple line. You can see that the mapping units are still lacking
- In the map window of **High_res_image** select *Edit / Edit layer* and select the segment map **Unit_boundaries**

Now you enter into the segment editor, in which you can digitize segments (lines) and edit existing ones.

Some more information about digitizing with ILWIS.

ILWIS allows you to digitize two objects: **points** and **lines** (called **segments**). Point digitizing is done using a point map, and in the point editor, and line digitizing is done in the segment editor.

You cannot directly digitize polygons in ILWIS. Polygons are generated by combining a segment map with a point map. The segments will give the boundary lines of the polygons and the points will give the labels. Therefore the domain of the points used in the generation of the polygons is the same as the domain of the resulting polygon map. (Polygons can also be made by vectorizing a raster image, but that is another procedure). You can also edit polygons in a polygon editor, but then you can only change the names of the polygons, and not the boundary lines. These should be changed in the segment editor.

How to digitize

You can digitize in two ways:

- Using a digitizing tablet. This used to be the standard method in the past. Paper maps were fixed on the tablet and a digitizer cursor was used to digitize.
- Screen digitizing. This is now the standard method. The map or image you want to digitize is scanned and is displayed on the screen as a raster map. You then digitize directly with the mouse. This method is followed here.

Digitizing segments.

A segment always consists of nodes (the beginning and the end) and intermediate points. The intermediate points are connected by straight lines, so to make complicated curved segments you need to digitize more intermediate points than when you digitize straight lines.

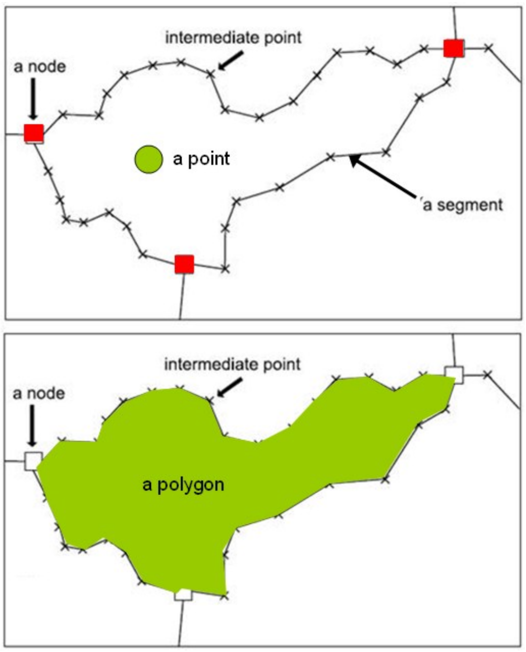
You can digitize in two ways:

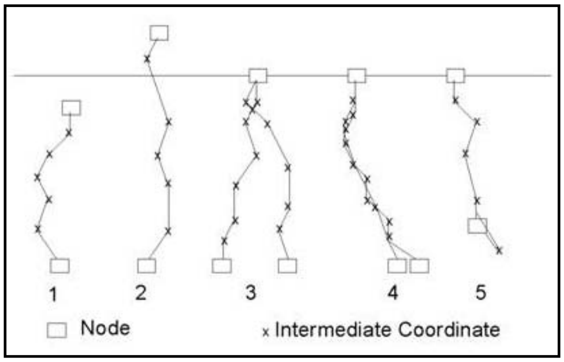
- **Point mode**: you press the mouse (digitizing) button and move further and then press again. Only when you press the button an intermediate point is digitized. This is OK for rather straight lines.
- **Stream mode**: you keep the mouse (digitizing) button pressed continuously while following the line you want to digitize

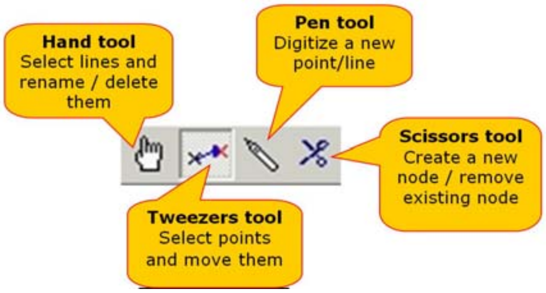
Segments that are used for the generation of polygons should always be connected. All the nodes should connect to another node, and lines cannot cross each other or themselves without a node. This requires careful digitizing. And it is required that you check the segments before you can create polygons. During digitizing several errors can occur that are illustrated in the figure:

- **Dead end in segment** (1 in figure): A node of a segment is not connected to another node. You have to create a node in the upper segment (by cutting it with the scissors tool) and connect the nodes with the tweezers tool.
- **Intersection without node** (2&3 in figure). The lines cross without a node. Edit with Scissors and tweezers tools.
- Self overlap (5 in figure). A segments overlaps itself. Use tweezers to untie the knot.
- Double line (4 in figure). In case you accidentally digitized the same line twice. Use the hand tool to select one and delete.

Important: always manually edit the errors, and don't accept the automatic corrections suggested by ILWIS, as this normally makes things only worse.







As you can see it may not always be so easy to digitize the mapping units, because the buildings are of different sizes, and the shadows of the buildings also play a role.

Figure: Left: High-resolution image and right segments of mapping units. One new segment has been added.

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- You can use the on-screen-digitizing functionality to create the boundary of the mapping units inside it. Given the resolution of the imagery available, it will be very difficult to digitize individual buildings (also because there are just too many). If the building is large enough, you may also decide to map individual buildings. Also digitize vacant land. Use the pen in the editor menu to digitize.

- Make sure that the lines are given the code: **Unit_boundaries**
- When you finish digitizing one segment, select the segment with the *Select Mode* icon (the hand) and choose the correct class. Next select the *Insert Mode* icon (the pencil) and digitize the following segment.

The image that you see when digitizing the blocks in the center of the city is shown in the figure below.

It doesn't matter if you do not finish the exercise. The aim of this exercise is just to make you aware how the mapping units have been defined

Figure: Right: completed section of digitized mapping units

Watch Demo 10 for instructions

☞ .

- After finishing (part) of the digitizing, go to the *File* menu and select *Check Segments*. Select *Self Overlap*. Repair the mistakes. Ask a teacher to assist you the first time, if you have no experience with it.
- Then check segments using *Dead Ends*, and *Intersections*. Repair all mistakes.
- Close the map editor (using the symbol), and close the map window.

After digitizing the segments of the boundaries of the mapping units, the next step would be to create polygons from them. This polygonization procedure takes more time, because the segments should be checked for errors, and in each polygon there should be a point with an Identifier domain, indication the number of the mapping unit. This procedure takes a bit too much time to do this right now.

Step 2: Polygonize from segments.

- We will not do the actual polygonization of the segments now because that might take to much time, as you will have to edit the segement map. For that you have to make sure that all the segments are digitized, and that they connect to each other, without overlaps or dead ends. This is done through checking the segments in the segment editor. After all segments are OK, the next step is to select *Operations, Vectorize, Segment to Polygons*. Instead of having digitized the points within the mapping units with a unique identifier, it is also possible to do this automatically. Select the option *Unique Identifiers* in the operation window *Segments to Polygons*. This will result however, in a random selection of identifiers. The resulting polygon map will have different identifier than the polygon map **Mapping_units** which is already in the dataset. Make sure to name the output polygon file differently, e.g. **Mapping_unit_polygons**.Urban land use.
- You can also use pre-existing points in the segment to polygon operation. We have generated the points for you, in the point map **Mapping_units_points**.

Step 3: Estimating urban land use from image interpretation

In the exercises we generate a database where the polygon map **Mapping_units** is the central map, and attribute information is stored for the following attributes:

- Urban land use
- Percent vacant area
- Number of buildings
  - With 1 floor
  - With 2 floors
  - With 3 floors
  - With > 3 floors
- Population
  - Daytime
  - Nighttime

After you have had an idea on how the segments were made using screen digitizing, and how these were used to generate polygons, let us look at the attributes that can be obtained. In the following exercises we will estimate these attributes. We start by estimating the urban land use. The vulnerability assessment will be largely based on the urban land use mapping, which will be combined with other information such as the number of buildings, and the height of the buildings.

For the multi-hazard loss estimation the urban land use is very important, as we can later define the population amount which might be in the mapping unit at a particular time of the day. That is why it is important to differentiate between the land use types that would have different activity patterns, at the same time of the day. For example, in residential areas, the population is supposed to be highest during the night, and lowest during the day, whereas in office buildings and schools it is reverse. On the other hand there are landuse types that have a very large number of people during a small period (e.g. stadium, religious buildings). Also it is important to map the areas that normally have no people (e.g. vacant areas). For the land use classification we have made the following legend (in ILWIS terms called a "domain").

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* Open the domain **Landuse** , (

)

* In the table below, indicate the importance of a number of the classes for characterizing the population and building vulnerability.

Name	Code	Description
Com_business	Com_b	Business offices
Com_hotel	com_h	Hotels
Com_market	com_m	Commercial area: market area
Com_shop	com_s	Commercial: shops and shopping malls
Ind_hazardous	ind_h	Hazadous material storage or manufacture
Ind_industries	ind_i	Industries
Ind_warehouse	ind_w	Warehouses and workshops
Ins_fire	ins_f	Fire brigade
Ins_hospital	ins_h	Hospitals
Ins_office	ins_o	Office buildings
Ins_police	ins_p	Police station
Ins_school	ins_s	Institutional : schools
Pub_cemetery	Pub_g	Cemetery
Pub_cultural	pub_c	Institutional: cultural buildings such as musea, theaters
Pub_electricity	pub_e	Electricity installations
Pub_religious	pub_r	Religious buildings such as churches, mosques or temples
Rec_flat_area	rec_f	Recreational: flat area or foorball field
Rec_park	rec_p	Recreational: park area
Rec_stadium	rec_s	Recreational : stadium
Res_large	res_5	Residential: large free stading houses
Res_mod_single	res_4	Residential, moderately sized single family houses
Res_multi	res_3	Residential: multi storey buildings
Res_small_single	res_2	Residential, small single family houses, mostly in rows
Res_squatter	res_1	Residencial, low class houses: squatter areas
River	riv	River
unknown	u	
Vac_car	vac_c	Vacant : car parking and busstation
Vac_construction	vac_u	Vacant area which is prepared for building construction
vac_damaged	vac_d	Area recently damaged by hazard events
Vac_shrubs	vac_s	Vacant land with shrubs, trees and gress

Important because

Having done this, let us now look more closely to the map **Mapping_units**, and you can define what the landuse should be yourself by interpreting the characteristics of the image.

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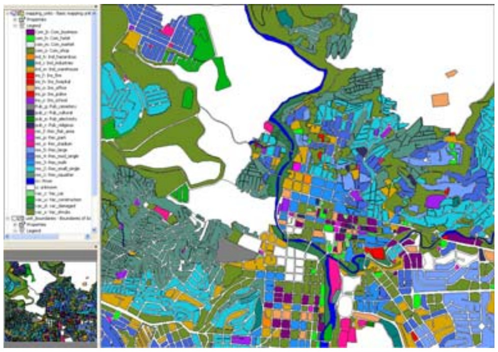
* Open the polygon map **Mapping_units**. If you click on one of the polygons, you can see that each of them has a unique identifier, so that it is possible to give each of them different attributes, which come from the attached table.
* Click with the right mouse button in the map, and select *Display Options*, and select **1 pol mapping_units**. The *Display Options* window opens again. Now select the option *Attribute*, and make sure the option **Pred_landuse** (predominant landuse) is selected. Select representation: **Landuse**. Now the map is displayed again, but now with the colors representing different land use types. Check this with the legend on the left. There are a number of white areas, which have been left open, and for which the landuse still needs to be indicated.



The map is now shown with white areas that do not have any land use classification. You can now use the information from the high resolution image to decide what is the most likely landuse type. For instance you can easily define the vacant areas, and the areas that have been damaged by the recent flood and landslide disasters that occurred in the area. If you look closely you can also find evidence in the city centre that there are religious building (e.g. churches), commercial buildings (e.g. market place), different types of residential buildings (e.g. those with single houses in gardens, houses in rows, squatters etc. See also the information in Chapter 4 of the Guide book.

Try to estimate the urban landuse for a number of the white areas in the map yourself.

☞

* Select *Layers / Add* layers and add the raster image **High_res_image**. Now you can see that the high resolution image is shown for the areas which are not coded.
* Zoom in on one of the areas without a land use class, and double click in it. The attribute window is now opened, and the attribute **Landuse_interpretation** is indicated: **unknown**. Click in this window on the name **unknown**. You can now open a list of other possible land uses. Select the one you consider right, and double click on another polygon.
* You can also select the other attribute "**Easy_to_interpret**" to indicate wheter it is easy to interpret the landuse class for this polygon based on what you see in the image.
* If you click the  button, you will see that the map is updated and the polygon will become colored.
* Zoom in on another unclassified area, and select again the right landuse.

Note: Alternatively click on the attributes Landuse_interpretation and Easy_to_Interpret. If you only click on one, the next time you can't select from the list, and then you click first on the other

* Do this for a number of the polygons that don't have a land use code yet.
* Which of the land use classes are most difficult to decide?

In reality you might have to carry out fieldwork to better characterize urban land use, or you might have an existing land use map. These are however, often too general in terms of the categories used. Later on in exercise 4c we will show how you can use Participatory GIS for collecting this type of information

Land use type	Easy to Interpret?	Why?

Step 5: Estimating the number of buildings

The number of buildings per mapping unit is also a very important attribute that is required for risk assessment. The estimation of the number of buildings per mapping unit can be done in two ways, considering the situation of a data poor environment:

- An accurate way is to actual count the number of buildings for all mapping unit from the high-resolution image. However, this would cost an enormous amount of time and is not very feasible.
- A less accurate way is to make a number of samples per mapping units for each land use type and count the number of buildings. Then the average building size is calculated, and for those mapping units where no samples were taken these average building sizes are used in combination with the area of the mapping unit to estimate the number of buildings.

We will follow the second method here. We did the sampling for you (lucky for you), and counted for a number of mapping units (approximately 140) the number of buildings. The sampled mapping units are stored in the table **Buildings_sampled**.

The accuracy of this method depends on the amount of samples that you make, and the amount of field checks you make. So as such the method might lead to good results in a data poor environment.

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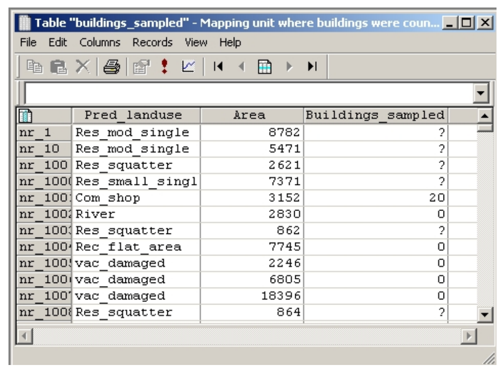
- Open the table **buildings_sampled**.

table has the following columns:
- **Pred_landuse**: the urban land use that you estimated in the previous exercise
- **Buildings sampled**: an indication of the number of buildings that was manually counted in some of the mapping units. This was done directly from the high resolution image.



	Pred_landuse	Area	Buildings_sampled
nr_1	Res_mod_single	8782	?
nr_10	Res_mod_single	5471	?
nr_100	Res_squatter	2621	?
nr_1000	Res_small_singl	7371	?
nr_1001	Com_shop	3152	20
nr_1002	River	2830	0
nr_1003	Res_squatter	862	?
nr_1004	Rec_flat_area	7745	0
nr_1005	vac_damaged	2246	0
nr_1006	vac_damaged	6805	0
nr_1007	vac_damaged	18396	0
nr_1008	Res_squatter	864	?

As you can see most of the records of Buildings samples have a **?**, meaning that they are not sampled. Those that have a 0 value do not have buildings, as can be deduced from the urban landuse (vacant). We will now use some steps to make a rough estimation of the number of buildings for each mapping unit. We do this by making the following assumptions:

- **Step A**: We can calculate the average area of buildings for the mapping units that were sampled.
- **Step B**: We assume that buildings in the same land use class have more or less the same area.
- **Step C**: We then divide the area of the mapping units that were not sampled by the average building area to obtain a rough estimation of the number of buildings.

The ILWIS procedure to do this is given below:

In the procedure we make use of several ILWIS tools: Table operations including table calculations and aggregate functions.
Map and Table Calculation:
ILWIS has two options for calculation:
Map calculation, where the output is always a map. You type the formulas in the command line of the main window.
Table calculations where the output is always a column. You type the formulas in the command line of the table window.
The syntax for both types of calculations is very similar.
Check on the ILWIS HELP for an overview of the operators and functions used in map and table calculation.
Check for instance the use of the **conditional IFF function** and the logical operators (**and, not, or, xor**).

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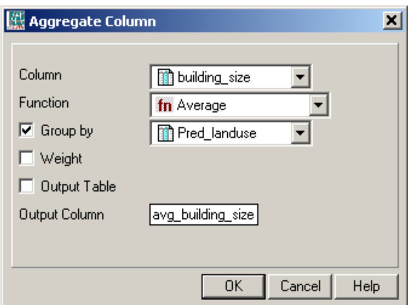
- Open the table **buildings_sampled**.
- **Step A:** Use the following formula to calculate the building size in the mapping units, where samples were taken.

building_size:=iff(buildings_sampled=0,0,area/ buildings_sampled)

Use a precision of 1.

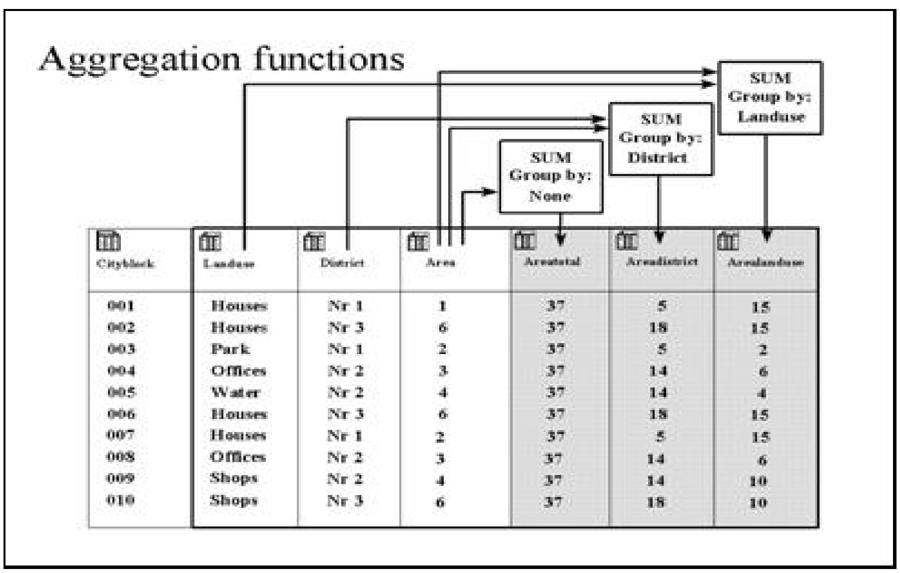
This formula means "if the value in the column **building_sampled** is 0 (meaning that the areas are vacant and don't have buildings) then the resulting building size is 0. If not divide the area by the number of buildings sampled. Now for all sampled mapping units we have calculated what the building size was.

- **Step B:** Now we want to know the average building size per land use . Select *Columns / Aggregation*. Select the column **Building_size**, and the function *Average*. Group by **Pred_landuse**. Name the output column: **avg_building_size.** See the example screen.



Aggregation functions.
They aggregate the values of a column in the current table. The following aggregation functions are available: Average, Count, Maximum, Median, Minimum, Predominant, Standard deviation, Sum.

- All aggregation functions can be used to aggregate the values of a whole column: you obtain one output value. For all records, the same aggregation value will appear.
- All aggregation functions can be used to aggregate values in a column per group: use a '**group by**' column. Then, for all records that have the same class names or IDs in the selected 'group by' column, the same aggregation value will appear.
- The Average, Median, Predominant and Standard Deviation functions can be used to calculate weighted averages, etc.: use a weight column.
- If you do not select a 'group by' column, you will obtain one output value.
- If you also select a 'group by' column, you will obtain one aggregation value per group.



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- **Step C:** Use the following formula to estimate the number of buildings for all units:

nr_buildings:=iff(isundef(buildings_sampled) , area/avg_building_size, buildings_sampled)

Use a precision of 1.

This formula means: if the column **Buildings_sampled** is undefined (has no value) than we divide the area of the mapping unit by the average building size (based on the same land use). If the column **Buildings_sampled** is not undefined, then we use the information from the column: **Buildings_sampled**.

Undefined values in ILWIS can mean several things:

- No data is available for a pixel.
- A pixel is located outside the study area.
- The result of calculation was wrong (for example if the formula is wrongly made).
- Calculated values in an output map fall outside the value range defined by the output range values.

Isundef() function tests whether a field in the column or a unit in a map is undefined or not known. Check the ILWIS guide for further explanation.

Now we can bring in the number of buildings that we have calculated in the table **Buildings_sampled** into our standard table that is linked to the map we use in risk assessment: **mapping_units**. We use the operation: table joining for that.

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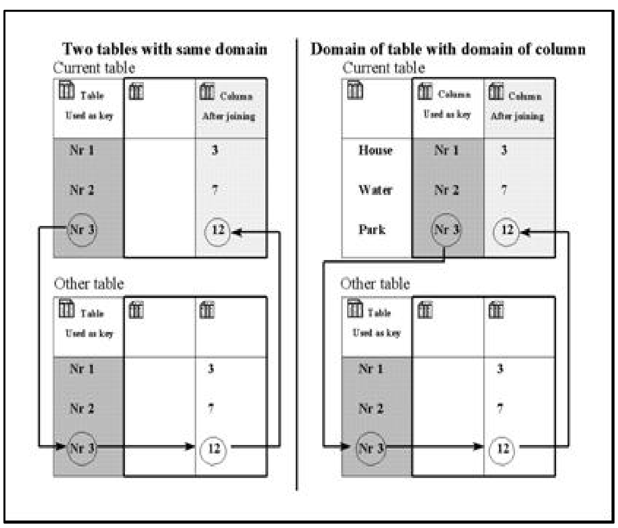
- Close the table **Building_samples** and open the table **Mapping_units**.
- Select *Columns / Join*, and join with the table **Buildings_sampled**, and select first the column **Pred_landuse**. Click *Next, Next* and *Finish* in the join wizard.
- Select *Columns / Join*, and join with the table **Buildings_sampled**, and select the column **Nr_buildings**. Click *Next, Next* and *Finish* in the join wizard.



The figure shows two different ways of table joining. Dark shaded columns are used as key. The arrows indicate how the link is made. Left: The domain of the current table is the same as the domain of the other table from which you want to join a column. Right: The domain of a column in the current table is the same as the domain of the other table from which you want to join a column. The easiest way to join columns from another table into a current table is to use the Join Column wizard. The wizard needs to know the table name from which you wish to get a column, the name of the column that you wish to join from that table into the current table, and the relation or link between the two tables. This link is made via a common domain that is used either by the tables themselves or by a column in the tables. This link or key, through which a join can be performed, should be a (common) Class or ID domain.

We can now display the results.

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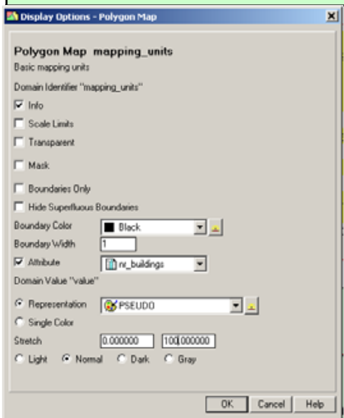
- Open the map **Mapping_units**, and display the attribute **Nr_buildings.** Select representation gray**.** Stretch between 0 and 100 (first make sure that you change the properties of the polygon map **Mapping_units**, and link to Attribute: **Mapping_units**). Overlay the high resolution image.
- Evaluate the results by comparing the number of calculated buildings with those that you can see in the image



Naturally, if you check the actual number of buildings, the values of the estimated number of buildings will not be the same as the actual ones, because there may be exceptionally large or small buildings in the same landuse. It also doesn't consider the presence of vacant areas within the mapping units. We will check the accuracy of this method in section 3.2.

Step 6. Estimation of population distribution

In this analysis of population distribution we assume standard number of people per building for different land use type. We ignore the fact that larger buildings have more people.

Once we have estimated the number of buildings we can also estimate the population per mapping unit. Also here we assume that we do not have any other available data, such as population census data for the study area. We have to assume an average number of people per building, which depends on the land use type, as office buildings have more population than single houses. This information is already provided in the table **Landuse**. We can also calculate the population for a daytime and a nighttime scenario. For that we have also added two columns indicating the percentage of population that would be present in each type of building during the day and during the night.

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- Open the table **Landuse** and check the values for the three columns: **Person_building**, **Daytime** and **Nighttime**.

The table indicates the average number of people that would be in a typical building of a particular land use class. For instance, a building in a squatter area has an average of 7 people, whereas a large residential building has approximately 5 people. These value indicate the maximum number of persons that would be in a building. Depending on the day or night scenario these values would be multiplied by a factor, which would decrease these. For instance commercial buildings would be at full capacity during the day, and be empty during the night .

Make your own evaluation of the number of people and the daytime and nighttime factors that you find appropriate. You can of course simply agree with our estimates…

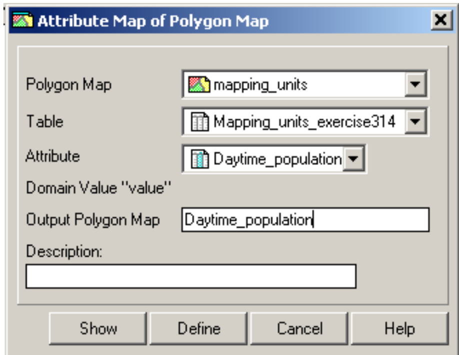
Land use class	Our estimation			You estimation		
	People per building	Daytime	Nighttime	People per building	Daytime	Nighttime
Com_business	20	1	0			
Com_hotel	100	0.1	1			
Com_market	1000	1	0			
Com_shop	10	1	0			
Ind_hazardous	10	1	0			
Ind_industries	25	1	0			
Ind_warehouse	20	1	0			
Ins_fire	25	1	1			
Ins_hospital	800	1	1			
Ins_office	100	1	0			
Ins_police	50	1	1			
Ins_school	300	1	0			
Pub_cemetery	0	0	0			
Pub_cultural	200	0	1			
Pub_electricity	0	0	0			
Pub_religious	500	1	0			
Rec_flat_area	0	0	0			
Rec_park	0	0	0			
Rec_stadium	20000	0	0			
Res_large	5	0.2	1			
Res_mod_single	6	0.2	1			
Res_multi	20	0.2	1			
Res_small_single	6	0.2	1			
Res_squatter	7	0.3	1			
River	0	0	0			
unknown	0	0	0			
Vac_car	0	0	0			
Vac_construction	0	0	0			
vac_damaged	0	0	0			
Vac_shrubs	0	0	0			

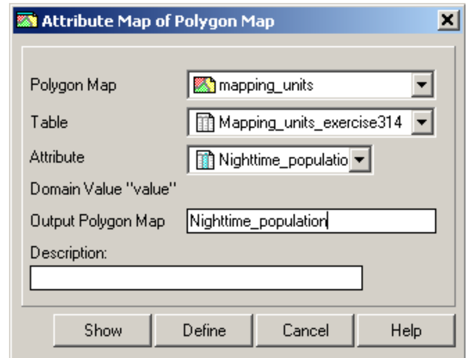
We have provided you the correct results for the previous steps in a table **Mapping_units_population_estimate**.

☞

- Open the table **Mapping_units_population_estimate** and compare the results with the ones you obtained in the earlier part of this exercise.
- We can now read in these three columns into the table **Mapping_units_population_estimate**. (We have already calculated the number of buildings resulting from the previous exercise in this table). Open this table and use the join operation with the table **Landuse** for that. Read in the columns **Person_building**, **daytime** and **nighttime**.
- Now it is simply a matter of multiplying the number of buildings with the population per building and the correction factor for day- or nighttime.

  Daytime_population:=nr_buildings * person_building * daytime
  Nighttime_popultion:= nr_buildings * person_building * nighttime
  (make sure to use a precision of 1, as we cannot have half a person)
- Display the results (make sure to link them with the map in the properties of the map **Mapping_units**), and check the pattern.
- Also make attribute maps of both. In the catalog right click on the polygon map **mapping_units**, then select *vector operations, attribute map*. Select the table **Mapping_units_population_estimate**, the attribute Daytime and call the output map **Daytime_population**. Do the same for the **Nighttime_population**. See the image below





Answer:

Is there an accurate division of population if you compare daytime and nighttime?
What could be the reason?
How could this be improved?

Period	Total population
Daytime	
Nighttime	
Difference	

Pocket Line Calculator:
To temporally view the outcome of an expression, without storing the results in a column, you can use the command line as a Pocket line calculator. On the command line type a "?" followed by an expression.

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- You can read the total Daytime and Nighttime population in the table **Mapping_units_population_estimate** , activating the statistic pane in *view, statistic pane*, and reading the value **sum** under the column **Daytime_population** and **Nighttime_population**.
- For the evaluation of the difference you can use a generic calculator or typing directly in the command line of ILWIS the following formula:

?183779-143379

Now you have generated a basic elements at risk database from scratch, basically only based on the interpretation of a high resolution image.

Exercise 4b: Generating a database of elements at risk using existing data

Expected time:	3 hours
Data:	data from subdirectory:RiskCity_exercises/exercise04b/data
Objectives:	This exercise shows you a method for the generation of a database for the elements at risk within RiskCity, focusing on buildings and population. We assume that we have detailed building information available, in the form of a building footprint map, and that we have a LIDAR image from which we can calculate the height of buildings, and the floorspace of buildings per land use type. Population estimates are made based on the building floorspace, and census data.

Risk assessment with GIS can be done on the basis of the following basic equation:
Risk = Hazard * Vulnerability * Amount of elements at risk

In this exercise we are limiting ourselves to only the upper row : buildings and population. This is due to the limited time for the exercises. Also because in practice they are considered first. However, a complete risk assessment should also evaluate the direct and indirect impacts of the other types of elements at risk.

The elements at risk that may be affected by hazardous events are numerous, and can be classified in many different ways. The table below provides an example of such a classification.

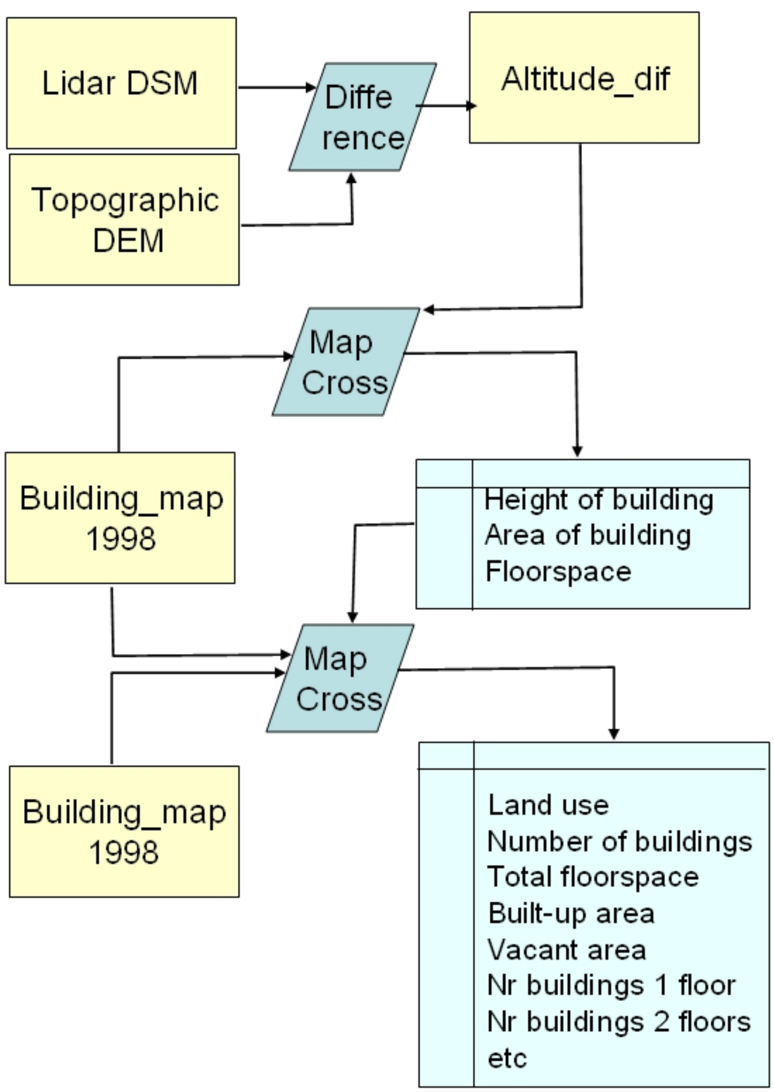
Physical elements Buildings: Urban land use, construction types, building height, building age, total floor space, replacement costs. Monuments and cultural heritage	**Population** Density of population, distribution in space, distribution in time, age distribution, gender distribution, handicapped, 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, acuifers, flora, fauna, biodiversity.

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. The area within a mapping unit can be considered as more or less homogeneous, and the buildings have more or less the same urban land use, and the same building type. We do not carry out risk assessment for individual buildings because the hazard and vulnerability information is not detailed enough to do that at such a detailed level.

Depending on your interest in the topic you may select to either do Exercise 4a (creating a database by starting from scratch), or Exercise 4b (creating a database with available footprint information). You can also decide to do both exercises, although that might perhaps take a bit too much time

The following data will be used in this exercise

Name	Type	Meaning
Image data		
High_res_image	Raster	High resolution image of the situation in 2006
Height information		
Altitude_dif	raster map	A raster map showing the difference in elevation between the Digital Surface Model from Lidar and a Digital Elevation Model from interpolated contourlines.
Elements at risk		
Mapping_units	Polygon map	Mapping units used as the basis for the risk assessment. The table contains a landuse classification
Buiding_map_1998	Segment map	Updated segment map of buildings for the situation after the disaster of 1998.
Building_map_1998	Raster map	Updated map of buildings for the situation after the disaster of 1998.
Ward	Polygon map	Map of the wards (neighborhoods) of the city.

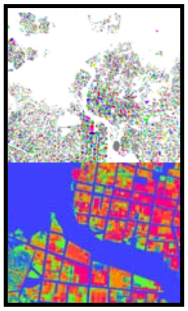


The Procedure that will be followed in this exercise is given in the flowchart. Since we have a building footprint map, which contains the outlines of the the buildings in RiskCity it will be easier to make a good estimate of the nuber of buildings per mapping unit, then in the method explained in exercise 4a. The Building footprint map that was used in the previous exercises was adjusted to remove the buildings that have been destroyed during the disaster of 1998. That is why this map contains less buildings, especially in the flooded area and the area affected by the large landslide that dammed the river.

In this exercise we also have information on the altitude of the buildings, derived from Lidar data. This information (map **Altitude_dif**) will enable us also to estimate the height of each buidling in number of floors. The map was made in exercise 1 by calculating the difference between the Lidar Digitial Surface Model (DSM) and the Digitial Elevation Model obtained by interpolating contour lines from the topographic map (with 2 meter contour interval).

We will use the Cross operation 2 times and will aggregate the building information in the attribute table linked to the map **Mapping_units**. This will be the basis for generating the vulnerability and risk maps in the following exercises.

Generating a database of elements at risk using existing data



In many cases you might have existing information to build your elements at risk database, and the results you will obtain will be much more accurate. In this case we are including several crucial data layers in the analysis:

- Building footprint map (in this database called **Building_map**), which contains the location of all buildings prior to the flooding and landslide disaster. This allows us to better calculate the number of buildings per mapping unit.
- The Lidar Digital Surface Model, and the detailed Digital Elevation Model made from contour interpolation. The difference between these (the map **Altitude_dif**) gives us detailed information on all objects, including buildings. The Lidar data was obtained after the flood and landslide disaster. This data allows us to better quantify the height of the building, and the total floorspace (= area of the building * the number of floors).
- Census data, which is only available per ward. The table Ward contains information on the residential population, the division male/female and some other attributes. These data are still at a too generalized level, as we would like to have the population distribution per mapping unit instead of wards. So we later will later have to subdivide the population amounts per ward based on the land use and floorspace.

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- Display the map **Altitude_dif** and overlay the segment map **Building_map_1998**.
- Check out where differences in terrain are not related to buildings. Find some of these and indicate what might be the reason. These areas should be masked out.
- Also check out some areas where there are buildings in the map but no real altitude difference. What could be the reason?

There are several reasons why the altitude difference map does show differences even though the building map doesn't contain buildings. Also the opposite is true: there are locations where the building map indicates a building but where the difference is almost zero

Answer:

X	Y	How much Difference?	Possible reason

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- Also display the map **Mapping_units** (boundaries only in red lines) and use PixelInformation to consult the maps **Mapping_units**, **Altitude_dif** and **Building_map_1998**. Evaluate the relation between urban land use, building presence and height of buildings.

Calculate the height of buildings

We start by calculating the elevation elevation of the buildings. We can do that using the altitude difference map (**Altitude_dif**) that was calculated earlier on in exercise 1, by simply subtracting the Topo DEM from the Lidar DEM.

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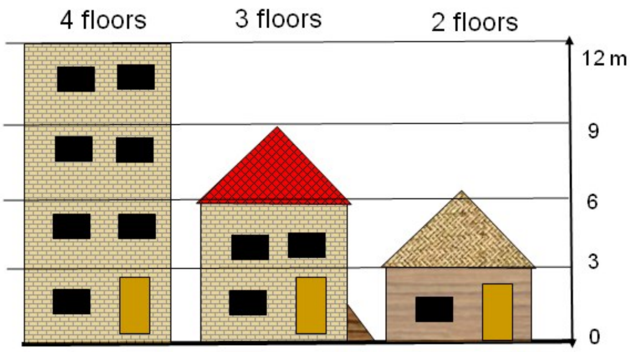
- Open the map **Altitude_dif** and overlay the segments of the buildings (file **Building_map_1998**). Check with Pixel information the altitudes of objects.

Before we work further with this data we would like to simplify the altitude difference map.

We assume that the average height of 1 floor is 3 meters for all building types. This will be different from building to building, but can only be made more precise after detailed fieldwork.



Since we are only interested in areas where there are buildings, we can mask out the differences in all other areas. Also it is better to work with the number of floors instead of the actual altitude of the buildings. This makes other operations more easy.

To calculate the number of floors we divide the object altitude by the average floor height, so that we obtain the number of floors. We assume here that the average floor height is 3 meters.

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- This can be done using the following formula on the command line:

  floor_nr=iff(Altitude_dif <2,0,iff(altitude_dif<3,1, Altitude_dif /3))

- What do we do here ?: if the difference in elevation is less than 2 meters, then we know for sure that it is not a building, so we change the value to 0. If the altitude is between 2 and 3 meters then we assign it as 1 floor, and if the altitude is more than 3 meters, we divide the altitude by 3 to get the number of floors.
- Make sure to select a precision of 1.
- Open the map **floor_nr** and check the result with the high resolution image. What are your conclusions?

We can also mask out all areas that are not buildings, and only have the number of floors for those areas where there is an actual building. This can be done with a simple Map calculation statement

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- This can be done using the following formula on the command line:

  Nr_floors:=iff(isundef(Building_map_1998),0,floor_nr)

- Make sure to select a precision of 1.
- Open the map **Nr_Floors** and check the result with the high resolution image. What are the main differences with the previous map?

- We now can combine the building map with the map **Nr_Floors** and find out for each building the number of floors. We do this in a few steps:
- We cross the maps **Building_map_1998** with the map **Nr_Floors,** which gives us all the combinations of floors per building type.
- Then we calculate per building the maximum/predominant number of floors and evaluate which one would be better to use.

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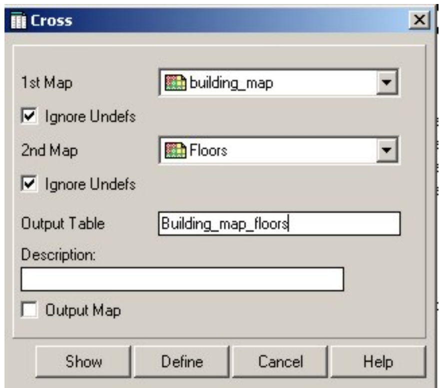
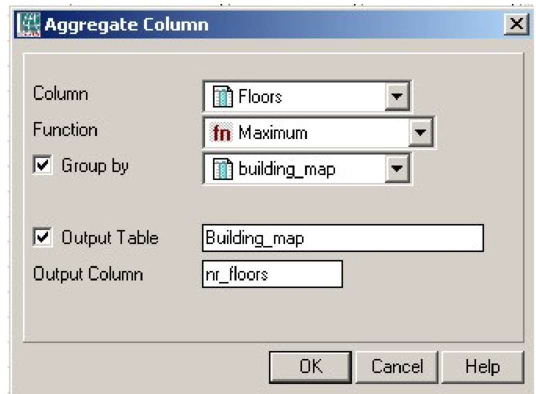
- Use the Cross operation and cross the map **Building_map_1998** with the map **Nr_Floors**. Name the Output Table: **Building_map_1998_floors**. Ignore the Undefs in both maps. Undefs are the <u>undefined values.</u> They are either not in a mapping unit or not in a building.
- See window below left

Undefined pixels or polygons don't have a meaning. They are indicated with a ? when you consult the map. They can be caused by:
- there is no data for the area
- it is outside the study area
- There was an error in the formula
- You specified the wrong data range, and the value is outside of the range.





Histogram: list the frequency information on the values, classes or ID in the map. The results are a table and a graph. You can calculate the Histogram of a rater map, polygon map, segment map and point map. Check the ILWIS guide if you need further explanations.

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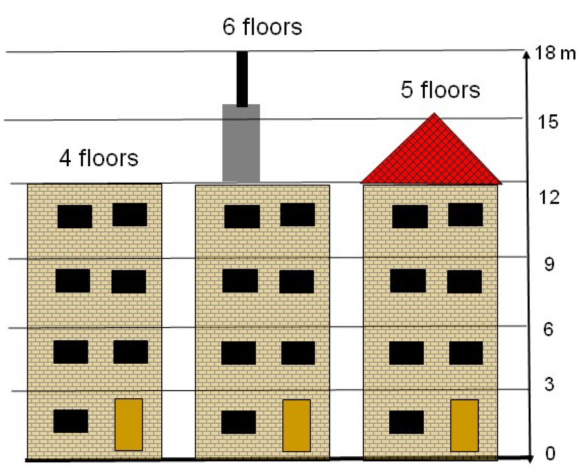
- In the Cross table **Building_map_1998_floors**, make the following calculation:

  Nr_floors_new:=iff(nr_floors=0,?,nr_floors)

  We do this to avoid that there are buildings with the majority of 0 floors.
- Use aggregation: column **Nr_Floors_new,** aggregation function **Maximum**, group by **Building_map_1998**, and store the results in the Table **Building_map_1998**, column **Nr_floors_max**. (See above right)
- Check the results in the table **Building_map_1998.**



One of the problems with taking the maximum number of floors for each building is that some buildings do not have a straight roof, and some buildings might have an irregular height, with smaller section (elevator shaft, chimneys, flagpoles) sticking out of the building. If we take the maximum number of floors (maximum height) of the building this might lead to problems with some of the buildings. For instance check the stadium (ID: B_29210). The altitude difference is quite variable for the stadium. It also has two small towers that reach up to 23 meters high, but the majority of the stadium is around 15-16 meters high. Also if the polygons of the buildings and the Altitude difference map have a small difference in their x,y location, it is possible that one pixel that is much higher and actually of the neighbouring building, makes that the entire building is considered too high (if we use the Maximum height). It could be possible to use the Predominant number of floors instead of the maximum.

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- Now we will calculate the predominant number of floors for each building:
- In the Cross table **Building_map_1998_floors**, use column **Nr_Floors_new**, aggregation function **Predominant**, group by **Building_map_1998**, weighted by: **Area** and store the results in the Table **Building_map_1998**, column **Nr_floors_pred**.

Now which one is better? Maximum or predominant heights per building? Let us check this. First we will count the total number of buildings with 1, 2, 3 , 3 to 10, and more than 10 floors.

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- Make a *class/group* domain **Nr_floors_clas** (if it does not exist already) make the classes indicated in the table below File, Create, Domain, Select Class, Click Group). Use Upper boundaries and class names as indicated in the table below.
- In table Building_map_1998 use the following statements:

  Nr_floors_max_class:=CLFY(Nr_floors_max, nr_floors_clas)
  Nr_floors_pred_class:=CLFY(Nr_floors_pred, nr_floors_clas)
- Now you can use aggregation function Count for these two columns, (group by the same column) and store results in a **table NR_floors_clas**.
- Open this table (**NR_floors_clas**) and you find the data on the number of buildings per class. Fill in the table below.
- Open the map **Building_map_1998** and also open *PixelInformation*, and also add the map **Altitude_dif**. You can now compare the values for the maximum number of floors and the predominant number of floors. Check out a number of buildings.

This method makes the assumption that a building has a fixed number of floors and is not composed of sections with different heights. Think of patios for example.

Upper boundary	Class Building height	Use Maximum		Use Predominant	
		Number	Percentage of total	Number	Percentage of total
1	1 floor				
2	2 floors				
3	3 floors				
10	4-10 floors				
25	>10 floors				
Maximum height …….. floors					

Now let us look at it in the map

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- Open the map **Building_map_1998** and also open *PixelInformation*, and also add the map **Altitude_dif**. You can now compare the values for the maximum number of floors and the predominant number of floors. Check out a number of buildings. Also check the stadium for instance.

Conclusion: is it better to take maximum height or predominant height for each building for estimating the number of floors?

Make a balanced choice to continue with Nr_floors_pred or with **Nr_floors_max**

Calculate the floorspace of buildings

Now that we know the height of each building we can also calculate the floorspace per building.

The floor space for each building is the multiplication of the area of the building and the number of floors.

To calculate the total floorspace for each building we need to multiply the number of floors with the area covered by the building. This information can be obtained from the histogram of the **Building_map_1998**.

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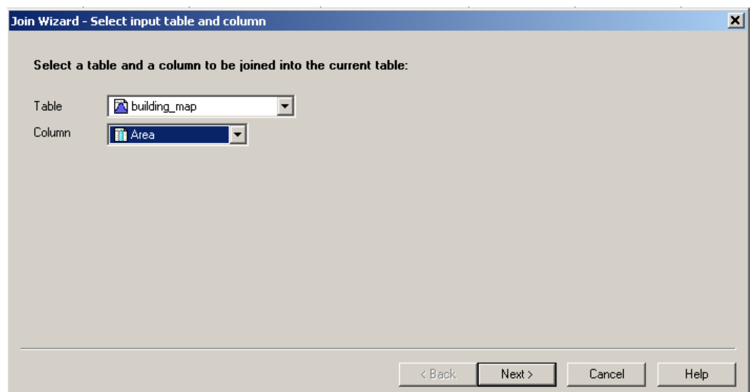
- Calculate the histogram of the **Building_map_1998.**
- In the table **Building_map_1998** join with the histogram and read in the **Area** of each building. Call it: **Area_building**. See below
- The floorspace per building can now be calculated by:

Floorspace:=Nr_floors_pred*Area_building

Or

Floorspace:=Nr_floors_max*Area_building

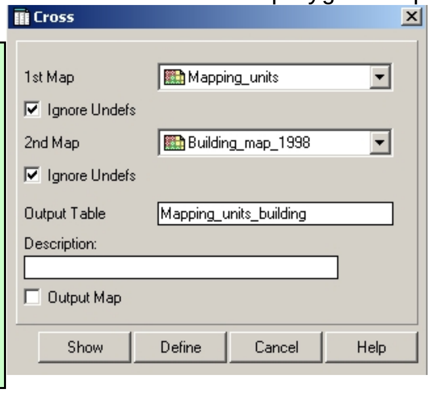
Note that it is possible also join a table with a histogram, because the histogram, as already explained, is composed by a graph part and a table part.



Crossing the Buildings with Mapping units

Now we have the height information and floorspace per building, but we want to aggregate this for the mapping units. We can only do this using a table that contains both domains of the mapping units and that of the buildings.

We can start by making a joint frequency table (Cross table) by combining the **Mapping_unit** and **Building_map_1998** data layers. But first rasterize the polygon map Mapping_units with georeference Somewhere.



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- Select *Operations, Raster Operations, Cross*
- Cross the map **Mapping_unit** with the map **Building_map_1998**. *Ignore Undefs* for both maps
- Name the output table: **mapping_units_building**
- Open the table **mapping_units_building** and check the result.
- Sort the table by the column **Npix**

As you can see there are a number of buildings with a very small size (the smallest is 10 square meters).

☞

- Open the cross table **Mapping_units_building**. And join with the table **Building_map_1998.** Read in the columns: **Nr_floors** , **Area_building** and **Floorspace,** one by one.

Before we can aggregate the results to the mapping_units we will calculate individual columns with the buildings that have 1 floor, 2 floors, 3 floors, 4-10 floors, and > 10 floors.

☞

- Open the cross table **Mapping_units_building**. and calculate:

```
floor1:=iff(nr_floors=1,1,0)
floor2:=iff(nr_floors=2,1,0)
floor3:=iff(nr_floors=3,1,0)
floor4_10:= iff((nr_floors>3)and(nr_floors<11),1,0)
floor_over_10:= iff(nr_floors>10,1,0)
```

Aggregating the information per mapping_unit

Now we know for each combination of **Mapping_units** and **Building_map_1998** how many buildings there are, how many floors and how much the floorspace is. We can then aggregate these values and calculate the predominant building height per mapping unit, and the total floorspace per mapping unit.

How many building per mapping unit

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- Open the cross table **mapping_units_building**.
- Select *Columns, Aggregation*. In the window that appears, select the following options. Column: **Building_map_1998**, Function: **Count**, Group by: **Mapping_units**, Output_table: **Mapping_units**, Output_Column: **Nr_b**
- Open the table **Mapping_units** and check the result. How many buildings are there in RiskCity? Fill in the value in the table.
- We still have to adjust for those mapping units where there are no buildings. These are now undefined. We calculate in table Mapping_units_1998:

  Nr_buildings:=iff(isundef(Nr_b),0,Nr_b)
- Close the table **mapping_units**. If you don't close it you will not see the result of the next aggregation. So close it before doing a next aggregation operation.

Total	
Number of buildings	
Total building area	
Total floor space area	

Total floor space per mapping unit

☞

- Open the cross table **mapping_units_building**.
- Select *Columns, Aggregation*. In the window that appears, select the following options. Column: **Floorspace**, Function: **Sum**, Group by: **Mapping_units**, Output_table: **Mapping_units**, Output_Column: **Floorsp**. (see below)
- Open the table **Mapping_units** and check the result. How much is the total floorspace are there in RiskCity? Fill in the value
- We still have to adjust for those mapping units where there are no buildings. These are now undefined. We calculate in table Mapping_units_1998:

  Floorspace:=iff(isundef(floorsp),0,floorsp)
- Close the table **mapping_units**. If you don't close it you will not see the result of the next aggregation. So close it before doing a next aggregation operation.

Total built-up area per mapping unit

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- Open the cross table **mapping_units_building**.
- Select *Columns, Aggregation*. In the window that appears, select the following options. Column: **Area_building**, Function: **Sum**, Group by: **Mapping_units**, Output_table: **Mapping_units**, Output_Column: **Area_b**. (see below)
- Open the table **Mapping_units** and check the result. How much is the total building area in RiskCity? Fill in the value

- We still have to adjust for those mapping units where there are no buildings. These are now undefined. We calculate in table Mapping_units_1998:

  Area_Building:=iff(isundef(Area_b),0,Area_b)
- In order to know how much percentage of the mapping unit is built-up and how much is still vacant we first need to know the area of each mapping unit. We can calculate that using the histogram.
- Calculate the histogram of the map **Mapping_units.**
- In the table **Mapping_units** join with the histogram and read in the **Area** of each Mapping unit. Call it: **Area_Mapping_unit** (precision 1.0)
- Now you can calculate the area of the mapping unit that is vacant:

  Area_vacant:=Area_mapping_unit - Area_building

  Perc_vacant:=100*(Area_vacant/Area_mapping_unit)
- Close the table **mapping_units**. If you don't close it you will not see the result of the next aggregation. So close it before doing a next aggregation operation.

Note: we will not do the population estimation here. This will come in exercise 4c, dealing with participatory GIS.

For experienced ILWIS users:

Calculate the percentage with buildings of 1,2,3 and more than 3 floors per mapping unit.

Calculate the average building size for each of the land use classes. In exercise 4a we needed to have information on the average building sizes for each land use class. We then based these values on a limited number of samples. Now that we have the information of the building footprint map, we can do this much better. Try to design a method to do this. Hint: use aggregation functions, after bringing in information on the land use in the cross table **mapping_units_building**. You can then calculate the average building size per land use class and store it in the table **Landuse**. Also calculate the standard deviation in building sizes. Compare the results with those of exercise 4a.

Exercise 4c: Participatory GIS for risk assessment.

Expected time:	3 hours
Data:	data from subdirectory:RiskCity_exercises/exercise04c/data
Objectives:	This exercise shows you the possibilitis that are available when you carry out a survey using participatory GIS . You will learn how the collection of local knowledge will help you to better characterize the buildings, describe the population with its vulnerability and capacity, evaluate the problems related to landslides, and reconstruct historic flood scenarios.

The collection of local knowledge is very important in risk assessment. Local communities are the most important stakeholder in risk assessment, and are often the ones that are most at risk. They have local knowledge that is indispensable for hazard assessment, elements at risk characterization, vulnerability & capacity assessment, and development of risk scenarios. Disaster Risk Reduction efforts should be tailored to the local communities and be implemented in consultation with them, and mostly by them.
In a course like this it is not possible to go and collect information using Participatory GIS techniques by yourself. You cannot visit RiskCity. Therefore we will concentrate no such much on how data can be collected locally, but focus more on what you can do with local data.

Name	Type	Meaning
Image data		
High_res_image	Raster	High resolution image of the situation in 2006
Airphoto_1998_ortho	Raster	Orthorectified airphoto taken just after the disaster event in 1998.
Participatory GIS data		
PGIS_Location	Point map	A point map with the locations of the interviews that were carried out for 200 buildings, of which 100 are located in the floodplain and 100 on steep slopes.
PGIS_survey	Table	Table with the main results of the Participatory mapping exercise. This table contains columns related to building attributes, population characteristics, landslide damage , and reconstruction of flood scenarios.
Flood data		
Flood_100y, Flood50y, Flood_10y	Raster map	Flood depth maps resulting from flood modeling study for scenarios with 100, 50 and 10 year return period.
Other data		
Building_map_1998	Raster map	Updated map of buildings for the situation after the disaster of 1998. For all buildings information is available on the urban landuse, number of floors, building area, and total floorspace.
Building_map_1997	Segment map	Boundary lines of the buildings in the area, for the situation before the disaster in 1998.

Participatory GIS approach

The survey was carried out in 2008, 10 years after the major disaster event of 1998, which produced a large number of landslides, and caused widespread flooding in the area. The survey was carried out by interviewing persons in 200 buildings, located either in the flood affected area, or in one of the landslide prone areas. Mapping was carried out together with representatives of the communities (See photo).

The representatives of the community serves as guides and translators and introduced the mapping team to the inhabitants of the buildings where the interviews would take place. These ladies were also an important source of local information, as they were very well aware of the hazards in the area and how these affect the daily life of the inhabitants of the squatter areas in RiskCity.

The interviews were recorded and information was collected using Mobile GIS linked with a GPS. The high-resolution image and the building map were used as backfrop information in the handheld device. The results were stored in a table (**PGIS_survey**) that is linked to a point map (**PGIS_Location**).

Figure: Representatives of the community that were involved in the Participatory mapping in RiskCity.

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- Open the image **Airphoto_1998_ortho**. Display the segments of the buildings made in 1997: **Building_map_1997.** Also display the buildings that are now in the area: use the segment map **Building_map_1998.**
- Compare the building maps, in particular in relation to the flooded areas and landslide areas.

As you can see many of the buildings that were present in 1997 were destroyed in 1998, or have been subsequently demolished. The map **Building_map_1998** contains the building information after the year 1998. Now we will add the point that have been mapped using the Participatory approach.

If you open Pixel Information you can select Options, Always on Top, so that the window is always visible

☞

- Add the point map **PGIS_Location**.
- Open **PixelInformation** and add the map **PGIS_Location.**
- Check a number of the points of the map **PGIS_Location** and their attribute information, stored in table **PGIS_Survey**.
- Display some of the attributes using the Display Option Window.
- Open the table **PGIS_Survey**.

The buildings that were destroyed during the large flood event of 1998 could still be identified, and neighbours could give information on the building type and the waterlevel that was experienced. However, there is no information available for these buildings regarding the population characteristics. These buildings are indicated in the PGIS_Survey with the landuse “Vac_damaged”.

This table **PGIS_Survey** contains the following columns:

Factor	**Meaning**	**Usefulness**
Building data		
Landuse	Urban Land use. Note that there are many buildings coded as "Vac_damaged".	Link to other information for the entire city.
Area_building	Area of the building in m2	Used for calculation floorspace and value of building & contents
Nr_floors	Number of floors	Used for flood and seismic vulnerability assessment
Building_type	Building type	Used for physical vulnerability assessment
Population data		
Nr_adults	Number of people between 18 and 60	Population characterisation and social vulnerability assessment.
Nr_old_people	Number of old people (>60) per building	
Nr_children	Number of children (<18) per building	
Nr_households	Number of households per building	
Nr_people_daytime	Number of people present in the building during the daytime	Population vulnerability assessment for different temporal scenarios
Nr_people_nighttime	Number of people present in the building during the nighttime	
Workers	Number of people per residential building that are working	Economic loss estimation.
Livelihood	Main type of work	
Landslide data		
Landslide_damage	Observed landslide damage in buildings	Landslide mapping
Flood data		
Remember_Flood_1998	Classes of the water height that people can still remember, for the 1998 event with a return period of 100 years.	Flood hazard assessment, validation of flood modeling maps, and flood vulnerability assessment
Remember_Flood_1993	Classes of water height, that people can still remember for the 1993 event with return period of 50 y.	
Remember_Flood_2007	Classes of water height, that people can still remember for the 2007 event with return period of 10 y.	
Flood_damage	Estimated degree of damage to the buildings and contents for the flood event of 1998, estimated by the people that were interviewed.	We will use this information in the exercise 5a dealing with vulnerability functions

The **Landuse** column in the table is very important: this forms the link between these sample points and the rest of the buildings in RiskCity. The information that is derived from the 200 interviews can then be used to characterize the buildings. Calculate how many samples have been made for each landuse class.

☞

- In the table **PGIS_Survey**, select *Column, Aggregate*. Select the column: **Landuse**, Function: **Count**, Group by: **Landuse**, Output Table: **Landuse** , Output Column: **Nr_samples**.
- Open the table **Landuse** and check the number of samples per land use type. Which one has the largest number of samples?

Most of the Interviews for the PGIS survey have been carried out in squatter areas. Also a substantial number of interviews were held to reconstruct information from buildings that have been destroyed during the 1998 event (**vac_damaged**).

	Number
Number of sampled squatter buildings	
Number of sampled buildings that have been destroyed	

Part A: Using PGIS for evaluating the building characteristics.

We will first use the PGIS survey to better characterize the building in RiskCity.
Several building types have been defined in the area. The most important ones are:

- **Wood and other scrap materials**: these buildings are made up of boards, plastic, corrugated iron sheets etc. They normally have only 1 floor.
- **Adobe**: these buildings are made of dried mud.
- **Fieldstone**: made of fieldstones with limited cementation, and wooden ceilings.
- **Brick in mud**: masonry building with homemade bricks not well cemented
- **Brick in cement:** masonry buildings that have been constructed with a bit more care, and often have columns with some reinforcement.
- **Reinforced concrete**: engineered reinforced concrete buildings.

The box shows a typical interview which was held with some of the people

Person: My dream is to built a real house for my family.
Interviewer: I thought your family had already a house, I was there.
Person : Of course not, you cannot call that a 'real house'.
Interviewer Then...What do you mean by a 'real house'?
Person A 'real house' for me is one made of concrete, where I know my family is safe and I would not be worried on what to do or what is going to happen whenever a typhoon is announced.

Person : Do you know the difference between a *house* and *home*?
Interviewer Well... I guess a house is the one made from bricks or wood and a home is formed by the people, the family...
Person : That's ok; so you will see how in this area everyone has a *home* but very few people have a *house*.

Figure Buildings in the confluence of the two rivers in RiskCity

A concatenated key is a key column that is made of two other key columns in a table. In ILWIS we can combine two class columns by first adding the two as strings and then converting to a new domain. We use the CODE term to only use the code and not the full class name

Let's find out the most important building types per landuse class.

☞

- In the table **PGIS_Survey**, select *Column, Sort*. Select the column: **Landuse**.
- Find out the most important building type for each landuse type (you would have to do this manually), and indicate this in the table below
- You can also do this more automated, by making a "concatenated Key". Type the following command:
  Landuse_building_type:= Code(Landuse)+Code(Building_type)
- Select Domain: **String**.
- After calculating double click on the column header **Landuse_building_types**, and click the button: *Create New Domain from Strings in Column*. Create the domain **Landuse_building_type**
- Now you can aggregate the information. Select column **Landuse_building_type** , use *Count* function, Group by **Landuse_building_type** , and output table **Landuse_building_type** with column **Number**.
- Also indicate what the predominant building height is for each type in Number of floors. Fill in the table below.

	Wood	Adobe	Fieldstone	Brick in Mud	Brick in Cement	RCC
Com_shop						
Ins_school						
Res_mod_single						
Res_multi						
Res_small_single						
Res_squatter						
Vac_Damaged						

	Wood	Adobe	Fieldstone	Brick in Mud	Brick in Cement	RCC
1 floor						
2 floors						
3 floors						
4 floors						
5 floors						
> 5 floors						

This information is very important because the vulnerability methods require to know the building type and the height of the buildings in stead of the land use type. Of course in this exercise we still have a limited sample of buildings to characterize the different building types per landuse. In a real application we need to know the building types in more detail.
We can also calculate the average floorspace per land use type.

☞

- In the table **PGIS_Survey**, calculate the floorspace per building using the equation:

Floorspace:=Area_Building*Nr_floors

- Calculate the average floorspace per landuse type (Use Column, Aggregation), and store the result in the table **Landuse**
- What is the most common building type and number of floors of the destroyed buildings?

The floorspace per building is very important because we need to know this for:

- Making a good population estimation. In the population estimation we use the sampled buildings to estimate the average area (in square meters) per person per land use class
- Making an estimation of the cost of buildings and contents.

The box shows examples of interviews in the flood affected areas.

Family Q.
Before November 2004 Family Q. used to get their livelihood from Mr. Q's Job (butcher) and a small shop attended by Ms. Q in a shed annexed to their house. During a cyclone the shop was smashed by an uprooted Mango tree and part of their house's roof and walls were blown away. The flood also ruined some vegetables Ms. Q grew to sell in the shop. Savings and relief from the government were used to rebuild the house; yet their economic reserves were not enough to restore the shop. They could not afford a loan or use their father' income as this was just enough to meet their daily needs. From their point of view their current situation is disastrous as after one year they have not managed to fully recover, they lost capital and a, much needed, second livelihood and now the entire family of five depends on the single income brought in by the father.

Mr M.
Mr M. used to work as an ice cream vendor in the area for which he uses a small wooden trolley. The daily income from this activity (around 200 pesos) was low but he managed to cover the basic needs of his family of three. During 1998 his house was destroyed and the trolley got shattered. To get some income he shifted his work to collect scrap material; from this activity he got half of the money (around 100 pesos/day), but most now he has to travel on foot across several other wards. One year later the family was still living with their in-laws and he had not managed to raise the capital for rebuilding their house and recovering his more convenient previous livelihood.

Part B: Using PGIS for evaluating population characteristics.

PGIS is essential for collection reliable population information. The census data for riskcity is not very reliable, and it is only available for large areas (Wards) which makes it difficult to break it up to the individual mapping units that form the basis of the risk assessment. In the survey we have collected different types of building information. This refers to the following aspects:

- The population distribution in age classes (adults, old people and children). This information is important for the population vulnerability assessment
- The population distribution in time (daytime and nighttime). This is important information for population loss estimations for instantaneous disasters like earthquakes, because they will cause very different losses depending on the time when they occur.
- The economic information of the population (Livelihood, number of workers). This information is needed in order to estimate the indirect economic losses, due to loss of income.

The livelihood information is summarized in the table below:

Group	Description
1: Labourers	People engaged in work that requires bodily strength and manual labour rather than skill or training. This consists of marginal or subordinate activities performed mostly outdoors, sometimes on mobile units (including carts and bicycles) and usually takes places close to the place of residence as transportation is too expensive. These jobs report daily earnings in unstable and irregular amounts and are highly susceptible to weather conditions and flooding. Activities found in the study area and classified in this group correspond to: Baggage and burden carrier, dispatcher; Food (candies) manufacturers and packers
2: informal workers and small business:	Correspond to a group of non- formal workers with special skills or knowledge; they supply day to day services and labour, often as freelancers, without formal contracts and benefits. Services are performed door to door or in the worker's house and usually provide daily, unstable and irregular income. Activities performed by this group of workers are highly susceptible to weather conditions and flooding (see Figure). However it was found that some of them render higher profits after typhoons and floods during the rehabilitation processes.
3: Formal workers	Includes educated/skilled workers usually working under formal conditions for medium and big scale business, shops and industries. Permanent or temporarily contracts provide stable income, even during flood or typhoon episodes; though not always high wages.
4: Highly skilled and independent workers	comprises University and highly skilled and specialized workers who most of the times run their own businesses or are absorbed by the governmental institutions and industry. Their income is stable, regular and not affected by weather conditions, flooding or typhoons.
5: Transferred income	This group is characterized by family units receiving their economic support from external sources or pensions. Relatives working abroad or in bigger cities (usually provide support by monthly sending money enough to sustain their families in Tegucigalpa). Remittances from external workers tend to be regular and are usually increased in order to assist their families during flooding or typhoon episodes

Figure : Examples of workers from groups 1 and 2. Left: a laundress, Right: a street vendor, both deal with rains and flooding characteristic of the wet season.

In this exercise we will only concentrate on the estimation of the average area per person per landuse type. This is very important information for the vulnerability and risk assessment procedures that we will do later. We will start by calculating from the table the floorspace per person per building. We have to use the daytime and nighttime scenarios as buildings have different number of people present in these periods. Some buildings, like school, even don't have any persons present during the nighttime but many during the daytime.

☞

- In the table **PGIS_Survey**, check the total number of people present in the daytime and compare it to those in the nighttime. What causes the difference?

	Total number of persons	Total floorspace in m2	Average floorspace per person
Daytime			
Nighttime			

Now we will calculate the floorspace per person per building during daytime and nighttime

☞

- In the table **PGIS_Survey**, calculate the floorspace per person during the daytime using the equation:

  Floorspace_person_day:=Floorspace / persons_day

  (Make sure to have a precision of 0.1, and)

  Floorspace_person_night:=Floorspace / persons_night

- Check your results. Which landuse types have the lowest floorspace per person? Note down the five smallest ones.

Land use		Average Floor space per person	
Daytime Land use	Nighttime Land use	Daytime	Nighttime
1.	1N.	1.	1N.
2	2N.	2.	2N.
3.	3N.	3.	3N.
4.	4N.	4.	4N.
5.	5N.	5.	5N.

The information on the floorspace per person for the daytime and nighttime scenarios are now average per landuse type. The results are stored in the table Landuse. Later on we can then extend this information over the rest of area, for buildings with the same landuse.

☞

- In the table **PGIS_Survey**, use the aggregation function to calculate the average floorspace per person in a daytime period. Group the information by **Landuse** , and store the results as **Avg_Floorspace_person_day**.
- Do the same for the floorspace per person during the night. Store the result in the table **Landuse** with column name **Avg_Floorspace_person_night**.
- Open the **Landuse** table and check your results. Which landuse types have the lowest floorspace per person? Which landuse type do not have any information obtained from the sample?

In order to be able to link this to the building map of the entire city we would need to fill in this table also for the other missing land use types

☞

- In the table below try to make an estimation of the floorspace per person per land use type for the missing classes*. Some of them you can directly fill in as 0, because they don't have any people. For other it will be more difficult. The larger the PGIS survey the better these values would have been.

  * Note: **Break the Dependency Link** of the column to fill in the values. Double click on the column heading and break the dependency link.

Landuse	Description	Average floorspace per person in M^2	
		Daytime	Nighttime
Com_business	Business offices		
Com_hotel	Hotels		
Com_market	Commercial area: market area		
Com_shop	Commercial: shops and shopping malls		
Ind_hazardous	Hazadous material storage or manufacture		
Ind_industries	Industries		
Ind_warehouse	Warehouses and workshops		
Ins_fire	Fire brigade		
Ins_hospital	Hospitals		
Ins_office	Office buildings		
Ins_police	Police station		
Ins_school	Institutional : schools		
Pub_cemetery	Cemetery		
Pub_cultural	Institutional: cultural buildings such as musea, theaters		
Pub_electricity	Electricity installations		
Pub_religious	Religious buildings such as churches, mosques or temples		
Rec_flat_area	Recreational: flat area or foorball field		
Rec_park	Recreational: park area		
Rec_stadium	Recreational : stadium		
Res_large	Residential: large free stading houses		
Res_mod_single	Residential, moderately sized single family houses		
Res_multi	Residential: multi storey buildings		
Res_small_single	Residential, small single family houses, mostly in rows		
Res_squatter	Residencial, low class houses: squatter areas		
River		0	0
Vac_car	Vacant : car parking and busstation		
Vac_construction	Area recently damaged by hazard events		
Vac_damaged	Vacant area which is prepared for building construction	0	0
Vac_shrubs	Vacant land with shrubs, trees and grass	0	0

Once you have filled these in the table, you can transfer them to the ILWIS table **Landuse**, in the column **AVG_Floorspace_person_day** and **AVG_floorspace_person_night (break dependency link)**

☞

- Open the table **Building_map_1998** and join with the table **Landuse**. Read in the two columns.
- Calculate the number of people:

  persons_day_new = floorspace / avg_floorspace_person_day

  persons_night_new = floorspace / avg_floospace_person_night

- Compare the two column persons_day and persons day also for the night.
- Now you can make an attribute map of the daytime and nighttime population for the entire city.
- How many persons are in RiskCity during the day and during the night? (2 answers)

Part C: Using PGIS for evaluating landslide problems

The area also has a number of neighborhoods with severe landslide problems. Within the city many steep slopes are occupied by residential areas. Most of these are squatter areas, with illegally constructed buildings, that have been slowly upgraded over the years. The municipality of RiskCity has provided electricity and water supply to most of these squatter areas. The squatter areas in these very steep slopes suffer frequently from landslides during the rainy period. Since the slopes are so steep, buildings are often constructed with a excavation in the mountain slope, and the buildings are constructed in steps, one almost on top of another. Landslides therefore often initiate in one part, but as they move down slope will affect many buildings. This is illustrated in the figure below.

Figure: Typical examples of landslides that affect squatter areas constructed on steep slopes.

Find out the number of buildings in squatter areas that are located on steep slopes (over 30 degrees).

☞

- Find out the number of buildings in squatter areas that are located on steep slopes (>30 degrees).
- You need the following maps to find this out: **Building_map_1998** (they have the landuse as attribute. Make sure to rasterize this map first) and **Slope_cl** (Slope class).
- Find out a method to do this yourself.
- Fill in the table below.

	Number of buildings
Squatter areas	
Squatter areas on steep slopes	

Although landslides are a real problem to many inhabitants in the area, the municipality has not put a major effort in evaluating the landslide problems or work on risk reduction measures. The municipal authorities mainly react in response to landslide disasters once they happen, but are not active in disaster preparedness and prevention. There have been a number of Non Governmental Organizations that have been working with the local communities in assessing the risk due to landslides.

In several neighborhoods they have carried out community mapping projects, resulting in maps as shown below.

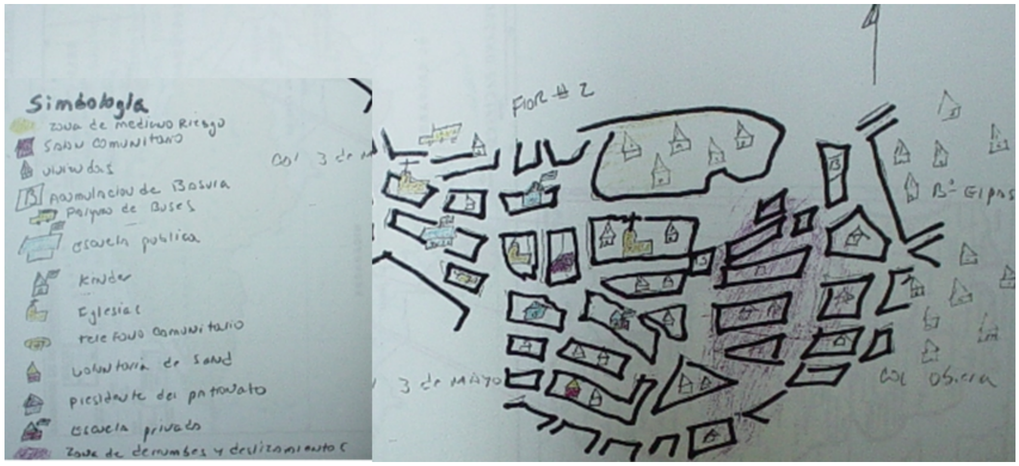


Figure: Typical example of a community map drawn during a workshop that shows the landslide problems in one of the neighborhoods.

Unfortunately such maps cannot be stored in GIS, and need to be translated first to a base map that has a proper georeference. In the framework of our project we have carried out a community mapping exercise in one of the neighborhoods of RiskCity with the most severe landslide problems.

☞

- Find out the names of the neighborhoods where the mapping was done.
- The neighborhoods are in the map **Wards**, and the location of the interviews are in the map **PGIS_Locations**.

In the Participatory GIS mapping, apart from the general aspects that have been mentioned before, we also have asked in the interviews to the inhabitants whether they have experienced problems with landslides in their buildings. The answers were interpreted into the following classes:

Class	**Meaning**
None	No cracks in the building and no cracks in the soil have been observed. Occupants are not worried about the landslide problem
Slight	The building shows some cracks, and is also located in a position where landslide might be a problem.
Moderate	The building has cracks and part of the soil as well. It is shows clear sign that the soil is moving. Urgent measures to stabilize the slope are needed.
Severe	The building has severe structural damage due to soil movements. It has many cracks, and also the soil has cracks. In future the building could collapse, and the building should be abandoned.
Collapse	The building has collapse due to landslide movements. The occupants have not reconstructed the building.

From the answers given by the inhabitants it might be possible to see a certain pattern that might help in identifying the main landslide problems in the area.

☞

- Find out the pattern of landslide damage in the neighborhoods that have been interviewed.

- Display the point map **PGIS_Locations** as attribute and show the attribute **Landslide_damage** on top of the high resolution image. (Use: representation: landslide_damage).
- What can you conclude regarding the location of possible landslide zones, and how do these related to the neighboring areas?
- Can you differentiate landslide areas based on the participatory GIS mapping?

One of the NGO's has been very active in this neighborhood together with the local population to help them to control the landslide problem. They did this using the following approaches:

- Several workshops were organized with the community to understand and discuss the landslide problems and how these affect their daily life.
- An emergency committee was organized with the most active members of the community. Over 70% of these were women. They have a very good local knowledge of the people living in the area, and the problems occurring. They have been trained to provide basic assistance to local people, for instance in the case of medical problems and with childbirth. Since the area is so steep, during the rainy period it is not possible to walk up the very steep paths. People living in the lower parts of the slopes therefore cannot leave their buildings in case of emergency, and they certainly cannot be transported on stretchers during en emergency to the medical centrer which is on the top of the slope. Therefore the assistance of local people is essential.
- The NGO has provided basic building materials to the neighborhood and training on the construction of simple retaining walls that are constructed between the buildings. The figure below illustrates this.

Figure: Support for community-based landslide risk reduction in RiskCity. Left: simple retaining walls are constructed by the local inhabitants with building materials supplied by the NGO. Righ: equipment donated by the NGO for local landslide risk management: raingauges, communication equipment etc.

- The emergency committee is also in charge of making a landslide warning to the people in the neighborhood. They have been given simple rainfall gauges, and are trained to record the daily rainfall and the accumulated rainfall over the past 3 days. When the rain surpasses a predefined threshold value of 60 mm in 3 days, then the system moves into "Yellow alert", which is moved to the stage of "Red alert" when small landslides are occurring. At this stage the local community starts with evacuation procedures. The evacuation is continued until the accumulated rainfall becomes less than 60 mm over three days. The figure below provides a simple flowchart of the evacuation procedures (adopted from Oxfam, ESFRA, ISMUGUA, Guatemala).

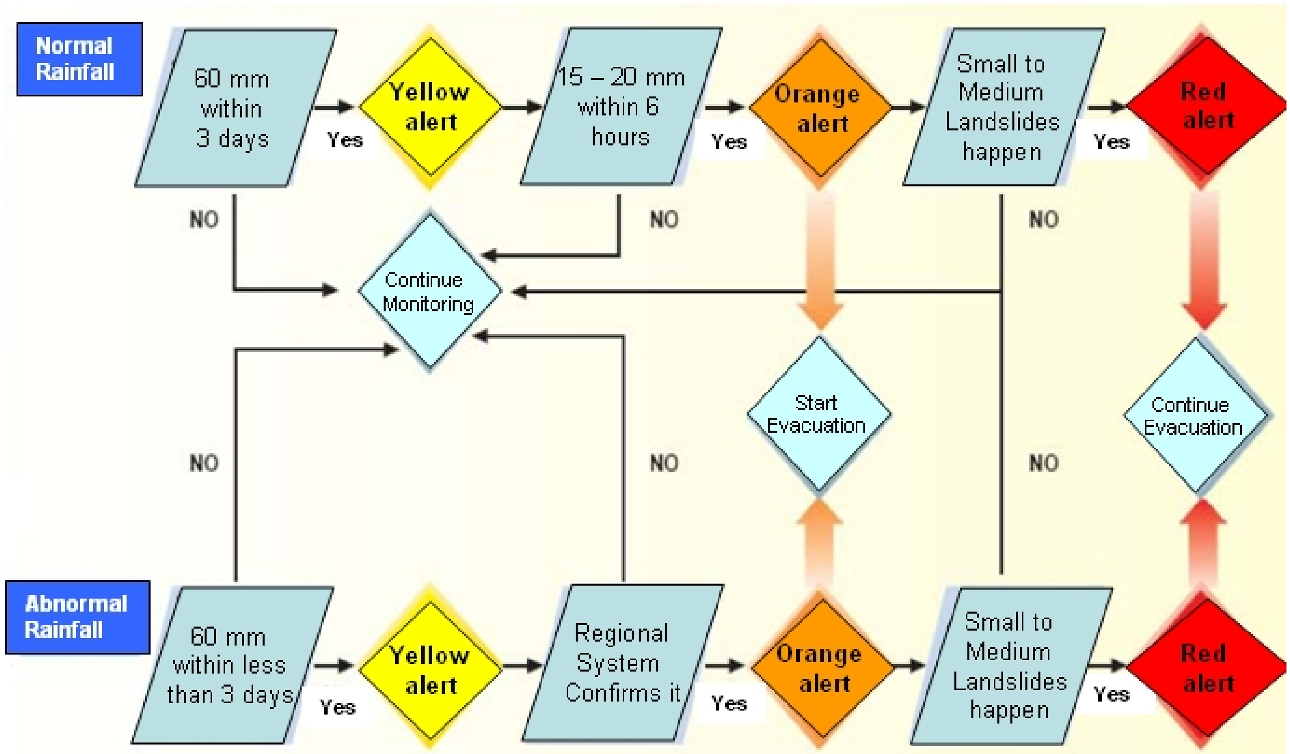


Figure: Simple alert system for landslide risk preparedness adopted by the local community with the help of an NGO (Source: Oxfam, ESFRA, ISMUGUA project in Guatemala).

We have information from the local rainfall station, called **Rainfall_station**, in the middle of the landslide prone area. We will use this information to decide the alert levels as indicated in the figure above.

If you use the notation [%R] it will give the record number in the table. Therefore %R-1 is the previous record and %R-2 two records before. This allows you to make a calculation of the cumulative rainfall over the last 3 days.

- Display the **Rainfall_station** on the map **Building_map_1998** and add the point map **PGIS_Locations** to it, which you display with the attribute **Landslide_damage**.
- Open the table **Rainfall_record**, and use the flowchart indicated above to calculate the alert levels for the days in the rainfall record.
- Create a new domain (class) , called alert_level . Add: no_alert, yellow_alert, orange_alert and red_alert.
- Calculate the cumulative rainfall over the last three days using the equation:

Rain2=Rain+Rain[%R-1]
Rain3=Rain+Rain[%R-1]+Rain[%R-2]
Yellow_Alert:=
iff((Rain>60)or(rain2>60)or(Rain3>60),"Yellow_alert","No_alert").
(use the domain: Alert_level for the output column)

- To calculate the "**Orange alert**":

Orange_Alert:=iff((yellow_alert="yellow_alert") and (six_hour_rainfall>14), "orange_alert", yellow_alert)

(use the domain: Alert_level for the output column)

☞ How many days have a "**Red alert**"? Define your own formula.

Write the results in the table below.

Alert level	Nr days	How many days without work?
Yellow Alert		
Orange Alert		
Red Alert		

Part D: Using PGIS for evaluating flood problems

During the PGIS Survey the flood height of historical events was not recorded in centimeters, but in the way the local people indicate it. The table below shows the 'reference' levels found during several fieldwork activities as used by the people to indicate and refer to floodwater depths.

Table. Community-based reference system for flood depths and their approximate equivalence centimeters

Community-based flood depth reference level in correlation to a person's body parts	Equivalence water height in centimeters
Ankle depth	0- 20 cm
Knee depth	20 – 50 cm
Hip depth	50 – 100 cm
Breast depth	100 – 150 cm
Head depth	150-250 cm
First floor flooded	250 - 350 cm
Second floor flooded	> 350 cm

As discussed during the workshops the average of 10 cm difference in height between men and women may determine differences in the perception of hazard. In order to minimize the inconvenience this could cause the participants agreed and expressed the water depths in ranges, rather than in absolute or sharp values.

Figure : Measurement of Community-based reference levels for flood depth in centimeters during workshops

We are going to evaluate the local knowledge on floods for three events that the local population was able to remember best:

- The main event from 1998, which was the most disastrous flood event in the area, and which destroyed also a number of buildings. The buildings destroyed during that event are indicated in the table with the landuse :

"**Vac_damaged**". For these buildings it was still possible to obtain the waterheight during the event from the people living in the neighbourhood, and also the type of building could be reconstructed. However, the population information could not be retrieved.

- Another major, but smaller event, that happened in 1993. Many people couldn't remember this flood event as well as the one from 1998, also because quite some people didn't live in the area by that time.
- A recent and small event that happened in 2007. Since this was the last event, the local people can remember the flood height of this event still rather well.

☞

- Open table **PGIS_Survey** and analyze the number of times each of the classes is mentioned.
- Use *Column, Aggregate* and select the column **Remember_flood_1993**. Use the function: *Count*, Group by: **Remember_flood_1993**. Store the results in Table **Water_heights**, as column: **Number_1993**. Do the same for the floods in 1998 and 2007.
- Open the table **Water_heights** and compare the results. Write down the numbers in the table below.
- What can you conclude from this?

Water height	**Number of times mentioned in 1993 event**	**Number of times mentioned in 1998 event**	**Number of times mentioned in 2007 event**
No_flood			
Ankle			
Knee			
Hip			
Breast			
Head			
First floor flooded			
Second floor flooded			
Total			

The three flood events cannot be remembered equally well. What would be the reason for that?

For the three events also a flood modeling study was carried out, and three flood height maps were produced: **Flood_100y** corresponding to the 1998 event, **Flood_50y** corresponding to the 1993 event and **Flood_10y** related to the 2007 event.

☞

- Display the map **Flood_100y**, and overlay the segment map with the buildings from 1997 (**Building_map_1997**). Also display the point map **PGIS_Location**, and select the attribute **Remember_flood_1998**.
- Open *PixelInformation* and add the maps **Flood_100y**, **Flood_50y**, **Flood_10y**, and the point map **PGIS_Location**. Compare the local information with the modeled results.
- What can you conclude?

The manual comparison of the local information on the three floods events with the three modeled maps (**Flood_100y**, **Flood_50y** and **Flood_10y**) is not always easy, as they have two different measurement systems (water height in meters and water height in "human terms"). To compare them it is better to convert the community information into meters as well.

☞

- Open the table **Water_heights** and add a column **Height_in_m** (Value, min: 0, max 15, precision 0.01).
- Fill in the values of the middle water height for each of the classes. E.g. Ankle: 0.1, Knee: 0.35 etc.
- Close the table **Water_heights** and open the table **PGIS_Survey.** Now Join with the Table **Water_height** and column **Height_in_m** and select key_1: **Remember_flood_1993**. Call the output column: **Water_height_1993.**
- Do the same for 1998 and 2007.
- Open PixelInformation again and check data against the three flood maps.

Finally we can also calculate the agreement between the modeled results and the PGIS results. We can do that for instance by crossing the point map with the flood maps, but in ILWIS we can also do that by reading the information from the flood maps for all the points, using the point map **PGIS_Location**. We have then to use the Option: *Open as Table*.

☞

- Right click on the point map **PGIS_Location** and select the option: *Open As Table*. Now the point map opens as a table, and you can see the coordinates of each point.
- You can read in the values of maps for the specific coordinates using the following equation (to view the command line, go to *view* and choose *Command Line*)::

  Water_Height_50y:=Mapvalue(Flood_50y, Coordinate)
- Do the same for the 100 year and 10 year flood.
- Close the point map **PGIS_Location** and open the table **PGIS_Survey**. Join with the point map **PGIS_Location** and read in the three columns you have just created.
- Now that you have the two types of information in the same table you can calculate the difference:

  Difference_50y:=Water_height_1993 – Water_height_50y
  Difference_100y:=Water_height_1998 – Water_height_100y
  Difference_10y:=Water_height_2007 – Water_height_10y

- Write the difference in the table below. What can you conclude?

Difference in water height between PGIS and model for	Minimum	Maximum	Average	Standard deviation
1993 (50 year flood)				
1998 (100 year flood)				
2007 (10 year flood)				

Exercise 5a. Generating vulnerability curves

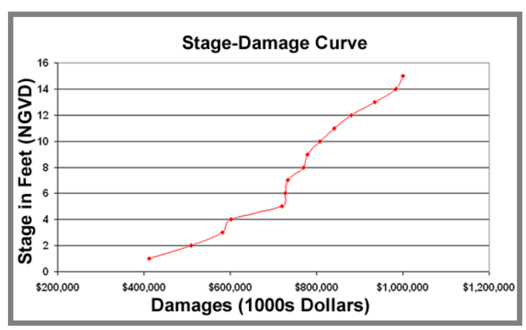
Expected time:	3 hours
Data:	data from subdirectory: Riskcity_exercises/exercise05a/data
Objectives:	In this exercise we will learn how to perform flood damage assessment using depth-damage functions. We will extract from PGIS data the parameters to calculate the depth-damage functions.

Input data

The data for this exercise consist of maps and tables related to: 1) Building types, 2) Flood depth, 3) Information related to the impact of flood on buildings from the PGIS survey.

Table / Maps	Column	Meaning
Building_map_1998	Landuse	Description of the building class
	Area	Area of the building footprint in m2
	Nr_floors	Numbers of floors
	Floorspace	Total area of the building (floorspace*number of storeys)
Building_map_1997		Building map showing the situation before the disaster in 1998.
Flood_100y map	Waterdepth (0.00 m)	Flood depth map calculated using outputs of HEC-RAS flood simulation model
PGIS_Survey table	Building type	Building types in the area
	Remember_flood_1998	Answers of interviews on flood height people remembered for the flood of 1998
	Nr_floors	Number of floors
	Flood_damage	Answers of interviews on flood damage to buildings that people remembered **for the flood of 1998(100 year flood)**
PGIS_Location map		Point map showing the location of the surveys during the PGIS activities.

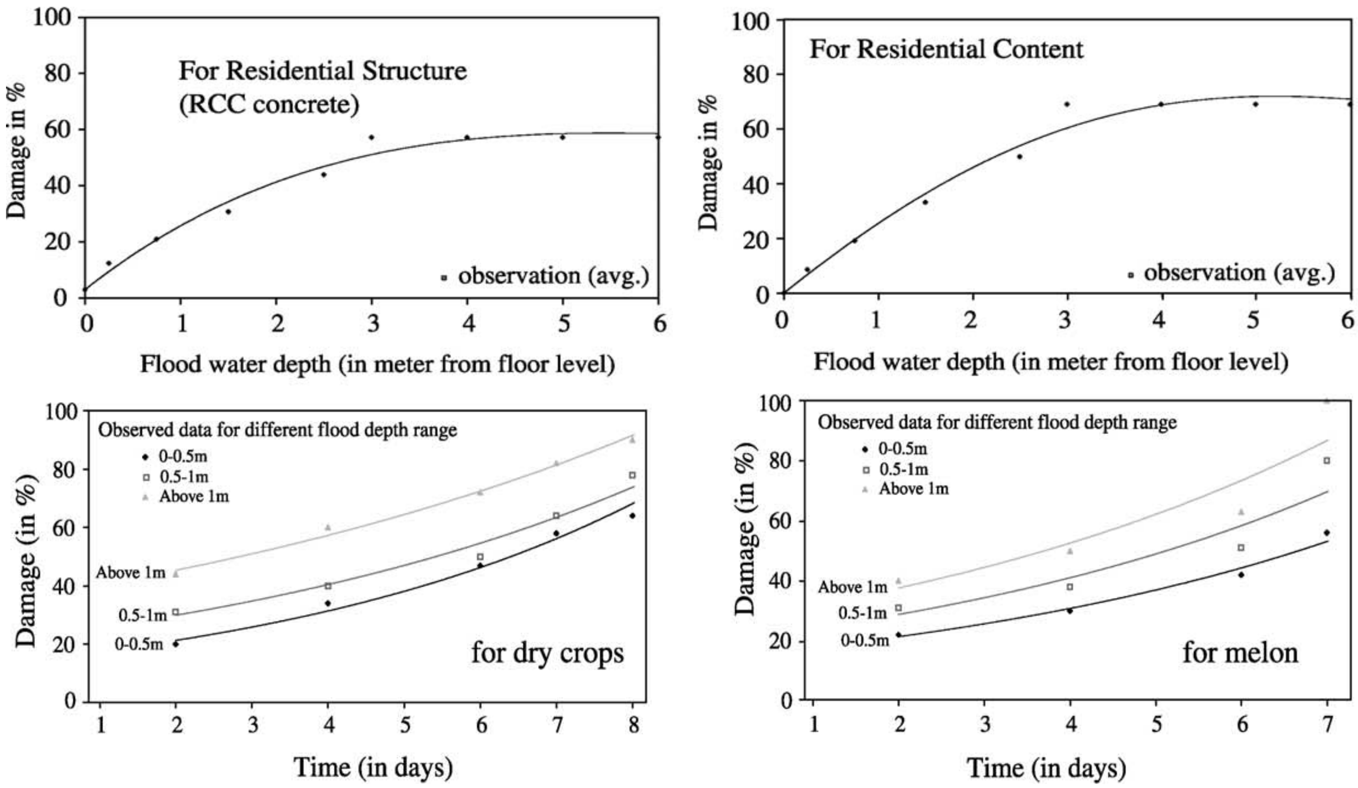
Flood damage assessment can be performed in a semi-quantitative way. It means that the damages have to be quantified per each category of asset according to the aggregation level chosen for the assessment. Stage-damage functions represent the most effective solution in relating flood parameters to damage in flood damage assessment models (Krzysztofowicz and Davis, 1983a; Krzysztofowicz and Davis, 1983b).



Step A: Extract vulnerability parameters from PGIS survey.

> Stage-damage functions are mathematical functions that express the relation between the degree of the damage and flood parameters: figure below shows two types of stage-damage functions.

In the following steps we will learn how to build depth-damage functions for different building types. Depth-damage functions are a particular type of stage-damage functions that relate the loss/damage to flood water depth. Stage-damage functions quantify, through mathematical equations, how the damage rate varies with the variation of flood parameter; therefore they are applied in semi-quantitative flood damage assessment. They express the vulnerability of each element at risk to a certain parameter when affected by a flood event. The elements at risk are grouped in classes according to the degree of aggregation at which we want to perform the risk assessment. Elements at risk can refer to building types (one storey wood buildings, single houses from bricks in mud, multiple storey reinforced concrete buildings, etc.) or they can be aggregated into residential, commercial, industrial and agricultural units. In figure X.X, two types of stage-damage functions are shown: the two graphs on top relate the damage expressed in percentage for residential concrete houses to water depth; the other two graphs represent the relation between the damage and the duration of flood for different types of crops (Dutta et al., 2003).



Stage-damage functions can be extracted following two strategies: the first consist of calculating the functions on the basis of historical flood damages data; the second is the calculation of functions from analysis based on: expert knowledge based estimations on assets classes, questionnaire surveys, and the aggregation of that information to assets units or landcover classes. In this case they are called synthetic stage damage functions.

We will gather the information needed to build the functions from the surveys realized during PGIS activities. The data collected are stored in a table called **PGIS Survey**; the data are related to landslides and flood hazards, but we will use only the data related to the three historic floods occurred in 1993, 1998, 2008. The table shows 200 locations of interviews; each one related to one building; the IDs F001 to F100 regard the flood events; every record is an average of the answers and estimations of all the single families that live or were living during the disasters in that particular building. The questions regarded flood depth, caused damage, behavior of people, cars, and buildings in relation to the strength of the flood. The answers are expressed by "codes" easily comprehensible for the population and meaningful for the further calculations.

☞ Open the table: **PGIS_Survey** and check the columns content. Write below for each relevant column the type of domain (Class, Identifier, Boolean, Value):

1) Landuse: _____________
2) Building_type: __________
3) Nr_floors __________
4) Remember_flood_1998: __________
5) Flood_damage __________

☞ **Water_heights**: the domain is related to flood depth, How can you identify intervals corresponding to the different levels? Write them below.

1) Ankle: from _____ to _____ meters.
2) Knee: from _____ to _____ meters.
3) Hip: from _____ to _____ meters.
4) Breast: from _____ to _____ meters.
5) Head: from _____ to _____ meters.
6) First floor flooded: from _____ to _____ meters.
7) Second floor flooded: from _____ to _____ meters.

The table is linked to the point map **PGIS_Location** that represents the position of each interview in RiskCity. We first have to check the position of the interviews in relation to the flood extent; show the survey location together with the 100 years return period flood map.

☞ Open the following maps in this order:

1) **PGIS_Location**: Check in the properties that the map is linked to the table **PGIS_Survey**.
2) In the same viewer add the map **Flood_100y** (assign transparency=50)
   Layers > Add Layers select raster map **Flood_100y** (assign transparency=50)

3) Add the segment map **Building_map_1997 in red color**
4) Add the segment map **Building_map_1998 in green color**

A part of the buildings shown in the 1997 map are no longer present in 1998, they have been totally destroyed or irreparably damaged hence abandoned.

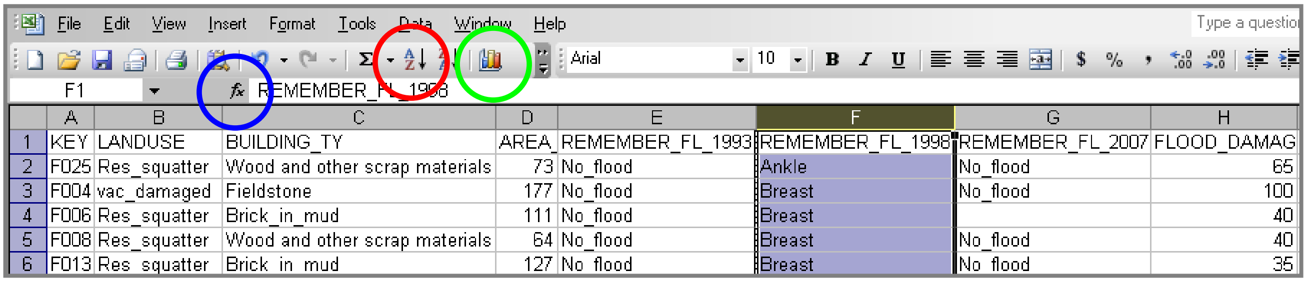
Define your self a method to calculate the number of buildings destroyed in the 1998 flood disaster?

We can now start to work at the extraction of the depth-damage functions. The damage data stored in the table are related to the major flood occurred in 1998, the depth-damage curves will be calculated on the basis of those data. First of all you need to vopy the **PGIS_Survey** table in Excel. Only the record related to floods are requested.

☞ You can do it in two ways:

- The best is to open the PGIS table in ILWIS, select and copy the information of the columns from records F001 to F100 and then paste them into an Excel sheet;
- or you can export the entire table by right-clicking on the table itself in the main window and by choosing *Export*; in this case you have to remember to choose the output format Delimited Text .TXT. Then in Excel you have to open it, and go through a number of steps.
- Once you have the table in Excel you need to delete the records and the columns that are not needed for this part of the exercise. Only keep the columns: **Building_type, Nr_floors, Remember_flood_1998** and

The table should appear like the example in the following figure (before to delete the columns not needed).



	A	B	C	D	E	F	G	H
1	KEY	LANDUSE	BUILDING_TY	AREA_	REMEMBER_FL_1993	REMEMBER_FL_1998	REMEMBER_FL_2007	FLOOD_DAMAG
2	F025	Res_squatter	Wood and other scrap materials	73	No_flood	Ankle	No_flood	65
3	F004	vac_damaged	Fieldstone	177	No_flood	Breast	No_flood	100
4	F006	Res_squatter	Brick_in_mud	111	No_flood	Breast		40
5	F008	Res_squatter	Wood and other scrap materials	64	No_flood	Breast	No_flood	40
6	F013	Res_squatter	Brick_in_mud	127	No_flood	Breast	No_flood	35

Table PGIS_Survey exported in Excel.

Step B: Calculate the stage damage function for all the buildings.

To calculate the depth-damage curves we use the records of the damages caused to the affected buildings; the data are stored in the table you just extracted in the column "Flood_damage". This column shows the damage of the flood in 1998. We need to calculate the average of damage for each water-height interval.

☞

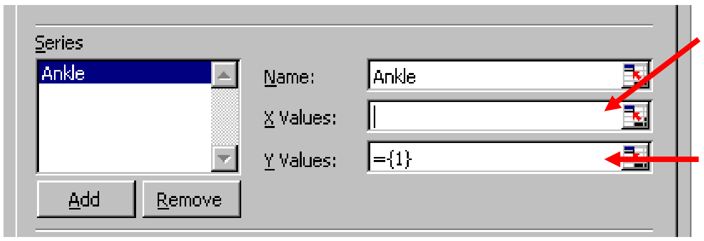
- Sort the records by water height related to the 1998 flood event in Excel: select the right column and click the button with the red circle in the upper figure
- Calculate the average of damage for each water height interval. Click the "Function" (blue circle) and chose "average".

Interval	Water height (m)	Centriod of the interval	Average Damage
Ankle	0 – 0.2	0.1	
Knee	0.2 – 0.5	0.35	
Hip	0.5 – 1.0	0.75	
Breast	1.0 – 1.5	1.25	
Head	1.5 – 2.5	2.0	
First floor fl	2.5 – 3.5	3.0	
Second floor fl	> 3.5	5	

Build in Excel a table with at least the last two columns; it will be used to show the results in an X/Y graphic. Add a row on top and a row at the bottom as shown here below. The first line represents the situation in which the buildings are not flooded; the last line represents the extreme situation with more than 7 meters of flood depth; we can assume that, when the flood depth is 7 meters or more, the average damage for all the building types is 90% (it has been previously calculated through other methods).

Interval	Centroid	Av_damage
No Flood	**0**	**0%**
Anke	0.1	__
Knee	0.35	__
Hip	0.75	
Breast	1.25	__
Head	2	__
First floor flooded	3	__
Second floor floded (>3.5m)	5	__
7 or more meters	7	90

Now we have to build a graph in Excel using the values of the centroid of each interval as X value and the average of the damage as Y value. Open the "Chart Wizard " in Excel by clicking the icon (see the green circle in figure x.x.) Chose "XY Scatter" and click next; then go to "series" tab; add a new series and fill the right side of the window as follows



1. Select the X Values and chose the cell where you stored the centroid of the interval "Ankle" **and the cell above (blue cells in the table).**

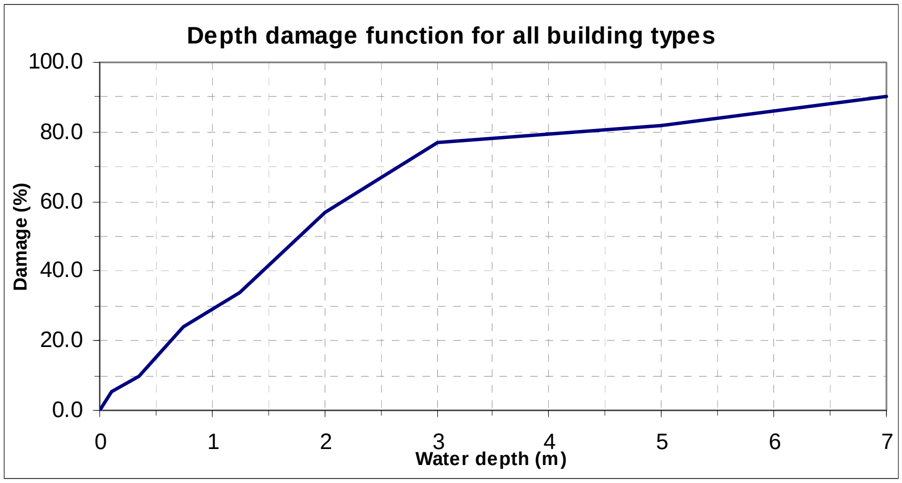
2. Select the Y Values and chose the cell where you stored the average of damages for that **interval and the cell above (green cells in the table).**

Follow the same procedure for all the intervals (from "Ankle" to "7m or more"). (For Knee deep: the values in the "red_boxes " etc.) Afterwards, display the graph.
If you don't see the line, right-click on each pair of points, chose "format data series", and, in "patterns" add the line. It should be similar to this figure.

In Excel 2010: Tab Insert > Scatter with only Markers > result is an empty graph > Right Click in this graph > Select Data > Add:
Series Name: Ankle
Select range X Values: Select cells 0 and 0.1 (Blue cells in the above table)
Select range Y Values: Select cells 0 and 5.5 (Green cells in the above table)

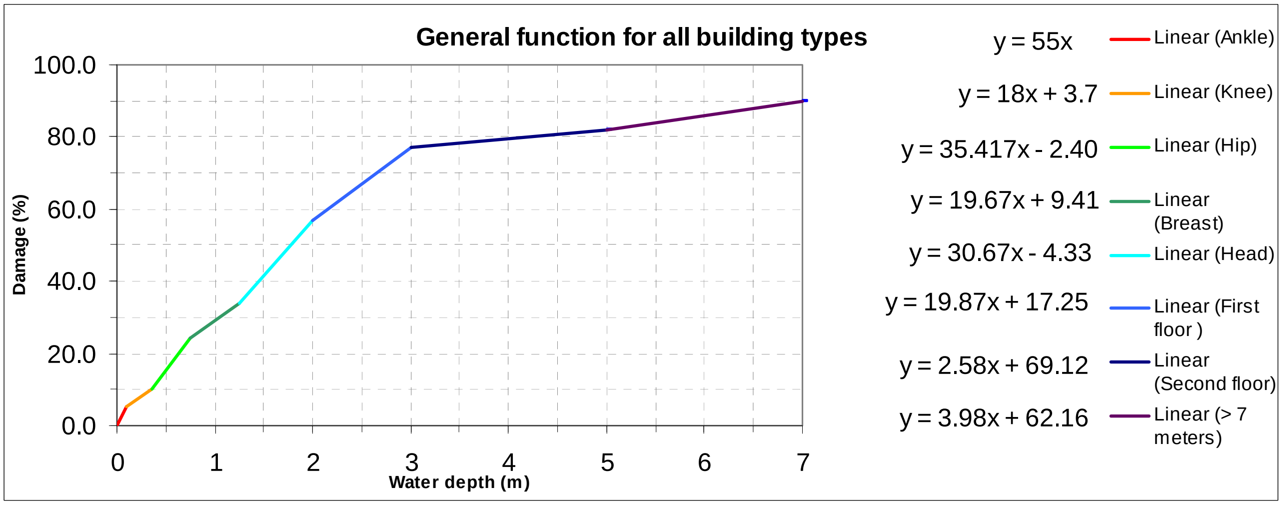
Press Ok
Rightclick on data to select Add Trend line and select Equation on chart.

Add the Knee / Hip etc in the same graph (rightclick again in the graph) continue to add series'



Damage function for all the buildings.

The next step consists of fitting the trend line for each series**. Right-click** on each pair of points, and chose **"add trend line".** In the "Type menu" chose "linear function" and in the "Option menu" select "display equation on chart" (for the "Ankle" series select also "Set intercept = 0".
When you right click on the line again you can Format the trend line and uder Patterns : format the trend line Custom: Select color.
Follow the procedure for all the series and at the end you should have the trend lines for all the points and their equations like in the following figure



Depth – Damage function for all the buildings: equations of the trend lines.

This multiple functions model represents the variation of the damage rate for all the buildings (expressed in percentage) in relation to the flood depth. With the equations displayed in the graphic we can now write a command in ILWIS to calculate the damage for all the buildings affected by any flood.

☞ ***Advanced task: application of the depth-damage function in ILWIS***

- Build a cross table between the **Building_map_1998** map and the **Flood_100y** map, and call it **Building_1998_100y_flood**.
- Open the new table, go to Columns / Aggregation, chose the column: Flood_100y, function: Average, group by: Building_map_1998, weight by: Area. Output table: Building_map_1998. Call the new column **Water_Height**. What does it represent?
- Open the **Building_map_1998** table. Now we have for each building the water height related to the 100year flood event.
- Apply the multiple functions we calculated in the previous part of the exercise to all the flooded buildings in RiskCity. You have to write an expression in the command line of the table Building_map_1998 that allows you to apply the equations; this could be an example. It has to be typed in a single line. Pay attention to the name of the maps!

Damage_perc_Buildings_100y:=
IFF(Water_Height<=0.1,Water_Height*55,
IFF(Water_Height<=0.35,Water_Height*18+3.7,
IFF(Water_Height<=0.75,Water_Height*35.42-2.40,
IFF(Water_Height<=1.25,Water_Height*19.67+9.41,
IFF(Water_Height<=2,Water_Height*30.67-4.33,
IFF(Water_Height<=3,Water_Height*19.87+17.15,
IFF(Water_Height<=5,Water_Height*2.58+69.12,Water_Height*3.98+62.16)))))))

- Check the column, **Damage_perc_Buildings_100y** especially the highest values; are they correct according to the meaning of the column? What is the cause of the inaccuracies? How would you avoid them?
- Create a new column called: **Vulnerability_buildings_100y**

  Vulnerability_buildings_100y:= Damage_perc_buildings_100y/100

- Create an Attribute map from the map Building_map_1998 by choosing the column **Vulnerability_buildings_100y**; call the new map **Vulnerability_buildings_100y.**

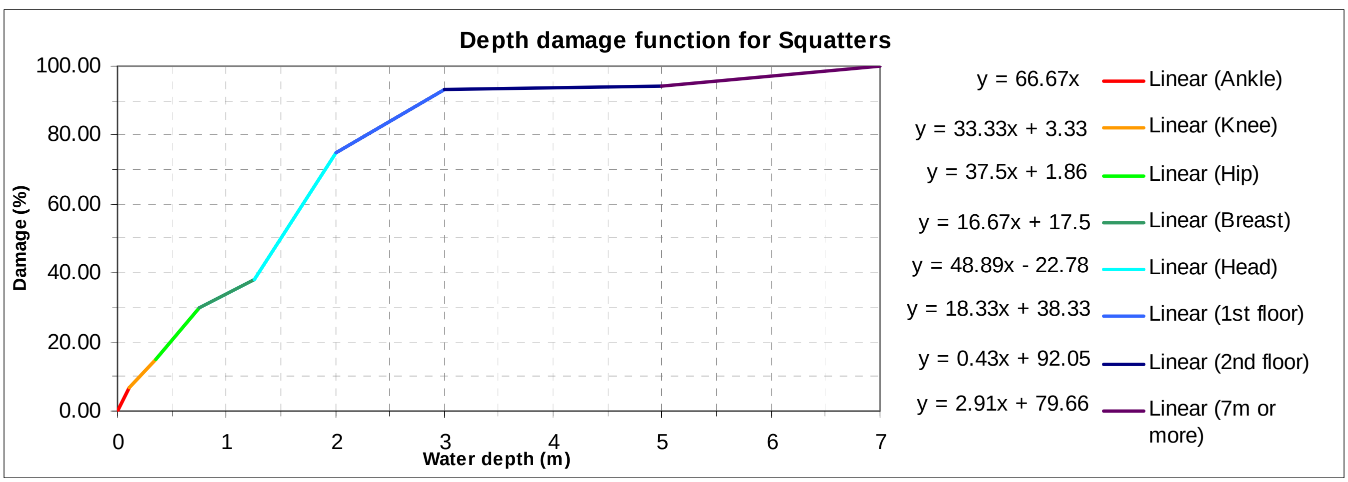
All the buildings are considered with the same characteristics and the different numbers of floors are not taken into account. A single storey squatter does not have the same damage rate of a 4 storey reinforced concrete building. In order to improve the procedure we should chose a smaller aggregation level. For instance we can start to calculate the depth-damage functions only for the Landuse Residential Squatters or at a more detailed level, for the different building types. The following instructions show briefly the procedure to calculate the functions for squatters, if you have time and you are interested in it, try to reach the task.

☞ ***Advanced Task: Calculation of more detailed depth-damage functions.***

- Copy again the **PGIS_Survey** table in Excel. Sort by ID and delete the records related to landslide damage(ID's starting with S) . Now sort the records by Landuse and save only the "Res_squatter" and "Vac_damaged". Sort by landuse and delete the records having a small number of records (they can affect the calculation) ; therefore it's better not to take them into account.
- Sort by water height related to the 1998 flood and apply the procedure illustrated in the previous part of the exercise. For the class "7 meters or more" use as damage value 100. Compare the two graphics and comment them. Do they differ from each others? Why?

- Once you created the multiple function, write an expression following the one used for all the buildings as guideline.
- Extract the water height in the table **Building_map_1998** from the column Water_height only for the squatters, and apply the ILWIS expression you created. Store the result in a column called **Damage_Squatters**. Compare the two columns Damage_buildings and Damage_Squatters; what can you conclude?
- Create an attribute map from the map Building_map_1998 using the new column and call it **Damage_Squatters**.

Here below, the graphic for the squatters is shown in order to facilitate the advanced task. The equations of the trend lines for each height interval are listed. If you don't want to calculate them by yourselves, use the ones shown in the graphic. (For the equations: small differences with your own data might occur depending on which records you have deleted e.g. records with building material fieldstone etc.)



Depth – Damage function for 1 storey squatters: equations of the trend lines.

You can find the ILWIS expression in the Excel sheet called “Stage-Damage Curves” in the folder Result files.

We can add few comments to the exercise. We calculated the depth-damage functions without taking into consideration various parameters that could largely affect the results: for instance the number of floors. This generalization was dictated by the small amount of data available. The exercise wanted to introduce the use and the concepts of such methodology in calculating the damage in flood damage assessment. Once again it is essential to remember that such methodology can be applied to historic data related to flood damage and/or to data resulting from laboratory tests. In this case we opted to use as input the results of Participatory GIS activities because historical data were not available.

References and further reading

Dutta, D., Herath, S. and Musiake, K., 2003. A mathematical model for flood loss estimation. Journal of Hydrology, 277(1-2): 24-49.

Krzysztofowicz, R. and Davis, D.R., 1983a. Category-Unit Loss Functions for Flood Forecast-Response System Evaluation. WATER RESOURCES RESEARCH, 19(6): 1476-1480.

Krzysztofowicz, R. and Davis, D.R., 1983b. A Methodology for Evaluation of Flood Forecast-Response Systems 1. WATER RESOURCES RESEARCH, 19(6).

Exercise 5b. Overall vulnerability assement using Spatial Multi Criteria Evaluation for qualitative risk assessment.

Expected time:	3 hours
Data:	data from subdirectory: RiskCity_exercises/exercise05b/data
Objectives:	In this exercises you will generate a number of indicators for social vulnerability, based on different administrative units. Also indicator maps of physical vulnerability will be generated, as well as some capacity indicators. The social and physical vulnerability indicators are combined into an overall vulnerability indicator using Spatial Multi Criteria Evaluation.

Introduction

Spatial multi criteria evaluation is a technique that assists stakeholders in decision making with respect to a particular goal (in this case a qualitative risk assessment). It is an ideal tool for transparent group decision making, using spatial criteria, which are combined and weighted with respect to the overall goal. For implementing the analysis in the RiskCity case study, the SMCE module of ILWIS was used (ITC, 2001). The input is a set of maps that are the spatial representation of the criteria, which are grouped, standardized and weighted in a criteria tree. The theoretical background for the multi-criteria evaluation is based on the Analytical Hierarchical Process (AHP) developed by Saaty (1980).

Objective

A qualitative risk assessment for defining the options of risk reduction using a multi criteria evaluation.

Risk reduction can be achieved if one of the factors of the risk equation is reduced.

Risk = Hazard * Vulnerability * Amount of elements-at-risk

Here spatial multi criteria evaluation is used to assess the overall vulnerability factor. The overall vulnerability is a function of the vulnerability and the capacity.

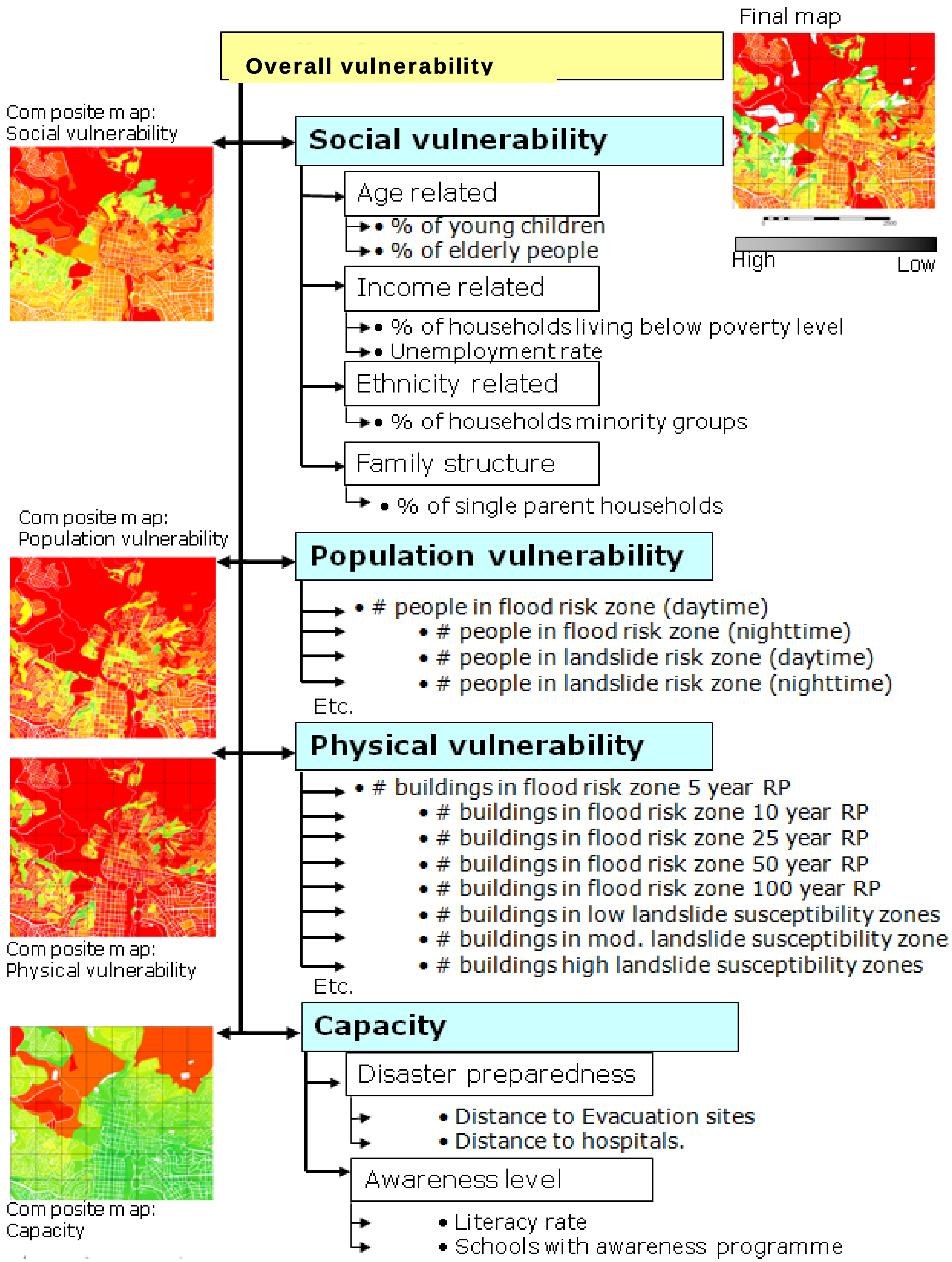
"**Capacity** is a combination of all strength and resources available within a community or organization that can reduce the level of risk, or the effect of a disaster. It may include physical, institutional, social or economic means as well as skilled personal or collective attributes such as leadership and management. Capacity may also be described as capability" (UN-ISDR, 2004)

The main goal of the SMCE is to define the **overall vulnerability**.

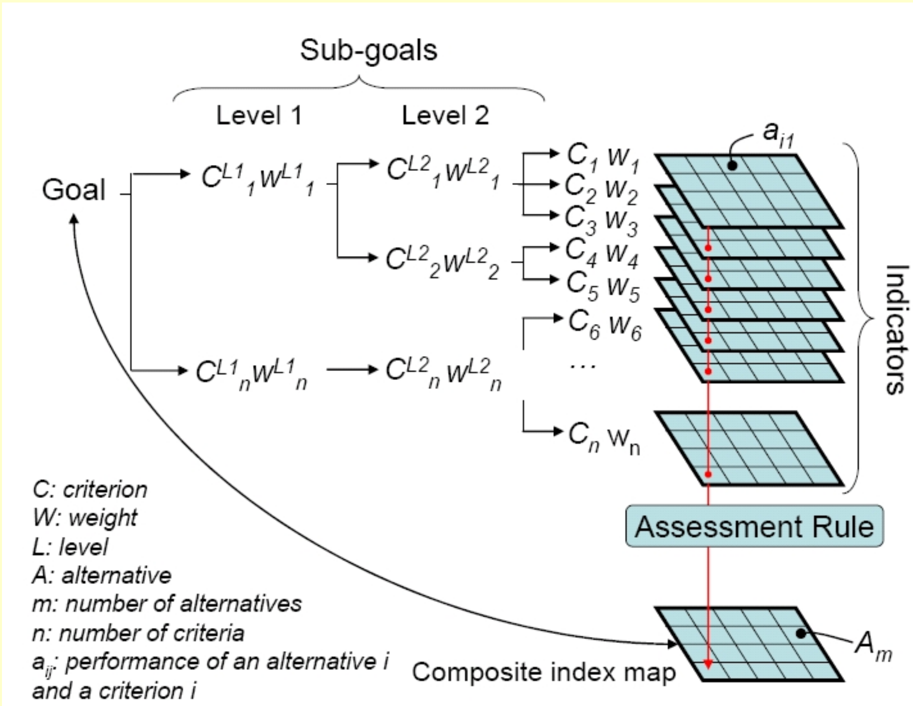
Sub-goals are:

- to define the **generic social vulnerability**,
- to define the **population vulnerability** for natural hazards considering a day time and night time scenarios.;,
- to define the **physical vulnerability** in terms of buildings at risk for specific natural hazards,
- and to define the **capacity**.

The figure below gives an overview of the goal, sub-goals and indicators used to define the sub-goals, in the Risk City exercise.



Procedure



For implementing the semi-quantitative model, the SMCE module of ILWIS-GIS was 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. The theoretical background for the multi-criteria evaluation is based on the Analytical Hierarchical Process (AHP) developed by Saaty (1980).

General steps in the process are:

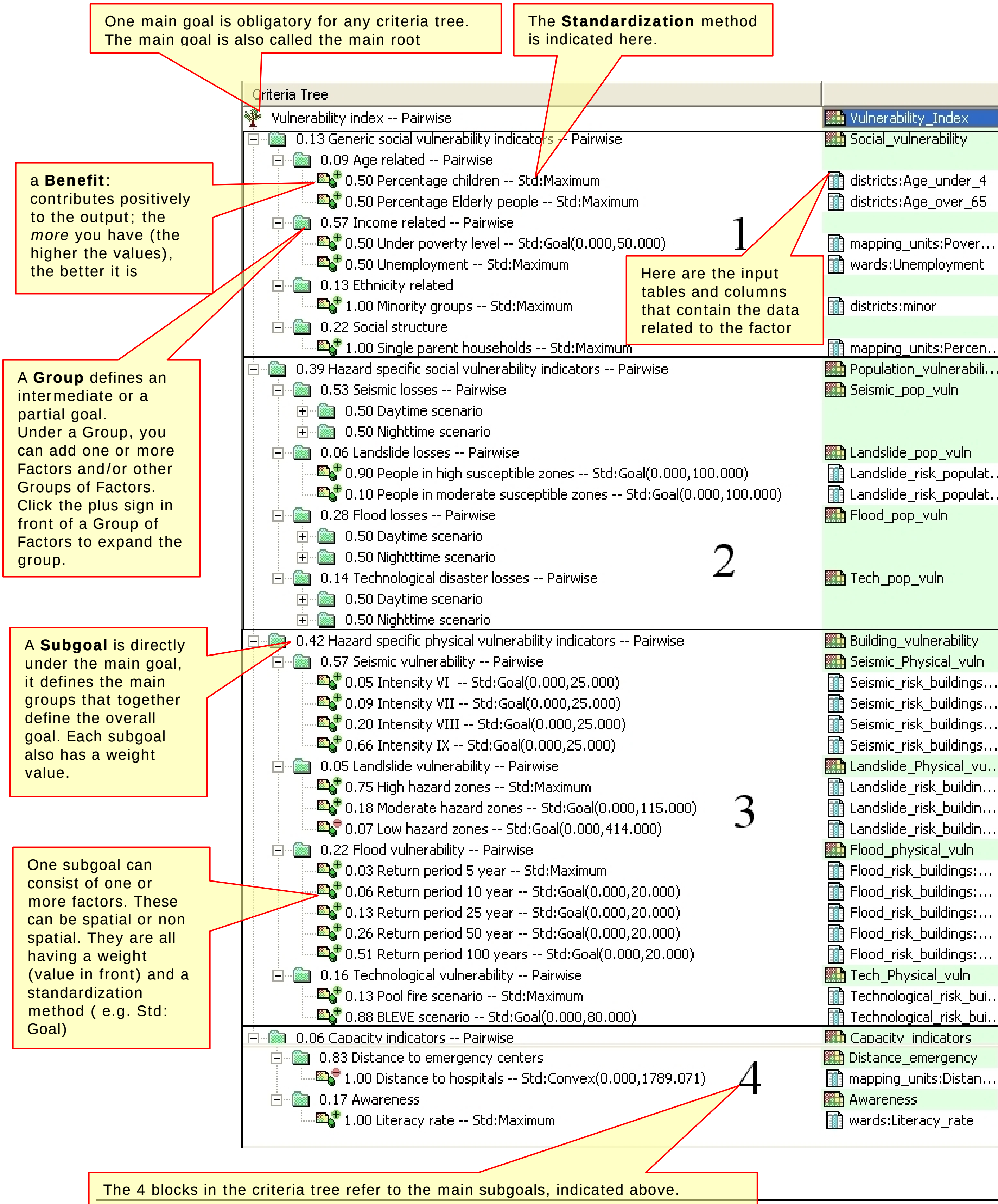
1. **Definition of the problem**. Structuring of the problem into a criteria tree, with several branches or groups, and a number of factors and/or constraints.
2. **Standardization of the factors**. All factors may be in different format (nominal, ordinal, interval etc.) and should be normalized to a range of 0-1. SMCE has some very handy tools for that especially for value data, making use of different transformation graphs.
3. **Weighting of the factors** within one group. SMCE has some very handy tools for that derived from Analytical Hierarchical Processing (AHP), such as pair wise comparison and rank ordering.
4. **Weighting of the groups**, in order to come to an overall weight value.
5. **Classification** of the results.

> Note: it is also possible to carry out the steps independently and also to skip one or more. If you are working in a group these topics could be done by individual team members.
> It is also possible to carry out the full analysis in one criteria tree (next page). However, we advise to do it in the individual components described above.

A criteria tree may contain:

Main goal: One main goal is obligatory for any criteria tree. The main goal is also called the main root.
Constraint: Constraints are binding criteria so no compensation is allowed. Areas in an input map (added as a constraint) that do not satisfy a constraint condition, will obtain a composite index value of 0, no matter how well these areas perform in any other criterion (factor). Constraints can only appear directly under the main goal.
Factor: Factors allow for compensation. Poor performance in one criterion can be compensated by good performance in another criterion. Factors may appear directly under the main goal or under a group of factors (sub-goal), or even under a sub-sub-goal (objective)**. A factor can be a benefit (the higher the value, the better), or a cost (the higher the value, the worse).**
Group of Factors: A Group defines an intermediate or a partial goal. Under a Group, you can add one or more Factors and/or other Groups of Factors. Click the plus sign in front of a Group of Factors to expand the group.

Figure 3 gives an overview of the final criteria tree that can be used for this exercise. It explain the procedure and terminology used in the ITC_ILWIS SMCE tool.



Input data

The following data are used in this exercise.

Name	Type	Meaning
Elements at risk		
Mapping_units	Polygon	Building blocks of the city
Mapping_units	table	Table containing general statistical information on the number of buildings and people per building block
Wards	Polygon	Ward of the city
Wards	Table	Table with population information derived from census data for the wards in the city
Districts	Polygon	Districts of the city
Districts	Table	
Losses for different types of hazards		
Flood_risk_buildings **Seismic_risk_buildings** **Technological_risk_buildings** **Landslide_risk_buildings**	Tables	Tables with the results of the loss estimations for flooding, earthquakes, landslides and technological hazards for buildings. These are the results of the previous exercises
Flood_risk_population **Seismic_risk_population** **Technological_risk_population** **Landslide_risk_population**	Tables	Tables with the results of the loss estimations for flooding, earthquakes, landslides and technological hazards for buildings. These are the results of the previous exercises
Other data		
High_res_image	Raster	High resolution image of the study area.

The general approach: selection of the indicators for the different sub goals.

The sub goals are defined using different indicators. Based on the Risk City data set the following 4 sets of indicators were generated:

1. **Social vulnerability indicators**, indicated in table 1, such as:
   - Percentage of young children
   - Percentage of elderly people
   - Population density in daytime
   - Population density in nighttime
   - Percentage of minority groups
   - Percentage of single parent households
   - Percentage of households living below poverty level.
   - Literacy rate
2. **Population vulnerability indicators** (indicated in table 2)
   - Number of people located in flood hazard zones, with different return periods, and with both a daytime and nighttime scenario
   - Number of people located in landslide hazard zones, with different degree of susceptibility to landslides, and with both a daytime and nighttime scenario
   - Number of people located in technological hazard zones, with different degree of susceptibility to landslides, and with both a daytime and nighttime scenario
   - Number of people located in seismic hazard zones, with different intensities and return periods and with both a daytime and nighttime scenario
3. **Physical vulnerability indicators** (indicated in table 3)
   - Number of buildings located in <u>flood hazard</u> zones, with different return periods
   - Number of buildings located in <u>landslide hazard</u> zones, with different degree of susceptibility to landslides
   - Number of buildings located in <u>technological hazard</u> zones, with different degree of susceptibility to landslides
   - Number of buildings located in <u>seismic hazard</u> zones, with different intensities and return periods
4. **Capacity indicators**
   - Awareness

☞

- Open the map **Mapping_units** , and add the maps **Wards**, and **Districts**. Rasterize these maps; use geo reference **Somewhere**.
- Use *PixelInformation* to find out the information from the attributes linked to these maps.

Table 1: Overview of available data for **Social vulnerability assessment**

Map	Table	Column	Meaning
Districts	Districts	Age_under_4	Percentage of young children, of pre-school age
	Districts	Age_4_to_12	Percentage of children, of primary school age
	Districts	Age_12_18	Percentage of teenagers, of secondary school age
	Districts	Age_18_24	Percentage of adolescents, following further education
	Districts	Age_24_65	Percentage of population in working age
	Districts	Age_over_65	Percentage of retired people.
	Districts	Minor	Percentage of population coming from minority groups.
Wards	Wards	Nr_buildings	Number of buildings per ward
	Wards	Daytime_population	Daytime population per ward
	Wards	Nighttime_population	Nighttime population per ward
	Wards	Unemployment	Unemployment rate per ward
	Wards	Literacy_rate	Literacy rate per ward
Mapping units	Mapping units	Pred_landuse	Predominant landuse per mapping unit
	Mapping units	PerVacant	Percent of mapping units that is vacant and could be used as shelter area, if it has the right landuse
	Mapping units	Percent_single_ household	Percentage single household per mapping units
	Mapping units	Poverty_level	Percentage of population in mapping unit living below poverty level

Apart from the social vulnerability indicators, we also take into account the population vulnerability indicators, which are given in the table below.

Table 2: Overview of available data for **population vulnerability assessment.**

Map	Table	Column	Meaning
Table: Mapping units Indicator: Flood risk to people	Flood_risk_population	day_pop_aff_10_year day_pop_aff_50_year	Number of people affected by a flood with a return period of 10 or 50 years, during daytime
	Flood_risk_population	night_pop_aff_10_year night_pop_aff_50_year	Number of people affected by a flood with a return period of 10 or 50 years, during nighttime
Table: Mapping units Indicator: Landslide risk to people	Landslide_risk_population	Pop_night_high Pop_night_moderate Pop_night_low	Number of people living in the high, moderate orlow landslide susceptible zones during the nighttime
	Landslide_risk_population	Pop_day_high Pop_day_moderate Pop_day_low	Number of people living in the high, moderate and low landslide susceptible zones during the daytime
Mapping units Indicator: Technological risk to people	Technological_risk_population	Pop_day_sc1	Number of people being present in the area that might be affected by pool fire during the day
	Technological_risk_population	Pop_night_sc1	Number of people being present in the area that might be affected by pool fire during the night
	Technological_risk_population	Pop_day_sc2	Number of people being present in the area that might be affected by BLEVE (explosion) during the day
	Technological_risk_population	Pop_night_sc2	Number of people being present in the area that might be affected by BLEVE (explosion) during the night
Mapping units Indicator: Seismic risk to people	Seismic_risk_population	VI_night_pop VII_night_pop VIII_night_pop IX_night_pop	Population in buildings of buildings that collapse under VI – IX earthquakes in the night
	Seismic_risk_population	VI_day_pop VII_day_pop VIII_day_pop IX_day_pop	Population in buildings of buildings that collapse under VI – IX earthquakes in the night

The third block of indicators are the physical vulnerability indicators, which are shown in table 3.

Table 3: Overview of available data for **physical vulnerability assessment**

Map	Table	Column	Meaning
Mapping units	Flood_risk_buildings	Buildings_5_year	Number of buildings affected by a flood with a return period of 5 years
	Flood_risk_buildings	Buildings_10_year	Number of buildings affected by a flood with a return period of 10 years
	Flood_risk_buildings	Buildings_25_year	Number of buildings affected by a flood with a return period of 25 years
	Flood_risk_buildings	Buildings_50_year	Number of buildings affected by a flood with a return period of 50 years
	Flood_risk_buildings	Buildings_100_year	Number of buildings affected by a flood with a return period of 100 years
Mapping units	Landslide_risk_buildings	Nr_buildings_high	Number of buildings located in the high susceptible zones for landslides
	Landslide_risk_buildings	Nr_buildings_moderate	Number of buildings located in the moderate susceptible zones for landslides
	Landslide_risk_buildings	Nr_buildings_low	Number of buildings located in the low susceptible zones for landslides
Mapping units	Technological_risk_buildings	Nr_buildings_sc1	Number of buildings located in the area that might be affected by pool fire
	Technological_risk_buildings	Nr_buildings_sc2	Number of buildings located in the area that might be affected by BLEVE
Mapping units	Seismic_risk_buildings	VI_collapse_max	Number of buildings that are expected to collapse under a VI intensity earthquake
	Seismic_risk_buildings	VII_collapse_max	Number of buildings that are expected to collapse under a VII intensity earthquake
	Seismic_risk_buildings	VIII collapse_max	Number of buildings that are expected to collapse under a VIII intensity earthquake
	Seismic_risk_buildings	IX_collapse_max	Number of buildings that are expected to collapse under a IX intensity earthquake

Part A: Creating the criteria tree for Generic Social Vulnerability Assessment.

In this step we will generate in the ILWIS Spatial Multi Criteria Evaluation (SMCE) software tool, a problem tree that will be used to calculate the generic social vulnerability.

We assume that you have some basic knowledge on SMCE, and will not explain a lot on the background. Please consult the ILWIS help if you need more information.

In general SMCE follows a number of steps (as mentioned before) :

1. **Definition of the problem**. Structuring of the problem into a criteria tree, with several branches or groups, and a number of factors and/or constraints.
2. **Standardization of the factors**. All factors may be in different format (nominal, ordinal, interval etc.) and should be normalized to a range of 0-1. SMCE has some very handy tools for that especially for value data, making use of different transformation graphs.
3. **Weighting of the factors** within one group. SMCE has some very handy tools for that derived from Analytical Hierarchical Processing (AHP), such as pair wise comparison and rank ordering.
4. **Weighting of the groups**, in order to come to an overall weight value.
5. **Classification** of the results.

Below we will take you through the procedure for the generic social vulnerability assessment. Later on you can do it yourself for the other groups.

A.1. Mode: Problem definition:

Which criteria to use, and how to order them? This is often one of the most difficult parts of the procedure.

The criteria tree is composed of the following criteria:

Constraints: these criteria are used to mask out the area where the goal can not be reached. In this case, where there is no social vulnerability, because there are no people living.

Factors: those are the criteria that contribute in different way to the goal (social vulnerability score in this case). We can group these into several sub-goals or groups.

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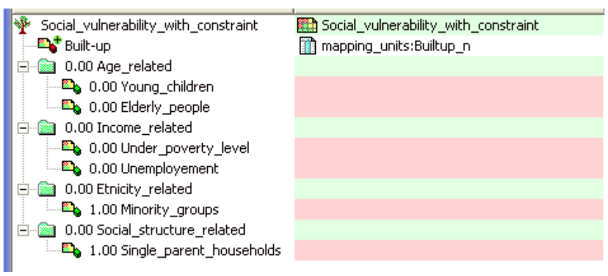
- Select *Operations / Raster Operations / Spatial Multi Criteria* Evaluation. Select the option Problem Analysis. An empty problem tree is opened (or select Spatial Multi-Criteria Evaluation in the Operations List)
- Change the goal (right click select Edit)to: **Generic Social Vulnerability**, and the name of the output map (in the right side) to **Social_Vulnerability**.
- Click on Generic Social Vulnerability and click on the insert group icon or Right click on **Generic Social Vulnerability** and select *Insert group*. Add the groups: **Age_related**, **Income related**, **Ethnicity related**, **Social Structure Related**.
- Include the various spatial factors for the individual criteria, as indicated below by right-clicking on the individual criteria and inserting the spatial factors or click the insert spatial factor icon .



You could also add a constraint, called **Built_up area**. This would be a Boolean column (True or False) from the **Mapping_unit** table, in which you indicate for each mapping unit if there are built-up areas or not. This could be done by first making such a Boolean column in the **Landuse** table, and then joining that with the **Mapping_unit** table.

QUESTION: Apart from the criteria that are given here, which other indicators do you think could be used in determining social vulnerability? Name a few examples, and indicate where you could get such data from, in your own country.

Next you will have to assign the spatial data that is relevant for each of the criteria that you have defined. These are mostly coming from tables, linked to the maps **Mapping_units**, **Wards**, and **Districts**. All age related data is available only at district level. Note: red areas in SMCE mean that data is still not defined.

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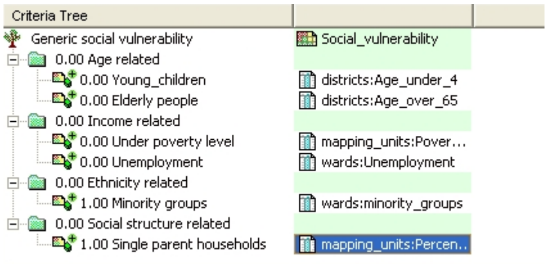
- Double click on the red area next to **Young_children**. Select from the map **Districts** the column: **Age_under_4**.
- Find also the relevant spatial information for the other criteria, and the result

is indicated below

- Save the criteria tree as **Social_vulnerability**..



The criteria tree should look like the example shown here to the left.

Note: all parts indicated in red should be completed before you can make the output map.

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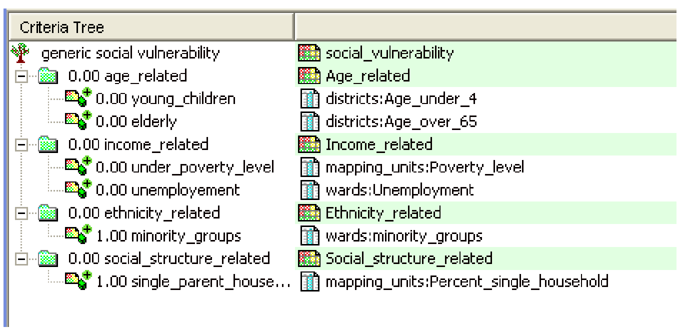
- Adding output maps : Double click on the green area next to " Age_related" and fill in Age_related; Press enter
- Do the same for Income_related, Ethnicity_related and Social_stgructure related.



A.2. Mode Multi Criteria Analysis: Standardization of the factors.

In this case all the factors used in the social vulnerability assessment are of the "value" type, and they are all stored as attributes in an attribute table linked to one map. Next we need to standardize these different values, and normalize them to values ranging from 0 to 1.

Standardization and the design of value functions is a crucial part of the SMCE. Different standardization methods express different utility of input values. When standardizing, depending on the type of input map, a dialog box will appear in which you can choose the "value function" by which the map or column values are converted to values between 0 and 1. Standardization is part of the Multi Criteria Analysis mode in ILWIS-SMCE.

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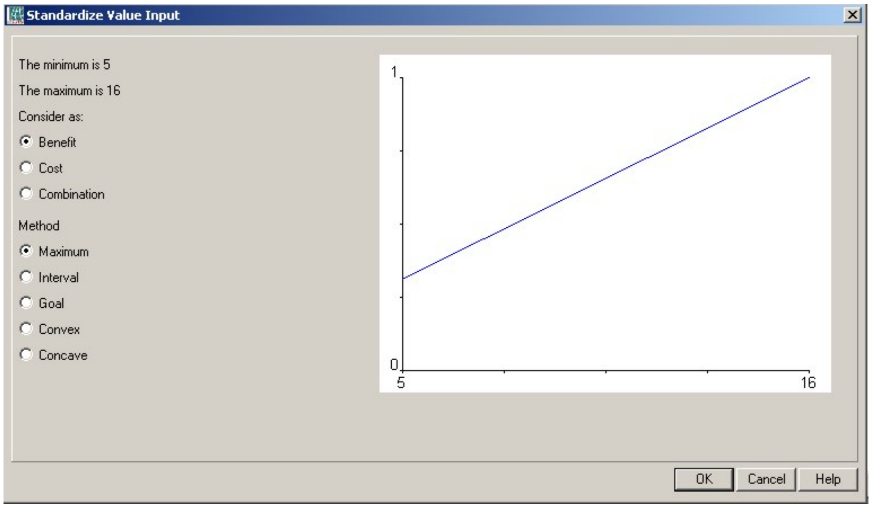
- In the SMCE window, change the Mode from "*Problem Definition*" to "*Multi Criteria Analysis*". Now you can start standardization.

- Double click on the red area indicating **0.00 Young_children**. Now a window opens in which a graph is shown fitting the data range of values for this factor over the range of 0-1.

How to standardize?
You have to define yourself the ranges between you standardize. Consider for each factor: how much should the value be in order to consider it very vulnerable? For instance: how large should the percentage elderly people per mapping unit be to give it a 1 value (highly vulnerable). These threshold values are often defined in a group decision making process

Maximum: The input values are divided by the maximum value of the map;
Interval: Linear function with the maximum and minimum values of the map;
Goal: Linear function with specified maximum and minimum values;
Piecewise linear: Linear function with two breaking points located between the extremes
Convex: Convex function with one user defined value to re-shape the curve;
Concave: Concave function with one user defined value to re-shape the curve;
U-Shape: U-shape curve with one user defined value to stretch or shrink the curve GaussianBell-shape curve with one user defined value to stretch or shrink the curve.



You have the option to select several ways of scaling the values between 0 and 1. The figure below shows the standardization window, and the various options.

When selecting the boundaries for standardization, you always have to consider the aim of the weighting and standardization procedure (in this case social vulnerability), and how this particular variable is related to that. In this case: the higher the percentage of children in an area, the higher the vulnerability of the population. In that case you can use a simple straight line, between 0 and the maximum value. In other cases there will be a maximum value above which you will always find it high. E.g. for the estimation of the population losses, you could say that anything above 20 is high, and should be 1. In that case you select the Goal option, and you can adjust the values manually.

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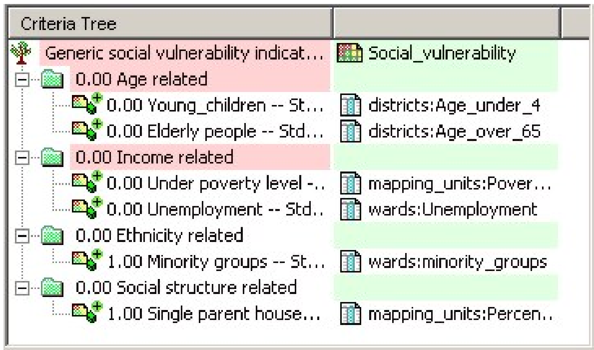
- Select the goal option and change the minimum X to 0 and the maximum to 20. Do the same for the variable **Elderly_people**.
- Standardize in the same way the other variables.

After standardizing all factors, your criteria tree will look like the one below in the picture. The red bars are showing the places where still you need to indicate weights.



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- To see the result of the standardization: Right click on the name **Young_children** and select *Show standardized*. A map opens that contains the standardized values.
- Open *PixelInformation* and add the map you just created and also the map district , linked to the table **District**. Compare the original values to the standardized values.

A.3. Mode Multi Criteria Analysis: Determining the weights among factors

Weights
- Weights are always numbers between 0 and 1.
- Weights cannot be negative.
- For the factors within a group, the sum of the weights of the factors equals 1.
- When a group only has one child, this child automatically obtains weight 1.
- Constraints are not considered during weighing.

The third step in the procedure is to define the weights between the various factors. This can be between the factors in the same group (e.g. the two factors "*Young_children*" and "*Elderly_people*" in the group "*Age related*"), or the weights among the groups (e.g. "*Age related*" versus "*Income related*"). There are two groups that have only one factor, and therefore the weights for these two are 1 (see above: "*Minority groups*", and "*Single parent households*").
For the determination of weights SMCE use 3 different methods:
- **Direct weights** (you indicate the weights directly in a table),
- **Pairwise comparison** (you compare the factors in pairs, and based on the consistency of your selection and relative importance, quantitative values are given to the factors), and
- **Rank ordering** (you indicate the relative ranking of the factors, and the software converts these in quantitative weights).

In this exercise we will work mostly with pairwise comparison.

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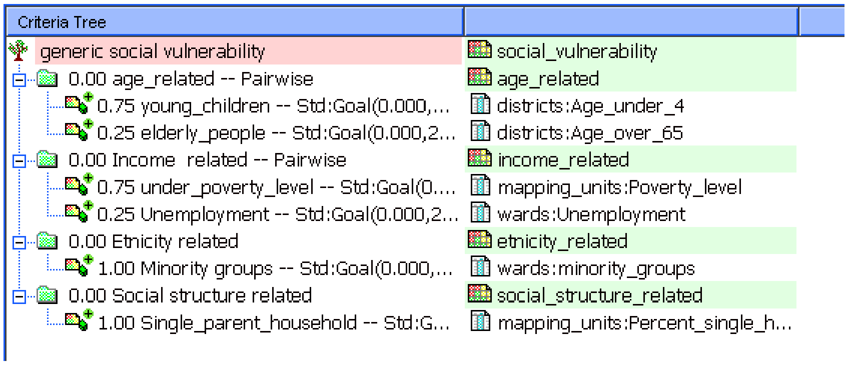
- Right-click the red indicated factor group "***Age related***", and select Weight. Select the option: *Pairwise*
- Determine whether for the determination of social vulnerability, the percentage of young-children is more important than the percentage of elderly people, or equal, or less. Discuss this with your neighbors / group members.
- Double-click in the green area next to age related and fill in age_related; Press enter. Double-click on the map name and generate the map. View the result.
- Standardize in the same way the other groups e.g. "Income related" and

make the intermediate maps for Income related , Etnicity related and Social structure related..

The criteria tree will then look like the one to the left.



A.4 Mode Multi Criteria Analysis : Determining the weights among groups

The fourth step in the procedure is to define the weights between among the groups (e.g. "*Age related*" versus "*Income related*"). There are four groups in this example. Also here pair wise method could be used, but you might also try out another one.

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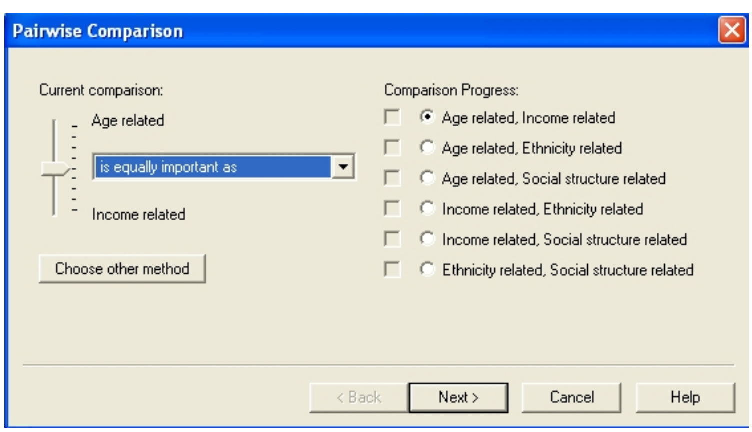
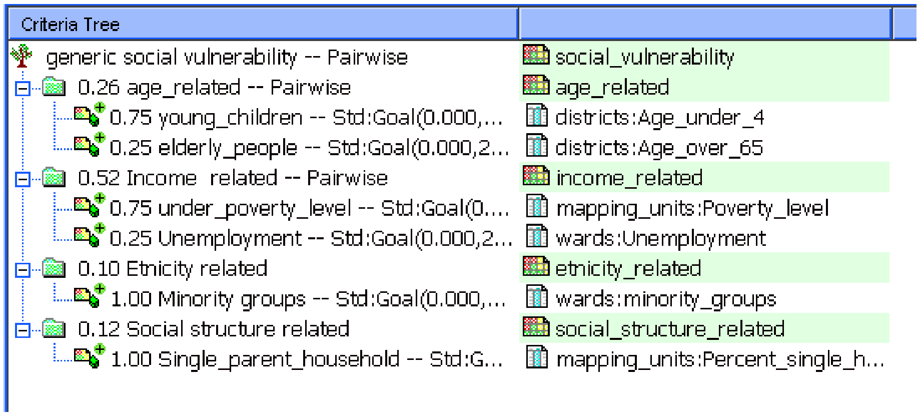
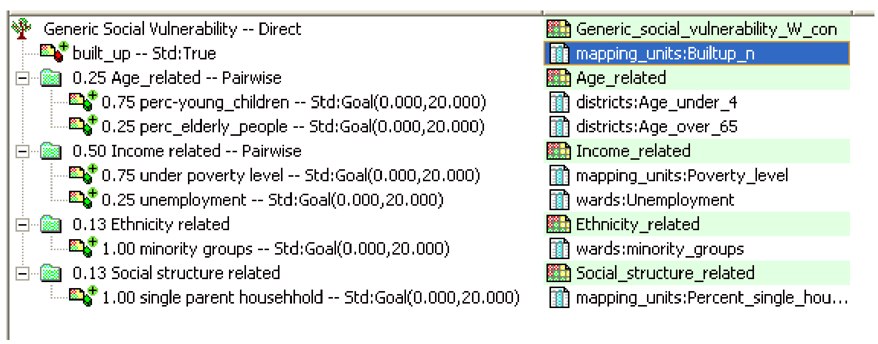
- Right-click the red indicated upper line *"Generic social vulnerability* ", and select Weight. Select the option: *Pairwise*
- Determine for each combination the relative importance (see below). Discuss this with your neighbors / group members. .



The resulting criteria tree might look like the one below (but the weights could be different, depending on the importance you gave to the different groups of factors.)



Or with constraint on built_up:



Now all the parameters are given and it is time to calculate the output map.

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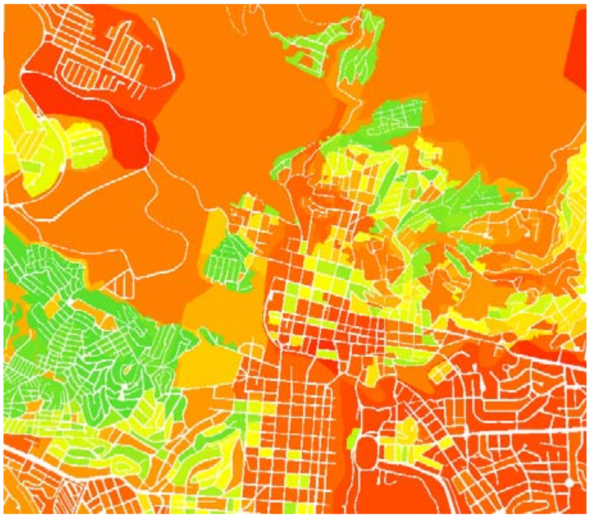
- Right-click the map icon "**Social_vulnerability**", and select Generate selected item.
- Display the result map. Use *PixelInfo* to compare the resulting map with the input maps. You can adjust the standardization, and weights if you would like to make adjustments.,



Question
What can you conclude from the pattern of social vulnerability?

Part B. Creating the criteria tree for Population Vulnerability Assessment (using hazard specific indicators)

In this part you will generate the maps required for the population vulnerability indicators using spatial multi-criteria analysis. The population that might be affected by earthquakes, landslides, flooding and technological disasters during a daytime and nighttime scenario, will be combined into one population vulnerability.

B.1 Preparation of input maps

In this step we will generate the maps required for the spatial multi-criteria analysis. In the SMCE software each table containing columns that are used as indicators should be linked to a raster map. As most of the attribute tables with the results of population and buildings losses are linked to the mapping_units map, we need to copy this map several times, so that each table has its own map.

☞

- Rasterize the polygon maps **Mapping_units**, **Wards**, and **Disticts** using the Georeference **Somewhere** if this hasn't been done yet.
- Select the map **mapping_units** and select the *Edit / Copy Object to* and select New Name. Name the file: **Flood_risk_buildings**.
- Change the properties of the raster map **Flood_risk_buildings**, and make sure it is linked to the table **Flood_risk_buildings**.
- Do the same for all the files in the table listed below, and give them the names as indicated.

Table 4: Copy the raster map Mapping_units to these names, and link each one of them to the table with the same name

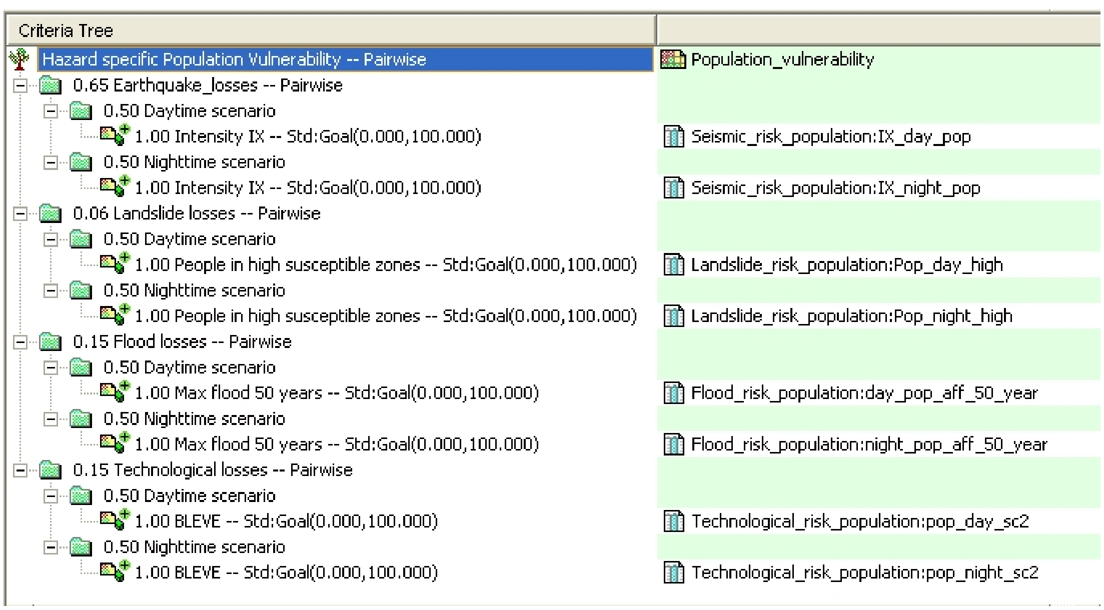
Table names.	
Flood_risk_buildings	Seismic_risk_buildings
Flood_risk_population	Seismic_risk_population
Landslide_risk_buildings	Technological_risk_buildings
Landslide_risk_population	Technological_risk_population

B.2 Generating the criteria tree for Population vulnerability

Once the input maps have been generated, you can start with the generation of the criteria tree and the multi criteria analysis. As the procedure was already explained in the previous section, we will not repeat it here again.

☞

- Create a new criteria tree: **Population_Vulnerability**, and the file name also the same.
- Add groups of the individual groups of factors: **Earthquake_losses**, **Landslide_losses**, **Flood_losses**, **Technological_losses**.
- Include for each hazard type, two subgroups: **Nighttime losses**, and **Daytime losses**.
- Enter the most relevant scenarios for each hazard type. For example, for earthquakes, only adding the IX scenario would be enough. You can compare it with the figure below, but you don't have to do it exactly the same



B.3 Standardizing and weighting

Once the criteria tree is made, you can define the related attributes and start the standardization. As the procedure was already explained in the previous section, we will not repeat it here again.

☞

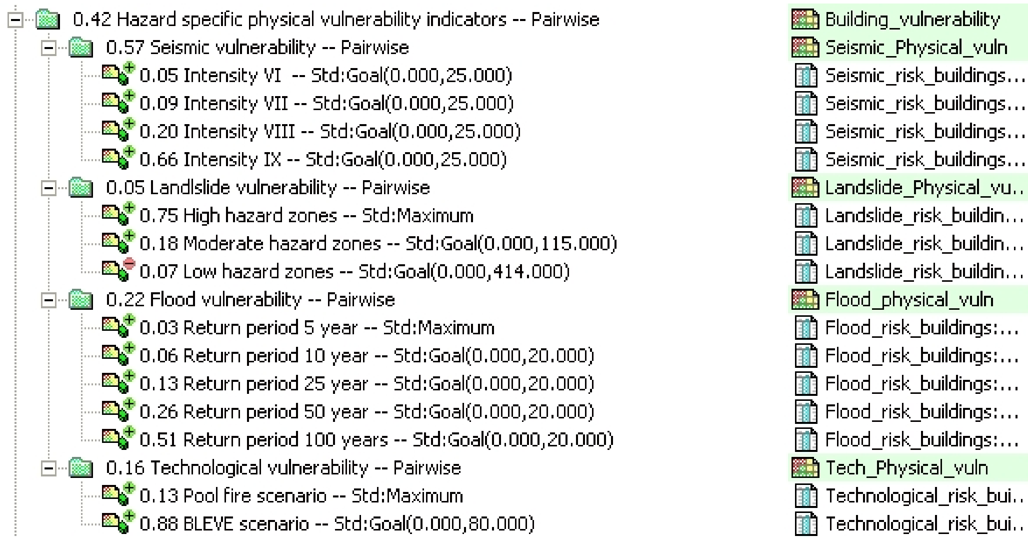
- Choose the relevant attributes from the “Population risk” columns linked to the maps of the **Mapping_units** for earthquakes, landslides, floods and technological hazards.
- Standardize all columns, using the same “Goal” function with for example the value 100 as the one reaching 1.
- Use the weighting of the daytime-nighttime losses, using a same weight of 0.5
- Use the pairwise method for the hazard and state which hazard you find more important than others.
- Generate the output map **Population_vulnerability**, and critically evaluate the result. If needed, adjust the criteria tree. An example of a possible criteria tree is given below.
- Do you think that the parameters taken into account are good indicators for the evaluation of the vulnerability? Do you have other ideas?

Part C. Creating the criteria tree for Physical Vulnerability Assessment.

In this part you will generate the maps required for the hazard specific physical vulnerability indicators using spatial multi-criteria analysis. The procedure for estimating the number of buildings that might be affected by earthquakes, landslides, flooding and technological disasters will be further explained in the exercises of session 6. Here we will combine them into one physical vulnerability index.

☞

- Create a new criteria tree: **Physical_Vulnerability**, and name the output file name also the same.
- Add groups of the individual groups of factors: **Earthquake_losses, Landslide_losses, Flood_losses, Technological_losses**.
- Include for each hazard type, all the calculated scenarios for each hazard type. For example, for earthquakes, add scenarios VI, VII, VIII and IX intensity.
- Choose the relevant attributes from the “Building risk” columns linked to the maps of the mapping units for earthquakes, landslides, floods and technological.
- Standardize all columns, using the same “Goal” function with for example the value 25 as the one reaching 1.
- Use the pairwise method for the scenarios within each hazard category
- Also use the pairwise method for comparing the various hazards and state which hazard you find more important than others
- Generate the output map **Physical_vulnerability**, and critically evaluate the result. If needed, adjust the criteria tree. An example of a possible criteria tree is given below.



Part D. Creating the criteria tree for Capacity Assessment.

The overall vulnerability is a function of vulnerability and capacity. Capacity expresses the positive managerial and operational resources and procedures for reducing risk factors. These actually help to reduce the vulnerability.

In our case study we are using only one capacity indicators: awareness level, expressed by the literacy rate. The capacity indicator should work opposite to the other vulnerability indicator.

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- Create a new criteria tree: **Capacity**, and the file name also the same.
- Add the group: **Disaster_Awareness.**
- Under this group, include one spatial factor: **Literacy_rate** Select the column **Literacy_rate** from the table **Wards**.
- Standardize the factor, keeping in mind that high values of literacy rate results in <u>high</u> values of the capacity index.
- Generate the output map Capacity, and critically evaluate the result.

Part E. Combing vulnerability and capacity indicators

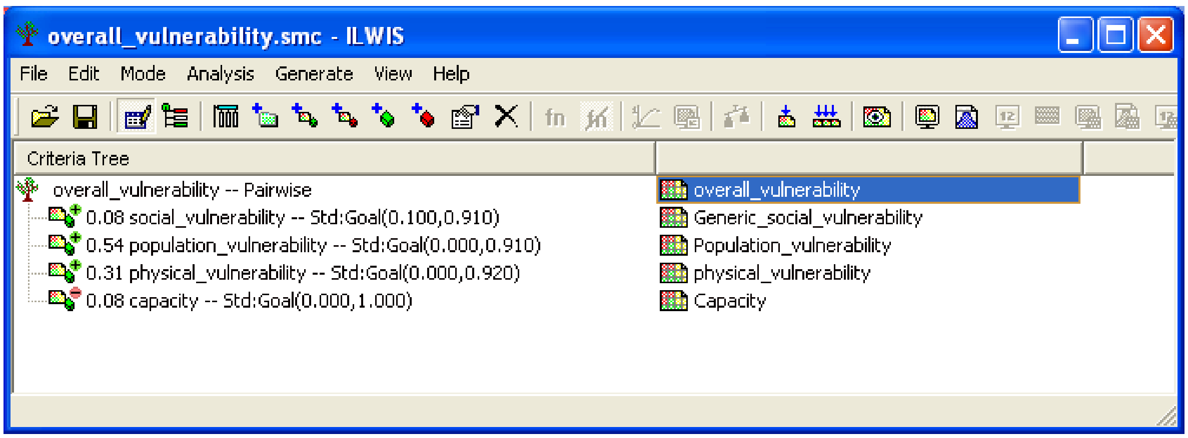
The overall vulnerability is made by combining the four "indicators" that we have calculated thus far in:

- Social_Vulnerability Assessment (Part A)
- Population_Vulnerability (Part B)

- Physical_Vulnerability (Part C)
- Capacity Assessment (Part D)

☞

- Create a new criteria tree: **Overall_vulnerability** and the file name also the same.
- Add the four spatial factors: **Social_vulnerability, Population_vulnerability**, **Physical_vulnerability and Capacity**.
- Link them to the four maps that were made in Part A, B, C and D.
- Standardize the four factors, and use **the pairwise method** for the determination of the weights.
- The **capacity will be made a cost**, since it is lowering the vulnerability.
- Generate the output map **Overall _vulnerability**.



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- Classify the output map in three classes and critically evaluate the result. (Create a histogram from the **Overall_vulnerability** and select 3 classes).

WHICH AREAS HAVE THE HIGHEST VULNERABILITY?

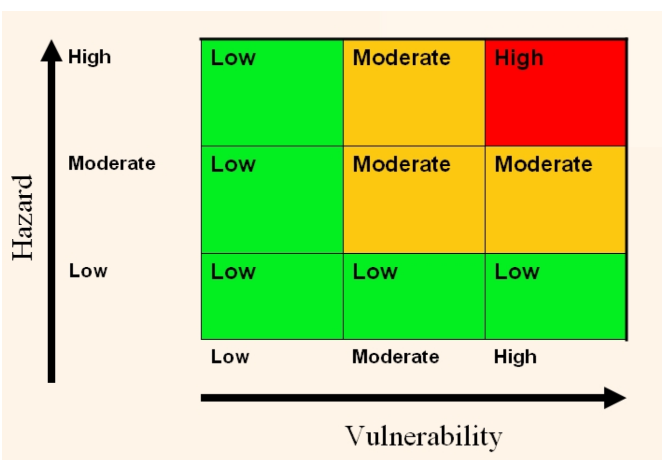
Exercise 6A. Qualitative risk assessment.

Expected time:	1 hour
Data:	data from subdirectory: Riskcity exercise/exercise06a/data
Objectives:	This exercise shows you a simple method for qualitative risk assessment, using a matrix to combine qualitative vulnerability and susceptibility classes. We take landslide risk as an example here.

Input data

In this exercise we will use the landslide susceptibility map (Susceptibility) that was generated using statistical method as in exercise 3L. For the elements at risk we will use the mapping units representing the building blocks. The map **Landslide_ID** is also required in order to change the susceptibility map into a hazard map, with the temporal landslide information.

Name	Type	Meaning
Elements at risk		
Mapping_units	Raster	Building blocks of the city
Mapping_units	table	Table containing general statistical information on the number of buildings and people per building block
Landslide data		
Landslide_ID	Raster	Points within each of the interpreted landslides with associated attribute table
Landslide_ID	Table	Attribute table with information on the landslides in the area.
Susceptibility	Raster	Landslide susceptibility map made using a statistical method.
Other data		
High_res_image	Raster	High resolution image of the study area.
Landuse	Table	Land use classification of the study area



In situations where there is not enough temporal information available to be able to estimate the hazard probability, it is better to use a simple method that combines qualitative hazard and vulnerability maps. The qualitative hazard map is in fact the susceptibility map, and the vulnerability map is showing the number of elements at risk (buildings and population in this case).

The matrix approach is based on the combination shown in the figure.

We will use the landslide susceptibility map, in which the actual landslides have been included as high susceptibility if they are active or as moderate susceptibility if they are old landslides. The landslide susceptibility map is called **Susceptibility**. We will also use the map **Mapping_units** and the table linked to that for analyzing the vulnerability.

Making the vulnerability map

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- Rasterize the map **mapping_units** using the georeference **Somewhere**.
- Open the table **Mapping_units** and have a look at the various columns
- Open the map **Susceptibility** and check the contents, also by overlaying the

landslides.

As you can see this table contains columns indicating the number of buildings and population per unit. We will use these columns for making a simple subdivision into three vulnerability classes. We will use the number of buildings, and we will use the following, very simple, classification (open for improvement if you like), indicate in the table.

This is of course a large simplification. If more time was available the vulnerability could be better evaluated using Spatial Multi Criteria Evaluation with many more criteria.

	Number of buildings per unit	Nighttime population
Low vulnerability	< 5	< 3
Moderate vulnerability	6 – 25	4 -20
High vulnerability	> 25	> 20

We will here only use the number of building for the Vulnerability matrix, but you can also see the result later if you base it on population.

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- Check the class domain **Vulnerability**,it has three classes (*Low_v*, *Moderate_v, High_v*). (If not present; make the class domain.)
- In the table **Mapping_units** create a column **Vuln_buildings**, which contains the criteria for the buildings in the table above, using a formula:

Vuln_buildings:=iff(nr_buildings<5,"Low_v",iff(nr_buildings<25, "Moderate_v", "High_v")) use; domain; Vulnerability

- In the table **Mapping_units** create a column **Vuln_population**, using a formula, based on the criteria given in the table above. Design the formula yourself.
- Combine the two types of vulnerability (from **vuln_buildings** and **vuln_population**)and determine the highest class in a formula. HINT: use the OR operator in your formula. Design the formula in the table yourself. Name the output column: **vulnerability** (Use the same domain **Vulnerability**)

Be careful to use the domain Vulnerability for the column "vulnerability" otherwise you cannot create the attribute map "Vulnerability". Is not possible derive an attribute map from a string domain.

Now that you have generated a column Vulnerability, you can simply make an Attribute map of this from the map **Mapping_units**.

☞

- Create an attribute map using the raster map **Mapping_units**, and the column **Vulnerability**.

Combining hazard and vulnerability

The next step is to combine the Vulnerability and the Susceptibility map into a qualitative risk map. We can do this using a so-called two-dimensional table, which looks like the matrix shown in the figure above.

Be careful to make in the window of the 2-dimensional table a new domain Risk, with three classes: High_risk, Moderate_risk, and Low_risk

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- Select File, Create, 2 Dimensional Table. Enter the following parameters:

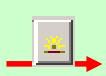


Table name: **Qualitative_risk**
Primary Domain: **Susceptibility**
Secondary Domain: **Vulnerability**
Contents Domain: make a new class domain **Risk**, and add the classes *High_risk*, *Moderate_risk*, and *Low_risk.*

- On the command line execute following formula:

Qualitative_risk = Qualitative_risk [Susceptibility,Vulnerability]

Have a good look at the resulting qualitative risk map.

☞

- Calculate the percentage of the area with high, moderate and low risk.

	Percentage of the area
High landslide risk	
Moderate landslide risk	
Low landslide risk	

For experienced ILWIS users

☞ **For experienced ILWIS users:**

Improve the vulnerability map

- This map can be improved by using another classification of the vulnerability components, for example by including also the the urban **landuse** as criteria in the analysis. Try to do this and see if it improves the result.

☞ **For experienced ILWIS users:**

Improve the susceptibility map

- You can also improve the method by using 4 hazard classes, including a very high hazard class that contains the recent landslides. Adapt the matrix so that it includes 4 classes of hazard and vulnerability.

Exercise 6E. Earthquake risk assessment estimation.

Expected time:	3 hours
Data:	data from subdirectory: RiskCity exercises/exercise06E/data
Objectives:	In this exercise we will demonstrate a method for the calculation of the range of buildings that might be collapsed or partially damaged by earthquakes under different earthquake intensity classes. We do this by making use of a vulnerability table, which gives a relation between earthquake intensity and degree of damage for a number of building types. We will not deal with the determination of the actual earthquake hazard, and calculate the degree of ground shaking under different earthquake scenarios and local soil conditions.

Input data

The following data are used in this exercise.

Name	Type	Meaning
Elements at risk		
Building_map_1998	Raster	Buildings of the city
Building_map_1998	table	Table containing information about: type, landuse, dimension of the building; number of people during day/night.
Mapping_units	Polygon and table	Polygon map of the mapping units (basic units for risk assessment), and associated table containing information on the number of buildings for different building types.
Earthquake data		
Damage	Script	Script file that will be used to calculate the earthquake loss for different scenarios
Other data		
High_res_image	Raster	High resolution image of the study area.

Depending upon the earthquake intensity and the building strength, a building may get damaged during an earthquake ranging from fine cracks in plaster to the total collapse of the building. Earthquake intensity is expressed in various scales. One the most used one is the Modified Mercalli Intensity (MMI), which gives pre-defined classes of earthquake effects on buildings, people and the environment, on a scale from I to XII (See also session 3E of the Guide book). Based on damage surveys carried out for historical earthquakes a relation has been established between MMI and the degree of damage to buildings. The degree of damage is related to the strength of a building, which again is related to the construction materials and construction types. We have a vulnerability table for the following building types (See also session 4 of the Guide book). The vulnerability table is shown on the next page.

- Adobe, Field Stone, Wood and other scrap materials (**AD**)
- Brick with Mud (**BM**)
- Brick with Cement (**BC**)
- Reinforced Concrete Frame with Masonry having three or less stories (**RCC3**)
- Reinforced Concrete Frame with Masonry having more than 3 stories (**RCC4**)

In the table, the vulnerability of the various types of buildings is expressed as the percentage of buildings that have collapsed or are partially damaged for different MMI classes and Peak Ground Acceleration (PGA) classes. The values in the table are given in percentages.

Building type: adobe + field stone masonry buildings (AD)

MMI	VI	VII	VIII	IX
PGA (%g)	5-10	10-20	20-35	>35
Buildings collapsed (%)	2-10	10-35	35-55	55-72
Buildings partially damaged (%)	5-15	15-35	35 - 45	45 - 28

Building type: brick in mud (BM)

MMI	VI	VII	VIII	IX
PGA (%g)	5-10	10-20	20-35	>35
Buildings collapsed (%)	0-6	6-21	21-41	41-61
Buildings partially damaged (%)	3-8	8-25	25-28	28 - 39

Building type: brick in cement (BC)

MMI	VI	VII	VIII	IX
PGA (%g)	5-10	10-20	20-35	>35
Buildings collapsed (%)	0-1	1-5	5-18	18-38
Buildings partially damaged (%)	0-11	1-31	31-45	45- 62

Building type: reinforced concrete with 3 or less floors (RCC3)

MMI	VI	VII	VIII	IX
PGA (%g)	5-10	10-20	20-35	>35
Buildings collapsed (%)	0-2	2-7	7-15	15-30
Buildings partially damaged (%)	0-4	4-14	14-30	30-60

Building type: reinforced concrete with 4 or more floors (RCC4)

MMI	VI	VII	VIII	IX
PGA (%g)	5-10	10-20	20-35	>35
Buildings collapsed (%)	0-2	2-8	8-19	19-35
Buildings partially damaged (%)	0-4	4-16	16-38	38-60

We will estimate the total number of buildings for each building type in the city and we will apply the vulnerability values for each intensity class. We will then also do the same at the level of the mapping units. Applying the vulnerability at individual building level is not correct. The values indicate the percentage of a group of buildings with the same characteristics that might collapse or be severely damaged. It doesn't indicate the percentage of each individual building. Therefore it can only be applied at an aggregated level, such as mapping units, or at the entire city level.

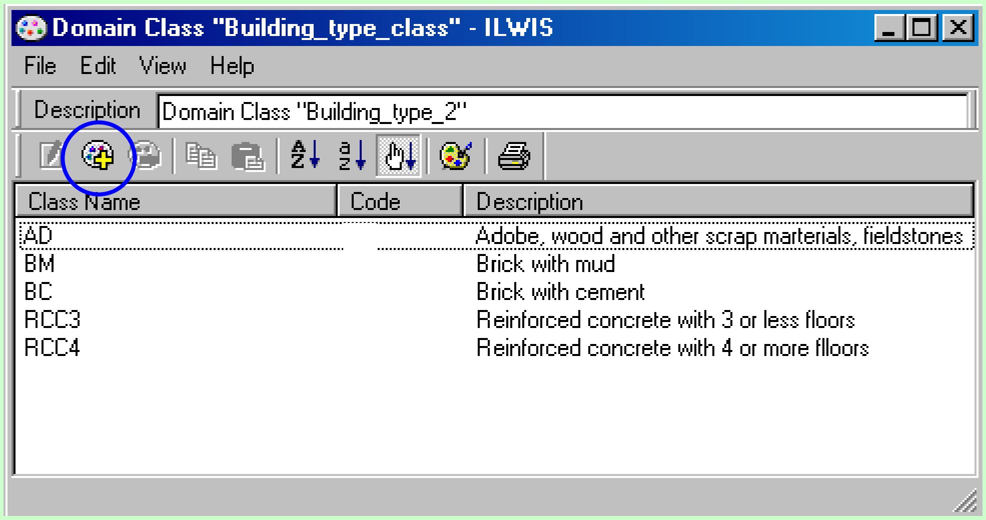
Estimating the number of buildings for each building type

We need to calculate the number of buildings of the different building types (AD, BM, BC, RCC3 and RCC4). In the table **Building_map_1998** we can observe that the buildings are originally divided into six classes: Adobe (AD), Brick in mud (BM), Brick in cement (BC), Fieldstone (FI), Reinforced concrete (RCC), and

Wood and other scrap materials (WO). First of all we need to reclassify them according to the building types described used in the table at page 6E-4. Basically we have to group the adobe, the field stone and the wood constructions into one class (AD) and we have to split the reinforced concrete buildings into two classes according to the number of floors (RCC3 and RCC4).

☞

- Open the domain **Building_type** and check the building types and their codes; they are the ones used in the table/map **Building_map_1998.**
- In order to reclassify the building types we need to create a new domain; go to *file / create / domain* and chose *class.* Call it **Building_type_class** and fill the domain window as it appears in the figure below. To add a new class, click the icon with the blue circle.



- Open the table **Building_map_1998.** create a new column using the following expression:

BT:= IFF((building_type="AD") or (building_type= "FI") or (building_type="WO"), "AD",IFF(building_type="BM", "BM", IFF(building_type="BC","BC", IFF((building_type="RCC") AND (Nr_floors <= 3), "RCC3","RCC4"))))

<u>IMPORTANT</u>: chose in the column properties window the domain **Building_type_class.**

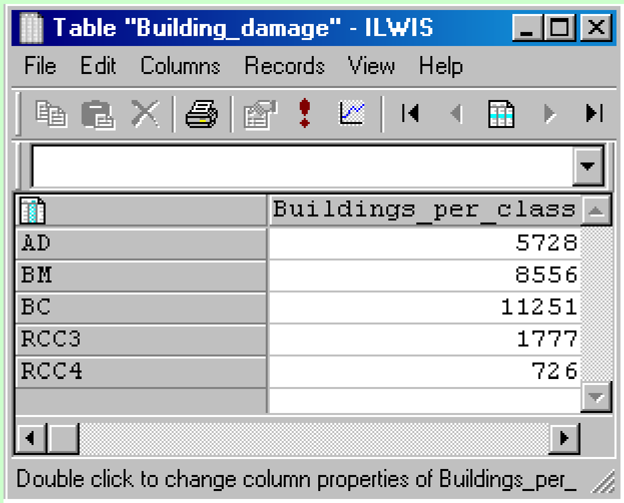
This formula contains 4 nested IFF statements. In the first IFF statement we group the 3 building types Adobe, Fieldstone and Wood together under the Class Adobe (as we don't have vulnerability values for the other two classes). If the building type is Brick in mud or Brick in cement, we leave it as it is. In the last IFF statement we divided the reinforced concrete buildings in those with less than 4 floor and more than 3 floors.

- Check the use of brackets in the formula. Can you explain why there are 4 closing brackets at the end?.

We created a column with the new classification of the building types. At this point we can calculate the number of buildings for each building class. Since we will deal with the total number of buildings and we will calculate quite some columns, we will make a new table and we call it **Building_type_class**.

☞

- Open the table **Building_map_1998** and create a new column with the number of buildings for each building class. Go to *columns / Aggregation* choose: *Column* : **BT**, *Function* : Count, and *Group by* **BT**. Output table: **Building_type_class**. Call the new column **Buildings_per_class**.
- Open the new table **Building_type_class**. At the end the table should appear as in the figure below.



	Buildings_per_class
AD	5728
BM	8556
BC	11251
RCC3	1777
RCC4	726

- What is the total number of buildings? Instead of doing the calculations manually, it is better to visualize the statistics pane; go to *View* and chose *Statistics Pane.*

Using vulnerability tables for the entire city

In the table shown above, the percentage of building-damage for different earthquake intensities (in MMI) and for five building types in the city is given. This data in this table were obtained from an NGO (NSET-Nepal). In the table two types of damage grades are given which were defined in the following way:

- Collapsed buildings
- Partly damaged buildings

Damage – intensity relationships for buildings are cannot be predicted very precise, because the amount of damage depends on many other factors (See session 4 of the Guide book). In the damage matrix table, the damage grades are not given with a single percentage value but as a range showing minimum and maximum percentages.
Regarding the procedure for applying the vulnerability curves to the RiskCity dataset, the following four types of columns for each earthquake intensity class (from VI to IX) will be created in GIS in order to calculate the number of vulnerable buildings:

- Partial damage min (Minimum probable number of buildings having partial damage)
- Partial damage max (Maximum probable number of buildings having partial damage)
- Collapse min (Minimum probable number of buildings having total damage)
- Collapse max (maximum probable number of buildings having total damage)

From the vulnerability table given above there are many different possibilities for combining the information: for different Intensities (VI, VII, VIII and IX) and for partial or complete collapse minimum and maximum values are given. We will only calculate here one scenario: minimum percentage of collapsed buildings in an earthquake with Intensity IX. The percentages related to the minimum buildings collapsed expected in this scenario are:

Building type	Min expected Buildings collapsed	(0 – 1)
AD	55%	0.55
BM	41%	0.41
BC	18%	0.18
RCC3	15%	0.15
RCC4	19%	0.19

(check these values by comparing them with those in the vulnerability table)

Now we can calculate the number of buildings collapsed for each of the building classes according to these percentages.

☞

- Open the **Building_type_class** table and add an empty column called **IX_collapse_min.** Assign it a value domain, *value range* between 0 and 1 and *precision* 0.01. Fill the new column with the correct values we extracted from the table, according to the building classes (Ex. AD = 0.55)
- Multiply the column **Buildings_per_class** by the column **IX_collapse_min** by typing in the column command line the following expression: **IX_tot_collapse_min:=Buildings_per_class * IX_collapse_min**
- Visualize the *Statistics Pane* and read in the sum row the total number of buildings collapsed for this scenario. How many building are expected to collapse? How many Adobe buildings? How many buildings in brick with mud
- Now do the same steps for MMI classes VI, VII and VIII and repeat them for the expected maximum number of building collapsed. Read the total values from the table and write them down. How many buildings might collapse in Intensities VI, VII, VIII and IX? Write the results in the table below.

	VI	VII	VIII	IX
Nr of Buildings Collapsed max / min				

Using a script for building loss estimation for mapping units

In the previous section we only calculated the maximum number of buildings that could be severely damaged for the entire study area.

However the risk assessment can also be done at a lower aggregation level. As mentioned before we cannot use the vulnerability values at the level of individual buildings. Therefore we will use the mapping units as the basic units for the risk assessment. We have already calculated the number of buildings in the 5 building types (AD, BM, BC, RCC3 and RCC4) per mapping unit.

☞

- Open the table **Mapping_units** and check the contents of the columns. What does **Nr_AD** mean?
- Display the map **Mapping_units** with the attribute: **Nr_AD**. Which pattern is visible?

To calculate the minimum and maximum number of buildings that might be severely or moderately damaged for all earthquake scenarios, would take a long time to do manually and can be better done in a script. We have prepared a script for that already. The script contains only two lines:

Script: Damage

```
Tabcalc Mapping_units %1_%2_%3:=(Nr_AD*%4)+(Nr_BM*%5)+(Nr_BC*%6)+(Nr_RCC3*%7)+(Nr_RCC4*%8)
%1%2%3:= MapAttribute(mapping_units,mapping_units.tbt.%1_%2_%3)
```

Parameters:

%1 = Intensity (VI, VII, VIII, IX)
%2 = Collapse or Partial
%3 = Max or Min
%4 = the value of damage for Adobe building (Nr_AD)
%5 = the value of damage for Brick in Mud buildings (Nr_BM)
%6 = the value of damage for Brick in Cement (Nr_BC)
%7 = the value of damage for RCC buildings with less than 4 stories (Nr_RCC3)
%8 = the value of damage for RCC buildings with more than 4 stories (NR_RCC4)
NOTE: you need a raster map of mapping units in order to run the second line of the script.

In the script, the eight required parameters are identified by the symbols %1 %2 … %8. The script function "tabcalc" is a function that creates a new table or a column in an existing table; in this case we will create a new column in the table **Mapping_units.** For more information on scripts check the ILWIS help and search for "script syntax". %1_%2_%3 indicates the name to be assigned to the new column. This is composed of the three first parameters %1 (intensity), %2 (Collapse or partial damage) and %3 (Max or Min). So in case you want to calculate the maximum number of partially destroyed buildings under Intensity VII, you have to use: VII Partial Max.
According to the input parameters that are provided by the user, the parameters %1, %2 etc. will be replaced with actual text. The first line in the script creates in the table **Mapping_units** the columns of the expected collapsed/damaged buildings for each class. The second line creates an attribute map from the columns created in the first line.

☞

- Use the script **Damage** and run it using the various parameters from the vulnerability table. For example:

Run damage VI collapse max 0.1 0.06 0.01 0.02 0.02

You can also create a script which serves as the input script for the script **Damage** and which will contain all scenarios.

We will concentrate on the calculation of the number of buildings that might be heavily damaged (collapse or unrepairable) under earthquake intensities VI , VII, VIII, and IX .

☞

- Create a script **Damage_input** and write the input for all scenarios in the following way:

Run damage VI collapse max 0.1 0.06 0.01 0.02 0.02
Run damage VI collapse min 0.02 0 0 0 0
Run Damage VII collapse max 0.35 0.21 0.05 0.08 0.07
Run damage VII collapse min 0.1 0.06 0.01 0.02 0.1
Etc.

- Run the script **Damage_input** by typing the following command on the command line:

  Run damage_input
- Display the results in a table below. Compare the results with those that you calculate for all buildings in the city?
- You can also display the resulting maps that were generated with the script Damage. Open for example the map IXcollapsemax, which is the "worst case scenario" for the city. Which areas have the highest losses?

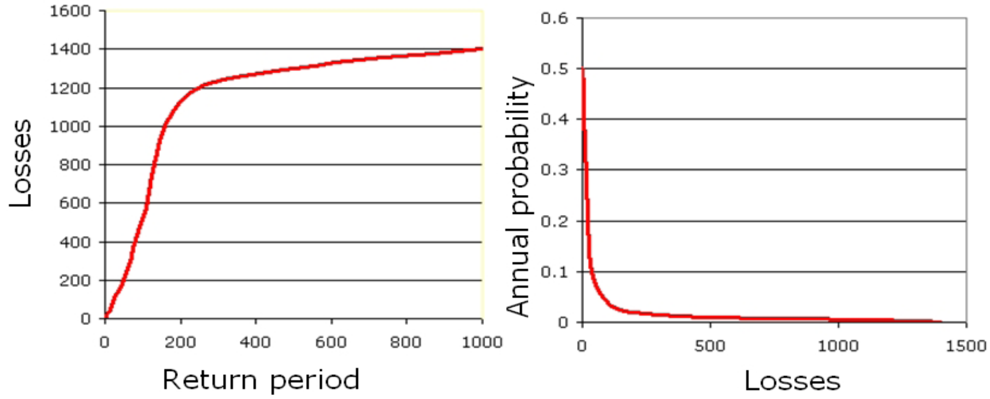
	VI	**VII**	**VIII**	**IX**
Collapse max				
Collapse min				

Generating risk curves

On the basis of studies on the earthquake catalog of the region and with the help of models for the calculation of earthquake attenuation, it has been determined that the various intensities occur with the following return periods:

	VI	**VII**	**VIII**	**IX**
Return period	10	25	50	100

The risk can 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). The left graph 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 calculate the Average Annual Losses (AAL). This is done by calculating the area under the curve (also Guide Book, session 6.5.5).



Two ways to represent a risk curve. Left: Plotting losses against return period. Right: plotting losses against annual probability.

☞

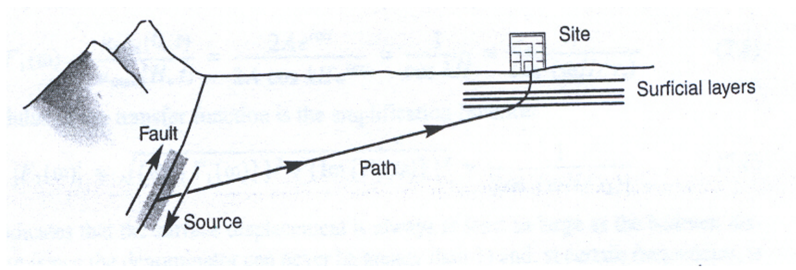
- Create the Risk curves, and plot the values for the 4 earthquake intensity scenarios in the graph. Do it for the minimum and maximum number of expected collapsed buildings.

☞ **Advanced Task**

- Up to now we calculated the estimated minimum and maximum number of collapsed buildings for each intensity scenario. Try to calculate by yourself the minimum and maximum number of expected partially damaged buildings.

Question:

We have now assumed that the entire city will have the same earthquake intensity under the same earthquake scenario, which is a particular earthquake with a certain magnitude occurring at a particular distance from the city. Is this a correct assumption? What should we have done to improve this result?



Exercise 6F: Flood Risk Assessment.

Expected time:	3 hours
Data:	data from subdirectory: Riskcity exercises/exercise06F/data
Objectives:	This exercise will demonstrate how to combine flood depth information, for example generated by a flood model, with building data, such a location, height and construction materials into a flood risk assessment. For three flood scenarios with different return periods (10, 50 and 100 years) the risk will be assessed. At the end of the exercise one should be able to understand and replicate the steps in the procedure.

Riskcity has experienced several severe flood events, which have caused damage. In order to evaluate the flood risk, flood depth maps have been generated with a hydraulic model for different return periods. Because of the limited amount of time, will only consider only three flood scenarios with return periods of 10, 50 and 100 years.

Figure Buildings in the confluence of the two rivers in RiskCity

Name	Type	Meaning
Flood data		
Flood_100y, Flood50y, Flood_10y	Raster map	Flood depth maps resulting from flood modeling study for scenarios with 100, 50 and 10 year return period.
Building data		
Building_map_1998	Raster map	Updated map of buildings for the situation after the disaster of 1998. For all buildings information is available on the urban landuse, number of floors, building area, and total floorspace.

PART 1

In this exercise we follow the quantitative risk assessment approach, which tries to quantify the risk according to the risk definition given in chapter 1 of the Guide Book. As explained in chapter 1 this equation has the basic form:

Risk = Hazard * Vulnerability * Amount of elements-at-risk

This equation is not only a conceptual one, but can 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). The equation can be modified in the following way:

$$R_S = P_T * P_L * V * A$$

in which:

P_T is the temporal (e.g. annual) probability of occurrence of a specific hazard scenario 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 given the local intensity caused due to the occurrence of the hazard scenario;
A is the quantification of the specific type of element at risk evaluated.

It is important here to indicate that the amount can be quantified in different ways, and that the way the amount is quantified also the risk is quantified. For instance the amount can be given in numbers, such as the number of buildings (the risk is then the number of buildings that might suffer damage), number of people (e.g. injuries/ casualties/affected), the number of pipeline breaks per kilometer network etc. The elements at risk can also be quantified in economic terms. It is then usually expressed as damage.
In order to be able to evaluate these components we need to have spatial information as all components 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 term (P_L) 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).

☞

- Open the raster map **Flood_100y** and add the raster map **building_map_1998.** Make this last map 50% transparent. Open the Pixel-Information window and explore the flooded areas and the water depths at these locations.
- Close the map window.

As you can see large parts of the center of the city are flooded, but also further North you will find buildings that are affected by the water. The water depths may reach up to 8 meters in certain locations!
In the following exercise we will analyse how many buildings are affected in the three flood scenarios.

☞

- Create a flood extent map by typing:

```
floodextent_010:=ifundef(flood_10y,0,1)
```

QUESTION 6F1:
What does this statement do?

- Look at the result.
- Cross the map **buildings_map_1998** with the map **floodextent_010** and create a cross-table **building_flooded_010**.
- Open the cross-table and add a column with the surface area of the houses. Do this using the join operator in the column menu. The surface area information can be found in the histogram **building_map_1998**, and add the column "area", but name it **area_building**.

QUESTION 6F2:
Why is this newly added column different from the existing column "**area"**?
Are the values different for all rows?

- Calculate the area percentage of the buildings affected by typing:

```
Perc_affected_010:= iff(floodexent_010=1,area/area_building,0)
```

- Calculate the number of buildings that are partially affected by the flood by typing:

```
partially_flooded_010 := iff(perc_affected_010>0,1,0)
```

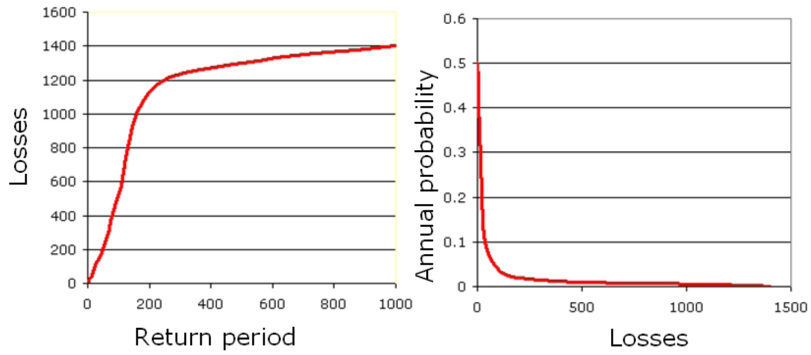
- And calculate the number of buildings that are completely flooded:

```
completely_flooded_010 = iff(perc_affected_010=1,1,0)
```

QUESTION 6F3:
How many houses are now completely flooded and how many partially? How many buildings are affected in total?

- Repeat this whole procedure for the other two flood maps (from the top of this box)
- Write down the number of buildings affected (total), and plot them in a risk graph See two examples below.

QUESTION 6F4
How is the risk quantified in this assessment?



Two ways to represent a risk curve. Left: Plotting losses against return period. Right: plotting losses against annual probability.

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 the graphs shown above 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). The left graph 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 calculate the Average Annual Losses (AAL). This is done by calculating the area under the curve (also Guide Book, session 6.5.5).

We will now add the calculated percentage of buildings affected to the table building_map_1998.

☞

- open the table: **Building_map_1998**
- **Join** to this table the table **buildings_flooded_010**, column **perc_affected_010**.
- Follow the steps through the join-wizard. Because the building_flooded_010 has more than one record for some buildings so you need to select an aggregation function.
- Select: MAXIMUM.

QUESTION 6F5:
Why are there more than one record for some buildings in the table **building_flooded_010**;
Why is the function "Maximum" the appropriate choice?

- Repeat this procedure (from the top of this box) for the other two flood scenarios (add columns **perc_affected_050** and **perc_affected_100** to the table **building_map_1998**)

PART 2

In the following part of this exercise we will make a link between the building properties (vulnerability of the elements-at-risk) and the characteristics of the hazard (in this case, flood depth). In order to do this we have to prepare the data to be able to make this link; The flood depth maps must be classified (sliced in ILWIS terminology) and the buildings must be characterized in a way that makes sense for flood risk. Based on experience of past flood events there are two major characteristics of buildings that define the vulnerability. These are: **construction material** and **number of floors.** We will create a new class based on a combination of these two parameters and we will link these with the classified flood depth maps.

☞

We will classify the three flood depth maps (flood_10y, flood_50y and flood_100y.

- Create a group domain **Flooddepth** and insert the following class-boundaries:

Upper Boundary	Class Name	Code
0.5	< 0.5 m	1
1	0.5 – 1.0 m	2
3	1.0 – 3.0 m	3
6	3.0 – 6.0 m	4
99	> 6 m	5

- Slice the three flood depth maps and name the: flood_010_cla, flood_050_cla and flood_100_cla.

Now we prepare the building characteristics. Step 1 is to create a domain with the three main types of building materials:

- Create a class domain **building_mat** and insert the following three classes:

Class name	Code
Adobe and wood	a
Brick	b
Concrete	c

- Right-click on the domain **landuse** and select “create table”. Name it **building_mat**
- Open the table **building_mat** and add a column **building_mat** and give it the domain **building_mat**
- Fill in the table as shown in the figure below.

	build_mat
Com_business	concrete
Com_hotel	concrete
Com_market	concrete
Com_shop	concrete
Ind_hazardous	concrete
Ind_industries	concrete
Ind_warehouse	concrete
Ins_fire	concrete
Ins_hospital	concrete
Ins_office	concrete
Ins_police	concrete
Ins_school	concrete
Pub_cemetery	brick
Pub_cultural	brick
Pub_electricity	concrete
Pub_religious	brick
Rec_flat_area	brick
Rec_park	brick
Rec_stadium	concrete
Res_large	concrete
Res_mod_single	brick
Res_multi	concrete
Res_small_singl	brick
Res_squatter	adobe and wood
River	adobe and wood
unknown	adobe and wood
Vac_car	brick
Vac_constructio	adobe and wood
vac_damaged	adobe and wood
Vac_shrubs	adobe and wood

Step 2 is to reclassify the building according to their number of floors. This was already done in the table building_map_1998, but this classification does not suit our purpose. We want to have the houses classified in three classes: 1 floor buildings, 2 floors and n floors. We do this because the floods usually affect the first (ground) floor, sometimes the second floor and only in exceptional cases it reaches the higher floors.

☞

- Create a group domain **Nr_floors** and insert the following classes:

Upper Boudary	Class name	Code
1.5	1 floor	1
2.5	2 floors	2
99	>2 floors	n

- Open the table **building_map_1998**
- In order to reclassify the number of floors type the following in the table command line:

```
Nr_floors_flood := CLFY(nr_floors,Nr_floors)
```

- Now we want to add the construction material to the table. We do this using the join option in the column menu.
- Select the table **Building_mat**, column **Building_mat** and go through the join-wizard accepting all defaults.

In the following step we will merge the building material with the number of floors so we have characterized the buildings as a function of these two parameters.

- Type the following instruction in the table command line:

```
Build_type:=code(building_mat)+code(nr_floors_flood)
```

A new column is added to the table with 9 codes: a1, a2, an, b1, b2, bn, c1, c2 and cn.

QUESTION 6F6:
What do these codes mean?

a1 =

a2 =

an =

b1 =

b2 =

bn =

c1 =

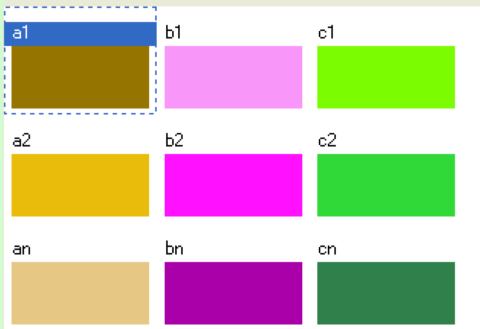
c2 =

cn =

The domain of these codes is “string” (check this!).

- Double-click on the column header and select the option “**create domain from strings in column**”. Domain name is **Build_type**
- Close the table.

- Adjust the representation of build_type to the following colour scheme:



- Create an attribute map **build_type** from the raster map **building_map_1998** (select column **build_type**) and have a look at the resulting map.

We have now almost all the required data for the flood risk assessment: We have a map with a characterization of the buildings (**build_type**) and we have three maps for different flood hazard scenarios (**flood_010_cla**, **flood_050_cla** and **flood_100_cla**). The only thing lacking are the vulnerability curves like the ones you created in exercise 5a. In the following, final part of this exercise we will create a 2-dimensional table in which we insert the flood vulnerability curves for each of the 9 buildings types. With this table we will obtain the damage fraction to the buildings caused by the flood.

- Create a new 2-dimensional table. Give it the name **flood_vuln;** Primary domain = **build_type,** secondary domain = **Flooddepth.** The value range is: 0 to 1 and precision is 0.01
- Fill in the table as shown in the figure below.
- Close the table

2-Dimensional Table "flood_vuln" - ILWIS

File Edit View Help

	0 - 0.5 m	0.5 - 1.0 m	1.0 - 3.0 m	3.0 - 6.0 m	> 6 m
a1	0.40	0.70	1.00	1.00	1.00
a2	0.30	0.50	0.80	1.00	1.00
an	0.20	0.40	0.70	0.90	1.00
b1	0.20	0.30	0.70	1.00	1.00
b2	0.10	0.25	0.60	0.80	1.00
bn	0.10	0.20	0.50	0.70	0.90
c1	0.20	0.30	0.50	0.80	0.80
c2	0.15	0.20	0.40	0.70	0.80
cn	0.10	0.15	0.30	0.50	0.70

☞

QUESTION 6F7:
The 2 dimensional table represents 9 vulnerability curves. Please draw the 9 curves in this space:

The 2-dimensional table is used to integrate the data from two different maps into one output map. We will compare the depth map with building type map and for each pixel the corresponding output value is read from the table, e.g. build_type = c2 and flood depth = 1.0 – 3.0 m, then the vulnerability value = 0.40.

☞

- To use the 2-dimensional table, type the following statement in the command line of the ILWIS catalogue window:

```
build_damage_010:=flood_vuln[build_type,flood_010_cla]
```

Question 6F8:
What does the output map represent?

- Repeat the use of the 2-dimensional table for the other two flood scenarios.

Now the vulnerability maps are finished. However, it is useful to be able to represent this map as an attribute map to the map **building_map_1998**. To do that we first cross the **build_damage** maps with the **building_map_1998** and then we join the resulting table to the table **building_map_1998**.

☞

- Cross the **building_map_1998** with the **build_damage_010** map and name the output table: **build_1998_damage_010.**
- Open the table **building_map_1998** and join it with the new table **build_1998_damage_010;** select column **build_damage_010.**
- Go through the join-wizard accepting the defaults but at the last window select as aggregation function **“maximum”** (There are some buildings that fall in two damage classes, and we select the worst case option).

- Repeat this procedure for the other two flood scenarios.

Now the building damage for each flood scenario is added to the building_map_1998 table. If we now would know the value of each building, the total damage of each flood scenario can be calculated and a risk curve can be constructed. This will be done in a later exercise.

To be delivered:
The three build_damage_xxx maps (screen-dumps or exported as bitmaps).

Exercise 06L: Landslide risk assesment

Expected time:	3 hours
Data:	data from subdirectory: Riskcity exercise/exercise06L/data
Objectives:	This exercise shows you a semi-quantitative method for landslide risk assessment, and intends to use landslides from different periods to calculate the temporal probability and convert susceptibility maps to hazard maps. These are then combined with elements at risk information to derive at risk maps.

Input data

In this exercise we will use the landslide **Susceptibility_map** that was generated using a statistical method in exercise 3.L. For the elements at risk we will use a map called **Building_map_1998** with the individual buildings and their characteristics. The map **Landslide_ID** is also required in order to convert the susceptibility map into a hazard map, by including the temporal landslide information.

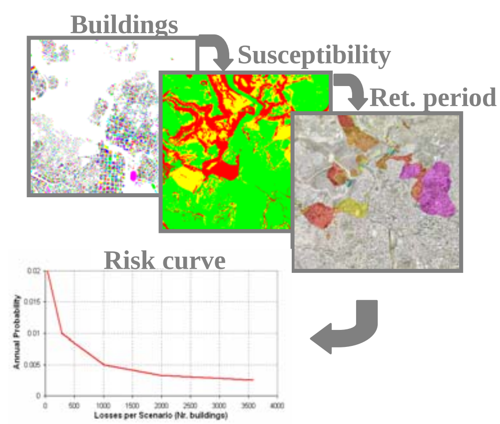
Name	Type	Meaning
Elements at risk		
Building_map_1998	Raster	Map showing individual buildings.
Building_map_1998	Table	Table showing buildings characteristics: landuse, nr of floors, building type, area building, floor space (persons per day, persons per night, size class – not used in this exercise).
Landslide data		
Landslide_ID	Raster	Points within each of the interpreted landslides with associated attribute table
Landslide_ID	Table	Attribute table with information on the landslides in the area.
Susceptibility	Raster	Landslide susceptibility map made using a statistical method.
Other data		
High_res_image	Raster	High resolution image of the study area.

- **General Risk formula:**

Risk =H*V*A
H= Hazard
V= Vulnerability
A= Amount of Elements at risk

- **Landslide Risk Formula:**

Risk = P_T*P_S*V*A
P_T=Temporal Probability
P_S=Spatial Probability
V= Vulnerability
A= Amount of Elements at risk



The first formula in the box on the left expresses the general risk related to a natural (or man induced) hazard. The first term "Hazard" expresses the temporal occurrence probability of the hazardous event. When we can exactly define the spatial occurrence of the hazard, H expresses the temporal probability (annual probability/return period) only. This is the case for flood hazard where a particular site is known to be flooded based on the results of a flood modeling study. A certain element at risk is in the hazard zone or not; therefore the spatial probability is equal to 1. For other hazards, like landslides (or forest fires), we don't know exactly where the hazardous event will occur; therefore we need to introduce in the equation the spatial probability. In this case, the formula has to include the spatial and temporal probability as indicated in the second formula in the left box. For a more in depth discussion see chapter 6 of the guidebook.

For this exercise, the spatial probability is calculated from the **Susceptibility map**, while the information about the return periods for the surveyed landslides provides the temporal probability. This information is stored in the **Landslide_ID map**. In the first part of the exercise we will follow a semi-quantitative approach for landslide risk assessment. This focuses on the "Amount" part of the formula. We combine the susceptibility zones with the different building types, and calculate the number of houses and people in High, Moderate and Low susceptibility zones.

The second part then continues with a quantitative approach for landslide risk assessment. We will combine the susceptibility with the information related to the return period of the surveyed landslides, in order to calculate the temporal probability. Moreover vulnerability values will be estimated according to the building type and the floor space. Vulnerability should be dependant on the characteristics of the elements at risk and on the hazard characteristics. In other words, a building is more or less vulnerable according to its material and its structure, and depending on the type and dimension of the landslide. Here, only the characteristics of the elements at risk are considered, due to the complexity of the vulnerability evaluation. We will than plot the Temporal Probability (**P_T**) against the spatial probability multiplied with the losses (**P_S*V*A).**

Calculate the number of buildings in high, moderate and low landslide susceptibility classes

The first step is to calculate the amount of buildings present in each of the three susceptibility classes (Low, Moderate, and High). We will calculate the amount of buildings per each susceptibility class according to the building types.

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- Select *Operations / Raster Operations / Cross*. Cross the raster map **Building_map_1998** with the raster map **Susceptibility***.* Call the cross table **Building_susceptibility.**
- Open the new table and check the content; you should see 4 columns, what does the column "**Area**" represent? In the column **Building_map_1998** we can observe that some buildings have more than one column; why?
- Identify which is the predominant susceptibility class for each building; go to *columns / aggregation* and chose *column*: **Susceptibility**; *function*: predominant; *group by*: **Building_map_1998**; *weight*: **Area**. Call the new column: **Susceptibility_per_building**. What does this operation calculate?
- Open the table **Building_map_1998** and join the column we created. Go to *Columns / Join*; chose the table **Building_susceptibility** and the column **Susceptibility_per_building**; call the new column **Susceptibility.**
- To calculate the amount of buildings with different building types in each class we need a further operation. In the command line of the table **Building_map_1998** type the following line:

  combine = code(building_type)+ "_" +code(susceptibility)

  IMPORTANT: this command creates a column with a combination of the code of the domain **Building_type** and the code of the domain **Susceptibility**. Carefully check that both the two domains contain a code for each class; otherwise add them (In the susceptibility domain add the following codes if not present; High class: **H**; Moderate class: **M**: Low class: **L**). Check the column **Combine**. What do the acronyms stand for?

- We want to store the results in a separate table. In the table **Building_map_1998** select the column **Combine** and right click on its header; open the option *properties* and chose *create domain from string of column.* Call the new domain **Buildtype_susceptibility.** In the main window right click on the new domain and chose Create table. Call the new table **Buildtype_susceptibility.** In the table **Building_map_1998** go to *Columns / Aggregation* and chose *column*: **Combine**; *function:* count; *group by:* **Combine**; store the new column in the output table **Buildtype_susceptibility** and call the column **Nr_buildings**. This new column shows the number of buildings for each susceptibility class according to their type.

Fill the table below with the results stored in the table **Buildtype_susceptibility**. You can create your own table in Excel and calculate all the required values.

		Susceptibility classes						
		Low	% of building type	Mod	% of building type	High	% of building type	**Total per type**
Building Types	Adobe	1288	45%	1187	41%	410	14%	**2885**
	Wood and others							
	Fieldstone							
	Brick with mud							
	Brick with cement							
	Reinforced concrete							
	Total per class	**19717**						**28038**
	Perc. of total	**70%**						

Once the table is filled you can explore the distribution of the buildings among the three susceptibility classes for each building type. Please answer the following questions.

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- Within the "brick with cement" type, how are the buildings distributed among the susceptibility classes? Give the percentages.

  Low _____ Moderate _____ High_____

  Within the "wood and other scrap materials" type, how are the buildings distributed among the susceptibility classes? Give the percentages

  Low _____ Moderate _____ High_____

  Comment the two different patterns and try to give your own explanation to justify the differences.

- For each of the susceptibility classes, extract the building type with the highest percentage; try to find out what is the most common landuse for the chosen building types (go to building_map_1998 and sort it by building_type).

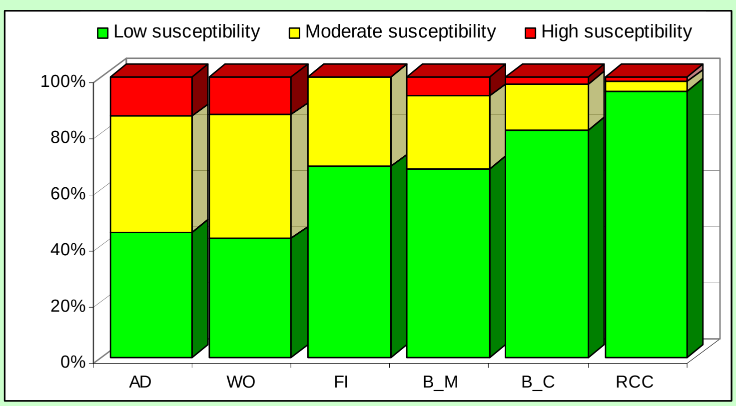
  Low: __________ Landuse: _______________

  Moderate: __________ Landuse: _______________

  High: __________ Landuse: _______________

  Why are those landuse classes predominant in those susceptibility classes?

- Try to show the results stored in the above table through a cumulative histogram in Excel and comment it. Check the example below.



We can also display the results in a map that shows the susceptibility class of each building.

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- Create an attribute map from the **Building_map_1998** using the column **Susceptibility**; call the new map **Building_susceptibility**; in the main ILWIS menu, go to *Operations / Raster operations / Attribute map*; chose *Raster map*: **Building_map_1998**; *Table*: **Building_map_199**8; *Column*: **Susceptibility**.

This output can be a good example of a simple landslides risk map used by local authorities to inform the population.

Quantitative calculation of annual risk and generation of a risk curve for landslides.

Up to now we calculated only the number of buildings in the different susceptibility classes. Referring to the general Risk formula, the number of buildings represents the Amount (A). Now we have to extract the Hazard (H) and the Vulnerability (V) to be able to calculate the Risk.

1. How much percentage of the high, moderate and low hazard classes may be affected by landsides?
2. In which period will these landslides occur?
3. What is the vulnerability to landslides for each building type?

From susceptibility to hazard

As we stated in the introduction of the exercise, in landslide risk assessment the Hazard occurrence probability is expressed by the Spatial and the Temporal probability. Therefore in the general formula:

Risk = Hazard * Vulnerability * Amount

The hazard is expressed as follows:

Hazard = Temporal probability * Spatial probability

In order to calculate the hazard probability, we need to have both the components:

- The **temporal probability** that landslides may occur due to a triggering event. Here we will link the return period of the triggering event with the landslides that are caused by it. We have differentiated return periods of: 50, 100, 200, 300 and 400 years. The required data are stored in the **Landslide_ID** map.
- The **spatial probability** that a particular area would be affected by landslides of the given temporal probability. This is calculated as the landslide density within the landslide susceptibility class.

If the indication of the high, moderate and low areas susceptibility is correct, different landslide events with different return periods will give different distributions of landslides in these classes. The probability can be estimated by multiplying the temporal probability (1/return period for annual probability) with the spatial probability (= what is the chance that a building is affected).

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- Make an attribute map of the column **ReturnPeriod** of table **Landslide_ID** using the map **Landslide_ID**. Name the map: **Landslide_RP**
- Check the contents of the maps **Landslide_RP** and **Susceptibility.**
- Cross the map **Susceptibility** with the map **Landslide_RP.** Go to *Raster Operations / Cross;* Select the option *do not ignore undefined values*. Create the output table: **Hazard_RP**.
- Calculate the area of each hazard class (use aggregation function) and write it in an Excel file with the same structure as the table below. Open the table **Hazard_RP**, go to *column, aggregation*, and select the column **area** and the function **sum**. Group by **Susceptibilty**. Call the output column **class_area**.
- In the table **Hazard_RP**, type the following formulas:

  Area_low:=iff(susceptibility="low",area,0)

  Area_moderate:=iff(susceptibility="moderate",area,0)

  Area_high:=iff(susceptibility="high",area,0)
- Go to *column, aggregation*, and select the column **area_low**, the function **sum,** group by **Landslide_RP**, store the result in the table **Landslide_probability** and call the new column **Landslide_area_low**. Do the same for the field **area_high** and **area_moderate** and store the result in the table **Landslide_probability.**

The hazard is calculated as the multiplication of temporal probability and spatial probability. So this is the annual probability that a given location (building) will be hit by a landslide within a certain hazard class. The required data are stored in the tables **Hazard_RP** and **Landslide_probability**. Follow the instructions below to fill the table as in the lines already completed. It is suggested to build the table in an Excel sheet to simplify the calculations. Use scientific annotation with 3 decimals.

Hazard		**1/50**	**1/100**	**1/200**	**1/300**	**1/400**
High	Landslide area	4.658E+04	3.759E+05	2.319E+05	1.910E+05	1.078E+05
	Cumulative landslide area	4.658E+04	4.225E+05	6.543E+05	8.453E+05	9.531E+05
	Class area	2.567E+06	2.567E+06	2.567E+06	2.567E+06	2.567E+06
	Spatial probability P_S (density)	1.815E-02				
	Temporal Probability P_T	2.000E-02				
	Hazard: P_T*P_S	3.620E-04				
Moderate	Landslide area	4.000E+00				
	Cumulative landslide area	4.000E+00				
	Class area	3.049E+06				
	Spatial probability P_S (density)	1.300E-06				
	Temporal Probability	2.000E-02				
	Hazard: P_T*P_S	2.600E-08				
Low	Landslide area	5.000E+00				
	Cumulative landslide area	5.000E+00				
	Class area	8.384E+06				
	Spatial probability P_S (density)	5.960E-07				
	Temporal Probability	2.000E-02				
	Hazard: P_T*P_S	1.190E-08				

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- Fill the table with the data calculated. The columns **Landslide_area_low**, **Landslide_area_moderate**, **Landslide_area_high**, in the table **Landslide_probability** provide the values of the *landslide area* in each susceptibility class. The values of the *class area* are stored in the table **Hazard_RP**, column **Class_area**.
- Calculate the cumulative landslide area (see example in the table) as the **assumption is that events with a larger return period will also trigger those landslides that would be triggered by events from smaller return periods.**
- The spatial probability is expressed as the density of the landslides in the susceptibility class: therefore it is given by the formula (in the Excel sheet):

  Spatial_probability = Cumulative_landslide_area / Class_area

- Now calculate the temporal probability per hazard class and per return period, and write the results in the table. Temporal probability = annual probability = 1/ return period.
- Calculate the hazard per hazard class and per return period, and write the results in the table: $H = P_T * P_S$

The temporal and spatial probabilities express the chance of occurrence of a landslide at each location. The first step in the loss estimation will be calculation of the **amount of losses for each scenario** (return period). To do this we will use only the information related to the spatial probability. The temporal probability will be introduced later when the annual risk will be calculated in the risk curve.

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- Right click on the domain Susceptibility and create a table **Spatial_probability**. Create five columns as indicated below. Use value range from 0 to 1, and a precision of 0.000000001 with 9 decimals. Fill the table below with the values of the spatial probability.
- Which hazard class has the highest spatial probability values? Is it the expected result?
- Try to explain why this class has the highest spatial probability of occurrence (Suggestion: explore together the **Susceptibility** map and the **Landslide_RP** map; think about how the susceptibility map was created).

		Spatial probability				
		Spat_prob_50y	**Spat_prob_100y**	**Spat_prob_200y**	**Spat_prob_300y**	**Spat_prob_400y**
Hazard Classes	**HIGH**	1.815E-02				
	MOD	1.300E-06				
	LOW	5.960E-07				

Estimating Vulnerability

Estimating landslide vulnerability is very complex. It requires knowledge on the building types and on the expected landslide volumes and velocities. These are difficult to estimate. Therefore, in many studies landslide vulnerability of buildings is simply taken as 1, assuming complete destruction of the elements at risk. In this case we don't have enough information about the landslides parameters (type, velocity, volume etc.). Therefore we will make use of a vulnerability scale based only on the building characteristics: type of construction and dimension of the building.

Of course one can debate the correctness of this. It is also possible to take into account the landslide volumes from the landslide map as indication of the possible landslide magnitudes, but that would make the exercise too complicated. Therefore we will limit the vulnerability assessment to the building characteristics mentioned above. The vulnerability calculation is carried out by expert engineers on the basis of physical studies on buildings behavior and on historic data related to damages caused by landslides. In the table below the damage percentages are given as function of the building type and building size.

VULNERABILITY

Building type: Adobe

Very small	Small	Medium	Large	Very large
1.00	1.00	1.00	1.00	1.00

Building type: Wood and other poor materials

Very small	Small	Medium	Large	Very large
1.00	1.00	1.00	0.90	0.80

Building type: Fieldstone

Very small	Small	Medium	Large	Very large
1.00	1.00	1.00	0.90	0.90

Building type: Brick with mud

Very small	Small	Medium	Large	Very large
1.00	1.00	0.90	0.80	0.70

Building type: Brick with cement

Very small	Small	Medium	Large	Very large
1.00	0.90	0.80	0.60	0.50

Building type: Reinforced concrete

Very small	Small	Medium	Large	Very large
0.60	0.50	0.40	0.35	0.30

The strength of a building is supposed to depend not only on its area but also on the number of floors: a building in brick with cement with 3 floors has a stronger structure than a 1 storey building with the same characteristics. Therefore, the buildings have to be classified in relation to their construction types and their dimension. We already have the building type classification but we need to classify them according to their dimension. We will define five classes (very small, small, medium, large, and very large). To define the boundaries of the five dimension classes (from *very small* to *very large*) we will use the overall building floorspace (area * Nr floors).

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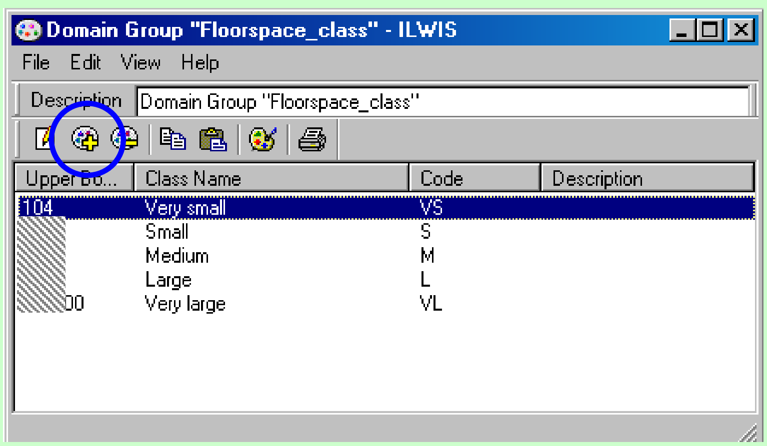
- Create an attribute map from **Building_map_1998** using the column **Floorspace** and call it **Floorspace_map.** Build the histogram of the map: right-click on the map go to *Statistics / Histogram.*
- Open the histogram and study it. What is the meaning of the columns **Value, Npixpct** and **Npixcum**?
- In order to define the boundaries of the floor space classes we will create a column with the cumulative percentage of the floor space. Visualize the command line in the histogram (if not already visible: select *View / Command line*). Type the following command:

  perc_cum = npixcum/3154801*100

  What does the large number refer to?
- We can divide the floor space into five classes according to their cumulative percentages. Fill the table with the correct values.

Class name	Cum. percentage	Floor space value (upper boundary)
Very small	20%	104
Small	40%	
Medium	60%	
Large	80%	
Very large	100%	

- Create a new domain, in the main IWIS menu go to *File / Create / Domain*; chose *Class / Group* and call it **Floorspace_class**. Fill the window using the values store in the table above as shown in the figure below; to add a new class in the domain, click the icon with the blue circle.



- Open the **Building_map_1998** table and type the following command in the command line:

  Floorspace_class = clfy(Floorspace, Floorspace_class)

  What does the function **clfy** calculate? What does the new column contain?

We created a classification for the floor space; now we cal apply the vulnerability values. To do this we have to create a 2D table where to store those values.

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- In the main ILWIS menu, go to *File / Create / 2D Table* and choose *as Table Name:* **Vulnerability_building** *Primary domain*: **Building_type** and *Secondary domain*: **Floorspace_class;** *Minimum*: 0; *Maximum*: 1 and *Precision*: 0.1. Open the table and fill it with the values reported in the vulnerability table shown above.
- Open the table **Building_map_1998** and type the following command in the command line:

  Vulnerability_building = vulnerability_building[Building_type, Floorspace_class]

- Check the content of the new column and explain the performed operation.

We just created a column with the vulnerability value for each building

Estimating losses and generating the Risk Curve

Now that we have calculated all components of the landslide risk we can start to calculate the risk itself. The calculation will be done in the table **Building_map_1998**. We will calculate the losses for the 50 year return period scenario. The first step is to assign the correct spatial probability (**P_S**) to each building based on its susceptibility class. We need the **P_S** values for the 50 years scenario stored in the table **Spatial Probability** we filled before in this exercise. (High: 0.01815; Moderate: 0.0000013; Low: 0.000000596, the values can be slightly different if you have used other precisions)

IMPORTANT!

We are dealing with very small numbers. When you create a new column, remember to set the precision to 9 decimal numbers and the number of decimals to 9 in the table properties window; otherwise you will run into calculation errors.

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- In the table **Building_map_1998**, join with the table **Spatial_probability** and read in the following column: **Spat_prob_50y**. Use value range from 0 to 1, and a precision of 0.000000001 with 9 decimals.
- To extract the total losses for the 50 years return period scenario, we have to multiply the spatial probability by the vulnerability for each building and sum up the losses.
- Multiply the two columns through the command:

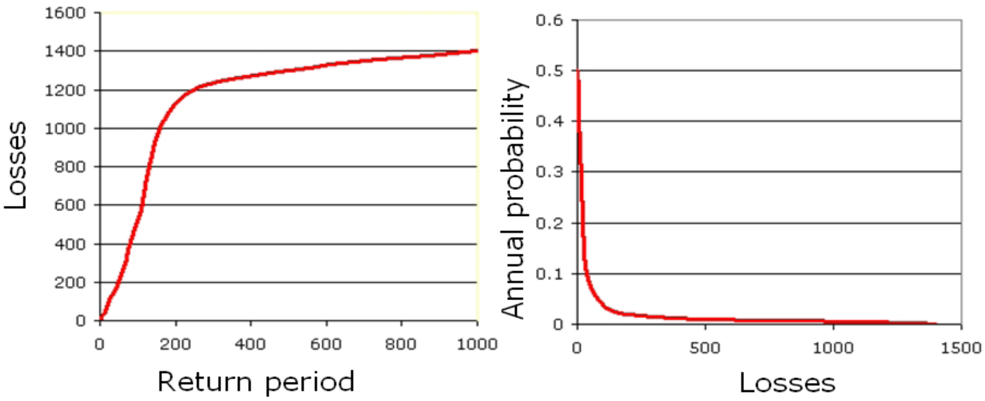
  Losses_50y:= Spat_prob_50y*vulnerability_building

- Show the statistic pane in the table and read the sum of the new column. <u>It represents the total losses for the 50 years return period scenario!</u>
- Apply the same methodology to the 100, 200, 300, 400 years return periods scenarios and calculate the total losses for each of them.
- In the calculations above we apparently don't take into account the **Amount** any more. Can you explain why there is no need here to use the amount of buildings calculated in the first part of the exercise? In which units are the losses indicated here?

We store the results in the table below for each of the scenarios (create your own table in the same Excel sheet).

Return Period	Temporal probability	Losses	Specific risk
50	0.02	31	0.62
100	0.01		
200	0.005		
300	0.00333		
400	0.0025		
Total risk (buildings)			

The risk can 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). The left graph 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 calculate the Average Annual Losses (AAL). This is done by calculating the area under the curve (also Guide Book, session 6.5.5).



Two ways to represent a risk curve. Left: Plotting losses against return period. Right: plotting losses against annual probability.

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- Create the Risk curves, and plot the values for the 5 return period scenarios in the graph. Display the risk curve in the two ways shown in the figure. Store it in the same Excel sheet and compare your results with the ones in Blackboard.

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- How to evaluate this risk? Is it high? How would it compare with other hazard types?
- Display the results also in the map by showing the attribute **Losses_50y** with the map Building_map_1998. Where are the zones with the highest individual risk levels?

Conclusion: if you look at the formula Risk = PT*PS*V*A, and if we want to calculate the losses for individual buildings, it becomes clear that the spatial probability that a landslide will occur at the location of a building is the most crucial aspect. This value was derived from landslide density within the susceptibility classes. So the better one can define the susceptibility classes, the higher the success rate will be and the higher the spatial probabilities will be.

Exercise 6M. Quantitative multi-hazard risk assessment, using risk curves

Expected time:	3 hours
Data:	data from subdirectory: RiskCity exercises/exercise06M/data
Objectives:	In this exercise we would like to calculate the risk for different hazard types and different return periods in a quantitative manner, using risk curves. The annual probabilities and associated losses are compared for the types of hazards and combined in an overall risk curve. We will also convert the risk information from number of buildings to monetary values.

In the previous exercises of this session you had the option to work out the quantitative risk analysis for one of the following hazard types: flooding, landslides, earthquakes, and technological hazards. In this exercise we will look at the results of these exercises and calculate Loss Exceedance Curves (LEC) for each type. We will then compare the results from the different types of hazards.
The data for this exercise is stored in a number of tables that can be linked to the polygon map of the mapping units. Below the tables, and their columns are listed, with an indication of their meaning.

Table	Column	Meaning
Flood_risk_buildings	Losses_10y	# of buildings affected by a flood with a return period of 10 years
	Losses_50y	# of buildings affected by a flood with a return period of 50 years
	Losses_100y	# of buildings affected by a flood with a return period of 100 years
Landslide_risk_buildings	Losses_50y	# of buildings damaged with 50 year return period event
	Losses_100y	# of buildings damaged with 100 year return period event
	Losses_200y	# of buildings damaged with 200 year return period event
	Losses_300y	# of buildings damaged with 300 year return period event
	Losses_400y	# of buildings damaged with 400 year return period event
Seismic_risk_ buildings	VI_collapse_max	# buildings collapsed in zone with intensity VI
	VII_collapse_max	# buildings collapsed in zone with intensity VII
	VIII_collapse_max	# buildings collapsed in zone with intensity VIII
	IX_collapse_max	# buildings collapsed in zone with intensity IX
Technological_risk buildings	Losses_sc1	# of buildings in area affected by "pool fire"
	Losses_sc2	# of buildings in area affected by "fireball" (BLEVE)

Risk assessment with GIS will be done on the basis of the following basic equation:
Risk = Hazard * Vulnerability * Amount of elements at risk

In this exercise we will first concentrate on the buildings, and later on convert the information on building losses to economic losses, only looking at the direct costs of the buildings. We will finally also consider the population affected in a daytime scenario, or in a nighttime scenario.

We will follow a number of steps:

- First we will generate different types of risk curves for building losses for the four different hazard types.
- Then we will convert the building losses into economic losses taking into account replacement costs of the buildings and the building contents. We will also make risk curves out of this.
- Finally we will look at the affected population in a daytime and nighttime scenario and make risk curves for theses.

As explained in session 1 and session 6 of the Guide book the equation for quantitative risk assessment has the basic form:

Risk = Hazard * Vulnerability * Amount of elements-at-risk

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). In order to calculate the specific risk the equation can be modified in the following way:

$$R_S = P_T * P_L * V * A$$

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.

Step 1: Checking building loss information for different hazard types.

In the previous exercises on risk assessment we have estimated the losses for different scenarios (return periods) for flooding, earthquakes, landslides and technological hazards. The table on the next page gives a summary of the components that were used to estimate the building losses. We will use the results from these exercises, but now in an aggregated manner: per mapping unit. Most of the exercises on risk assessment used the individual buildings to make a loss estimation, basically because the vulnerability curves that were used depended on the specific characteristics of the buildings (building type, number of floors, floorspace) and the specific hazard characteristics (waterdepth, distance from the explosion, Peak Ground acceleration(PGA), Modified Mercalli Intensity(MMI)). However, we do not want to express the risk for individual buildings because:

- We don't know enough of the characteristics of each individual building (maintenance, construction followed the codes, symmetry of the building, self constructed/contracted) which are very important to estimate the behavior of each individual building under a hazard.

- The hazard information is not so detailed that we can indicate it for every individual building.
- Presenting risk information at building level will cause problems related to privacy, and to lawsuits of individual building owners, as it will effect real estate values.
- Local authorities should take their decisions not on the basis of individual buildings but on larger aggregations.

Therefore the building loss information is aggregated to mapping units, which are more or less homogenous units in terms of urban land use and building types, and which are containing tens to hundred buildings. The boundaries of the mapping units are mostly the streets.

Table: Different steps used in calculated the risk for individual hazard types.

	Temporal Probability **P_T**	Spatial Probability **P_L**	Vulnerability **V**	Amount **A**
Flooding	10, 50 and 100 years floods	Considered as 1, because the area flooded was derived from the flood modeling results	Vulnerability curves were used that related **flood depth** with damage for building with different types, number of floors and area	GIS overlay of flood model outputs with building map.
Landslides	50, 100, 200, 300 and 400 year landslide events	Calculated by making landslide density calculations of landslides with different return periods in high, moderate and low susceptibility zones.	Vulnerability table that did not consider landslide magnitude, but only building type and floorspace	GIS overlay of landslide susceptibility classes with building map
Earthquakes	We used different MMI classes and assumed they were related with RP's:	Considered as 1, because the buildings are located in a particular MMI class.	Vulnerability table that considered relation **MMI / PGA** with damage for different building types & heights	No differentiation between MMI classes in the city for the same earthquake. So all buildings in city were taken
Technological hazards	We don't really know return periods for the two scenarios but make an expert judgment	Considered as 1, because the buildings are located within a calculated effect distance from the explosion.	Vulnerability table used considering **distance to explosion** and building characteristics (height and building type).	GIS overlay of effect distances with the building map.

We will start by visualizing the building loss information that is linked to the mapping units. All the tables with building losses (**Flood_risk_buildings, Landslide_risk_buildings, Seismic_risk_buildings and Technological_ risk_buildings**) are are using the same domain: mapping_units, and can be visualized through the polygon map **Mapping_units**. We have also made a representation (**Losses**) that allows displaying them in the same way.

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- Right-click on the polygon map **Mapping_units**, Select *Properties*. Select attribute table **Flood_Risk_Buildings.**
- Display the polygon map **Mapping_units**, with the attribute **Losses_10y** from the linked attribute table **Flood_risk_buildings**, using the representation **Losses**. Check the pattern of flood losses in the city.

- Also display the other loss scenarios for flooding (**Losses_50y** and **Losses 100y**). Compare the patterns.
- Link the map **Mapping_units** to one of the other tables with building losses and also visualize them using the representation Losses.
- What can you conclude on the spatial distribution of the building losses throughout the city?
- Why are the building losses indicated in decimals, and not as integers? What could be the reason for that?

It might also be good to actually bring all the loss information into one table, so that you can also see which mapping units have multiple risks. We need to bring all the columns of the 4 tables into a new one that we call **Building_losses**. This table is linked to the domain **Mapping_units**. We have already done this for you, as it may be boring to do this yourself. But if you are interested in the procedure; this is how it is done.

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- Right-click on the domain **Mapping_units** and select *Create Table*. Name the table **Building_losses**.
- In the new empty table, we will first create a new column that has the domain information (which is handy for later exporting it to Excel). Type on the command line:

Mapping_units:=%K

This means a new column is made called mapping units that copies the key column information (grey column on the left side). The domain should be Mapping_units.

- Now we will read in the building loss information from the hazard tables. Select *Columns/Join* and read in the loss columns from the 4 different hazard types. **Give them the name as indicated below in the table?**

Table	**Column**	New name
Flood_risk_buildings	Losses_10y	Flood_10y
	Losses_50y	Flood_50y
	Losses_100y	Flood_100y
Landslide_risk_buildings	Losses_50y	Landslide_50y
	Losses_100y	Landslide_100y
	Losses_200y	Landslide_200y
	Losses_300y	Landslide_300y
	Losses_400y	Landslide_400y
Seismic_risk_buildings	VI_collapse_max	Seismic_50y
	VII_collapse_max	Seismic_100y
	VIII_collapse_max	Seismic_200y
	IX_collapse_max	Seismic_500y
Technological_risk_buildings	Losses_sc1	Tech_sc1
	Losses_sc1	Tech_sc2

Now you can link the map **Mapping_units** to the table **Building_losses** and you can visualize each scenario much better.

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- Right-click on the polygon map **Mapping_units**, Select *Properties*.

Select attribute table **Building_losses.**

- Display the polygon map **Mapping_units**, with the attributes from the table **Building_losses** using the representation **Losses**.

We have the information now in the right shape to start analyzing it in detail.

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- Make sure to select *View/Statistics pane* so you can read the total values for the losses of the various scenarios.
- Answer the following questions and put the answers in the table below.

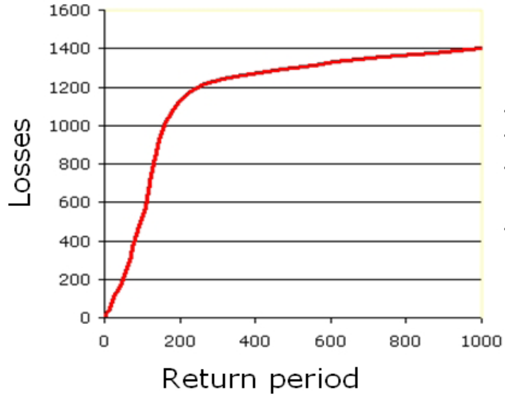
Question	Answer
Which scenario has the largest building losses?	
Compare scenarios with the same return period. Which one is the highest?	
Which mapping unit has the highest losses and in which scenario is that? (Hint: sort the table on the column with the highest losses in descending order)	
How many mapping units have no losses at all? (Hint: sort the table on the column with the highest losses in ascending order)	

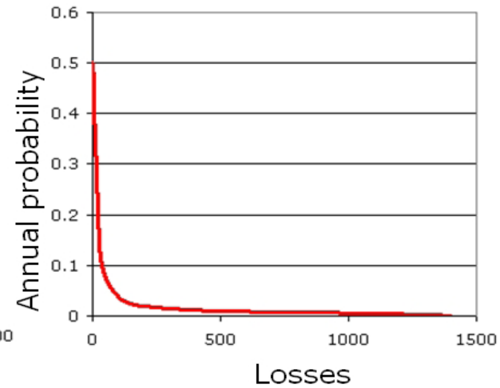
Step 2: Generating risk curves for building losses.

Now we have nearly all information to generate risk curves. The risk can be represented as a curve, in different ways:

1. Plotting the return period on the X-axis and the Losses on the Y-axis
2. Plotting the return period on the X-axis and the annualized risk on the Y-axis
3. Plotting the losses on the X-axis and the annual probability on the Y-axis . Such a risk curve is also called the Loss Exceedance Curve (LEC).

Option 1 and option 2 have the advantage that it is better visible which return periods have the largest contribution to losses. Option 3 can be used directly to calculate the Average Annual Losses (AAL). This is done by calculating the area under the curve (also Guide Book, session 6.5.5).





Before we can plot the risk curves for the buildings you need to still find out which returns periods to use for the scenarios of earthquakes and technological hazards. For the earthquake risk this information should come from a regional seismic hazard assessment. In our case we assume the following return periods:

Intensity	**VI**	**VII**	**VIII**	**IX**
Return period	50	100	200	500

For the technological risk it is very difficult to estimate return periods, since the amount of historical information is limited, and certainly not available for the same installation, as an accident is mostly a single time event. It is normally done by looking at the accident rate for the same type of installations within a country, continent or all over the world. The probability of the events of course also depends very much on the local safety standards and overall compliance with security regulations within the industry that is evaluated. In this particular case we assume the following return periods.

Scenario	**Scenario 1: Poolfire**	**Scenario 2: BLEVE**
Return period	50	500

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- Open the table **Building_losses** and read the total number of buildings affected for the various scenarios. Write them in the table below and in an Excel worksheet.
- Calculate the Annual probability and also the Annualized risk for the scenarios and indicate the values in the table above, or in an Excel sheet.

	Scenario	**Return Period RP**	**Annual Probability P_T**	**Building Losses V*A**	**Specific Annualized Risk P_T *V*A**
Flood	Flood_10y	10			
	Flood_50y	50			
	Flood_100y	100			
Landslide	Landslide_50y	50			
	Landslide_100y	100			
	Landslide_200y	200			
	Landslide_300y	300			
	Landslide_400y	400			
Earthquake	Seismic_VI	50			
	Seismic_VII	100			
	Seismic_VIII	200			
	Seismic_IX	500			
Technological	Tech_sc1	50			
	Tech_sc2	500			

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- Make 3 risk curves for landslide hazard:
- Plot the Return Period on the X-axis and the Building Losses on the Y-axis
- Plot the Return Period on the X-axis and the Specific Annualized risk on the Y axis
- Plot the Building losses on the X-Axis and the Annual Probability on

the Y-Axis.

- Compare the three types of graphs. What can you conclude on the usefulness of the different risk curve type?
- Now also make these 3 types of curves for the other hazard types, and compare them. (plot the 4 risk curves in one graph: X-axis Losses of Buildings; Y-axis: Annual probability)
- What can you conclude?

Step 3: Generating risk curves for economic losses.

In order to calculate the total building value we have to multiply the total floorspace within each mapping unit with the unit cost of buildings. We do that by linking the building costs with the urban land use types. So for each land use we have defined the unit cost of buildings and of its contents within the table **Landuse_cost**.

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- Check the unit costs for buildings and building contents in the table **Landuse_cost**.
- Open the table **Mapping_Units** and join with the table **Landuse_cost**, and read in the two columns **Building_sqm** and **Contents_sqm**.

Now you can simply multiply the floorspace with the unit building costs and the unit contents cost to find the total value.

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- Calculate the Building costs and the Contents costs.
- Also calculate the total costs per mapping unit. Display this also as an attribute of the map **Mapping_Units**.
- What kind of pattern can you see? How should you display the map best? Compare this pattern with the number of buildings. What can you conclude
- How much is “the entire city” worth?

We can now also calculate the average cost per building in each mapping unit.

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- Calculate the average costs per building:

  Cost:=total_cost/nr_buildings
- Perhaps even better: make a formula in which there are no undefined values in the output column
- What is the average costs per land use unit?
- What is the average costs of the buildings for the various landuse types? How would you calculate that?
- Generate an attribute map of this: **Cost**

In this section you will calculate the losses in monetary values for earthquakes, floods, landslides and technological hazards.

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- In the table **Building_losses** join with the table **Mapping_units** to obtain the column **Cost**. Multiply this with the building losses for each scenario. **Use precision 1.**
- (Column names: Flood_costs_10y etc.)
- In Excel use the total values of the monetary losses to calculate specific risk and to generate the risk curves.

Compare the annual risk values for seismic risk, flood risk, landslide risk and technological risk.

Exercise 06T: Technological risk assessment

Expected time:	3 hours
Data:	data from subdirectory:/exercise07
Objectives:	In this exercise we would like to evaluate the risks arising out of an industrial facility located in the city using the set of spatial data provided with this exercise and the basic knowledge of technological risk assessment acquired from the guidebook.

Input data

The following data are used in this exercise.

Name	Type	Meaning
Elements at risk		
Building_map_1998	Raster	Map showing individual buildings.
Building_map_1998	Table	Table showing buildings characteristics: landuse, nr of floors, building type, area building, floor space, persons per day, persons per night, size class.
Technological Data		
Accident Map	Point	Map representing the location of the Accident
Other data		
High_res_image	Raster	High resolution image of the study area.
Ancillary Data	Data	Information about the calculation of the magnitude of the explosion / blast according to the nature and the quantity on the hazardous material

The city, in addition to being very vulnerable to natural hazards (floods, earthquakes and landslides) may also be affected by technological risks, either triggered by natural hazards or due to a stand alone industrial accident.

On noticing carefully, you will observe that there are a number of sites with hazardous materials storage located within the city boundaries located in the middle of densely populated areas. In the domain of the land use there is one class called: **Ind_hazardous;** which indicates: Hazardous material storage or manufacture.

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- Open the domain **landuse** and check the presence of this class.
- Open the table **Building_map_1998,** and select the option Column/ Sort. Sort by **Column: landuse.** Check if there are buildings that have the name **Ind_hazardous**.
- How many buildings have hazardous materials? There are many strategies to extract this information. We will follow a method that will allow us to display the buildings in a map. In the table **Building_map_1998**, write in the command line this expression:

  Hazardous = iff(landuse="Ind_hazardous",%K,?)

- Check the new column; what does the expression produce? What does the code **%K** stand for? Now go to *Column / Aggregation*, chose Column: Hazardous, Function: Count, Group by: Building_Type; store the new column in a new table called **Hazardous_buildings** and name the column Nr**_buildings.**
- How many buildings are present in RiskCity in total? To which building type do

they belong and how many for each building type? Which is, in your opinion, the most vulnerable type in case of earthquake or technological hazard?

- Create an attribute map from the **Building_map_1998** by choosing the column **Hazardous**. Call the map **Hazardous_Buildings**.

7.1 Hazard scenario modeling

Now you see the locations of the sites with hazardous materials. In the building **B_29211** the company "*RiskyStorage*" is located. The bulk facility stores a huge amount of Pentane, a highly hazardous inflammable chemical for supplying to downstream users. The facility has been declared as a Major Accident Hazard (MAH) facility according to local bylaws of RiskCity. According to land-use specifications laid down by the legislation no new MAH industries should come up within the city limits. However, because of socioeconomic (employment and economic) considerations, RiskyStorage was allowed to continue operations after implementing necessary engineering safeguards and controls. For understanding the chemical properties of Pentane, please refer to the Material Safety Datasheet (MSDS) of Pentane Annexed with this Case Study.

The facility recently has been acquired by a different business group and as a result has undergone a major management reshuffle with change in operational responsibilities of key people. The emphasis on plant level safety has been reduced in order to cut costs.

On 15th of November, 05 at around 3 o'clock in the evening, an operator riding a vehicle within the plant premises (which was not allowed before) accidentally crashed into an over ground pipeline that is used for transferring Pentane from the Storage. The impact of the crash resulted in a fire in the pipeline and which started spreading towards the main storage. The fire is noticed by an onlooker outside the plant and is reported to the Industrial Emergency Management Centre (IEMC) of RiskCity by telephone. The IEMC has a GIS setup and all the data that is required to make a spatial analysis of an accident and take appropriate response decisions (the same data has been provided in the RiskStorage Folder). It must be understood here, that time is a major constraint in such emergencies as they typically evolve very fast (typically within an hour) and right decisions have to be taken quickly.

The site is indicated in the point map Accident.

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- Open the **New_high_res_image**, and add the point map **Accident.**

The consequences of technological accidents depend on a number of factors including nature of the chemical (physical and chemical properties), storage conditions (refrigerated or pressurized), nature of release conditions (through rupture of pipe or breach of containment of storage), atmospheric conditions, etc. The accident discussed in the overview section has a high probability of being a Pool Fire which is caused when a liquid inflammable substance like Pentane escapes from a refrigerated container and catches fire. The primary hazard resulting from such a fire is exposure to resultant heat radiation.

However, if a pool fire spreads to the main storage, an event called a Boiling Liquid Expanding Vapor Explosions (BLEVEs) may happen with very serious consequences. A BLEVE can be caused when flames impinge upon the vapor space of the tank causing excessive pressure in the tank causing the entire tank to explode. It will result in a huge fireball and involves the violent rupture of the container, with rocketing fragments. Though the explosion results in considerable overpressure, the most damaging impact is caused by the heat radiation, because it persists for quite some time.

Taking this into consideration, the following accident probable consequence scenarios were considered by the modeler's in the IEMC for the analysis of endpoint distances:

- **Scenario 1:** Rupture of the Pentane pipeline caused by the car crashing into an over ground valve located beside a site access road. The pipeline releases Pentane at the flow rate of the pipe for 10 minutes and forms a pool that spreads to 1 cm depth. The released pool is assumed to ignite and burn after 10 minutes of spreading.

- **Scenario 2:** The pool fire in the vicinity spreads to the Pentane tank and causes the tank to fail catastrophically resulting in a "fireball" or BLEVE. 10% of the contents explode as a vapor cloud.

The endpoints for the two scenario's has been calculated using US Environment Protection Agency (EPA) Equations for Consequence Analysis are presented below.

Pool Fires

The EPA equation is based on factors for estimating the distance to a heat radiation level that could cause second degree burns from a 40-second exposure. This heat radiation level was calculated to be 5,000 watts per square meter. The equation for estimating the distance from pool fires of flammable liquids with boiling points above ambient temperature is:

$$X = H_c \sqrt{\frac{0.0001A}{5000\Pi\,(H_v + C_p\,(T_B - T_A))}}$$

Where:

X = distance to the 5 kilowatt per square meter endpoint (m)

HC = heat of combustion of the flammable liquid (joules/kg)

HV = heat of vaporization of the flammable liquid (joules/kg)

A = pool area (m2)

CP = liquid heat capacity (joules/kg-ºK)

TB = boiling temperature of the liquid (ºK)

TA = ambient temperature (ºK)

Boiling Liquid Expanding Vapor Explosion

The equations used by the EPA to estimate impact distances for BLEVEs are summarized below:

$$X = \sqrt{\frac{2.2\,t_a\,R\,H_c\,W_f^{\,0.67}}{4\,\Pi\left[\frac{3.42 \times 10^6}{t}\right]^{0.75}}}$$

Where:

X = distance to the 5 kilowatts per meter squared endpoint (m)

R = radiative fraction of the heat of combustion (assumed to be 0.4)

tA = atmospheric transmissivity (assumed to be 1)

HC = heat of combustion of the flammable liquid (joules/kg)

Wf = weight of flammable substance in the fireball (kg)

t = duration of the fireball in seconds (estimated from the following equations)

For W_f < 30,000 kg

$$t = 0.45 W_f^{1/3}$$

For Wf > 30,000 kg

$$t = 2.6 W_f^{1/6}$$

Calculate the results in terms of endpoint distances for the two scenarios in Excel based on the information given above:

Scenario 1 = ………. m

Scenario 2 = ……….. m

What are the most important variables in this calculation, and how do they affect the results?

7.2 Evaluating the areas affected

We know, for both the scenarios, how far from the source the hazardous events can affect the buildings. The distances for the two scenarios have been previously calculated through an Excel sheet. The effects of the explosions are inversely proportional to the distance to the source; therefore, the vulnerability should decrease with the increase of the distance. First of all we have to calculate the area around the source hit by the explosion using for each scenario the distance we calculated.

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- Rasterize the point map **Accident** using the georeference **Somewhere.**
- Select *Operations / Raster Operations / Distance Calculation*. Select the input map **Accident**, and the output map **Distance_Accident_2** Select value range 0 to 1410 and precision of 1.
- Follow the same procedure but set the value range between 0 and 395. call the output map **Distance_Accident_1**. The two distance maps represent the areas affected by the two events (scenario 1 and 2).
- Open the map **New_high_res_image** and display the resulting map **Distance_accident_2** on top with 75 percent transparency. Make sure that the map is displayed on top; otherwise you will not see it. Do the same for the other scenario and visually evaluate the result.

We can now see the area that will be affected in scenario 1 and 2. Unfortunately the area is not a perfect circle due to the raster distance algorithm which is used in ILWIS (see ILWIS help for more explanation: search for Distance algorithm). Different kinds of buildings have different behaviors when hit by an explosion; moreover the presence of a tall building can protect a smaller one that is located behind it in relation to the source. These interactions would be too much complicated to be modeled; hence we assume that the vulnerability for each building is dependent on the distance from the source and on the building type and size. We will now evaluate the effect of the distance, by assuming that the vulnerability will decrease from 1 (source) to 0 (perimeter of the area in the distance maps).

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- Transform the distance maps into a map with value 1 for the center and value 0 at the boundary. For the scenario 1, write in the main ILWIS command line the following exression; give to the new map precision of 0,05.

  Vuln_Accident_1:=(395-Distance_Accident_1)/395

  What does the operation create? What is the lowest value in the map?

- The new map can already represent the vulnerability related to the distance to the source. To avoid vulnerability values equal to zero, a further correction is needed. Type an expression to exclude all the zero values. Use a precision of 0.05. This can be an example:

Vulnerability_Accident_1:=IFF(Vuln_Accident_1=0,?,Vuln_Accident_1)

- Follow the same procedure for the Scenario 2 using the map Distance_Accident_2 and its related value.

We have now the affected area; the next step is to estimate the buildings affected and the vulnerability rate related to the distance to the source.

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- In the main ILWIS menu go to *Operations / Raster Operations / Cross*; chose the maps **Building_map_1998** and **Vulnerability_Accident_1**. Call the new table **Building_Damage_1.** Open the table and check the content.
- In the new table menu, go to *Column / Aggregation* and chose Column: Vulnerability_Accident_1, Function: Predominant, Group by: Building_map_1998, Weight: Area. Call the new column **Vulnerability_Building_1**
- Does the new column differ from the Vulnerability_Accident_1? Why? What did we calculate?
- Open the **Building_map_1998**, go to *Columns / Join* and chose the table we just created; select the column **Vulnerability_Building_1**.
- Create an attribute map from the map **Building_map_1998** by choosing the column **Vulnerability_Building_1**; Call it **Vulnerability_Building_1**, open it and check the content.
- Go to Columns / Aggregation and choose Column: Vulnerability_Building_1, Function: Count; store the new column in the table **Buildings_affected** and call it **nr_buildings_1**. Check the results and fill the table: **Technological** Risk in the next page.
- Follow the steps for scenario 2 and store the values in the table.

7.3 Calculating buildings losses

As stated before, in this case we consider the vulnerability as related to the distance to the source and to the buildings characteristics. A building made in wood or other poor materials is likely to be destroyed / damaged by the blast than a building in reinforced concrete. Furthermore, the more a building is high, the more surface is exposed to the blast; thus the building is more vulnerable. From previous similar events, historic data have been collected and, based on them, the vulnerability rates for different building types with different floors numbers have been provided in the table below.

Vulnerability per building type and height

Building type	1 floor	2 floors	3 floors	4-10 floors	> 10 floors
Adobe	1.0	1.0	1.0	1.0	1.0
Brick with Cement	0.7	0.7	0.8	0.9	1.0
Brick with Mud	0.8	0.8	0.9	1.0	1.0
Fieldstone	0.8	0.9	1.0	1.0	1.0
Reinforced Concrete	0.3	0.4	0.4	0.5	0.6
Wood and others	1.0	1.0	1.0	1.0	1.0

In the next step we will build a table in ILWIS containing the vulnerability values. Then we will estimate the vulnerability per building for each scenario.

☞

- Go to the main ILWIS menu: *File /Create / 2 Dimensional Table*. Chose as 1st domain **Building_type**, as 2nd domain **Nr_Floors_Clas**; value range: 0 – 1. Call the new table **Vulnerability**.

- Open the 2D table and fill it using the values in the values above. What kind of table is it? Try to describe its meaning and its use (read the ILWIS help).
- Open the table Building_map_1998 and type in the command line the following expression:

Vuln_building_type:=Vulnerability[Building_type, Nr_floors_class]

- Check the column **Vuln_building_type** and try to explain what the expression calculates.

Now we can combine the vulnerability value related to the distance to the source and the vulnerability value related to the building type and the number of floors. With the total vulnerability we will be able to calculate the total losses for the two scenarios.

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- In the table Building_map_1998; type the following expression:

  Building_losses_1:=Vulnerability_building_1*Vuln_building_type

  This column represents the losses per building for the scenario 1, the sum represents the total losses for that scenario.
- In the table **Building_map_1998** go to Column /aggregation; chose Column: Building_losses_1. Function: Sum and Group by: Building_type. Store the new column in the output table **Buildings_Affected** and call it **Losses_1**.
- Follow the same procedure for scenario 2.
- Check the total amount of losses for each scenario and fill the two empty columns in the table below.

Table: Technological Risk

Building Type	Scenario 1		Scenario 2	
	Affected Buildings	Buildings Losses	Affected Buildings	Buildings Losses
Adobe				
Brick with Cement				
Brick with Mud				
Fieldstone				
Reinforced Concrete				
Wood and others				
Total				

We have calculated the losses per building and the total losses for each scenario. We can also display it in a map.

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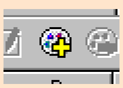
- Create an attribute map from the map **Building_map_1998**. Right click on the map, chose Raster Operations / Attribute table and chose the column **Building_losses_1**. Call the map **Building_Losses_1**.
- Do the same with the column **Building_losses_2**. Display the new maps in transparency on top of the High_Res_Image. Check the result.

7.3 Evaluating the impact on the population

Information about the population living in RiskCity is available in the table **Building_map_1998**. Now that we have extracted the losses for each building we can also evaluate how many inhabitants would be "at risk" by the event, and how many buildings would collapse in both the scenarios. To do this, some assumptions are required. A person has to be considered "at risk" (affected by the event) if the losses to the building are more than 15%. If the losses for a building are higher than 40% then the building is considered to be evacuated. To evaluate the number of inhabitants at risk we can create two different time sub-scenarios for each event: night-time and day-time. For the calculation of the population evacuated (and the buildings) we will use the night-time population because it represents the number of person that live in each building.
First of all, we will calculate the number of people at risk in day-time and night-time.

To add new classes in the domain window, click the button in the figure below.



☞

- Open the **Building_map_1998** and type in the command line the following expression:

Affected_pop_1 = IFF(Building_losses_1>=0.15,Persons_day,?)

The expression returns the day-time number of persons for those buildings with losses higher than 15%. Activate the statistics pane, if not visible, by going to *View / Statistics Pane* and fill the table below with the total number of people affected.

- By slightly changing the formula, calculate the number of people at risk in the nighttime scenario.
- Calculate the number of buildings that have to be evacuated. Create a new domain by going to the main ILWIS menu *File / Create / Domain;* chose group domain and call it **Evacuated_buildings**; the domain must have two classes:

0.39 (upper boundary) Not Evacuated (class name)
1.00 (upper5 boundary) Evacuated (class name)

- Close the domain and go back to the table Building_map_1998; type the following expression:

Evacuated_buildings_1:= clfy(Building_losses_1,Evacuated_buildings)

- Go to *Columns / Aggregation* and chose Column: Evacuated_buildings_1, Function: count, Group by: Evacuated_buildings_1. Call the new column **Count_evac_1.** In the column you can find the number of buildings that have to be evacuated.
- Calculate the number of people to be evacuated by typing the following formula:

Evacuated_pop_1=IFF(Evacuated_buildings_1="Evacuated",Persons_night,?)

- Read in the statistic pane the total number of person evacuated.
- Now you have all the values to fill the table below for the 1st scenario.
- Repeat the procedure for the second scenario: note that you don't have to calculate the domain **Evacuated_buildings** again!
- Fill the table below with the correct values for the 2nd scenario.

Building Type	Affected Population		Evacuated buildings	
	Day-time	Night-time	Nr of buildings	Nr of people
Scenario 1				
Scenario 2				

☞

- Can you explain the large difference between the daytime and the nighttime population involved in the disaster?

This information can be helpful in response activities; according to the number of people evacuated we can plan how many shelters we will need in case that such event happens. Moreover the number of people at risk can be used to plan first aid activities like health assistance, water and food provision, or the number of people that has to be involved in rescue and first aid activities: police, fire service, and hospital staff.

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- We can also show the buildings to be evacuated in a map for the first accident scenario; create an attribute map and chose the map **Building_map_1998** and the column **Evacuated_buildings_1**. Call the map **Evacuated buildings_1**.
- Do the same using the column **Evacuated_buildings_2** and show the map for the second scenario.

Exercise 7a: Risk information for emergency preparedness & response.

Expected time:	3 hours
Data:	data from subdirectory: RiskCity_exercise/exercise07a/data
Objectives:	The aim of this exercise is that you use the risk information that you have generated in the previous exercise 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.

Introduction to the simulation exercise

The Geo-Information department of the municipality of RiskCity is in charge of collecting and handling spatial information that should be used in the emergency preparedness phase in order to provide the decision makers with the adequate information to respond to disasters (Figure 1). You have a GIS database and you will have continuous access to Blackboard and e-mail where you may receive regular situation reports on which you have to react. You will also receive messages from the emergency management group of the municipality of RiskCity, which will request particular types of information.

You have the following tasks:

- **Task 1: Planner**. The planner reads and interprets the messages that are received regarding the situation. He/she also will receive messages from the emergency managers in RiskCity asking for specific information. The planner should use the available information and plan the tasks that should be carried out by the analyst.
- **Task 2: Analyst**. The analyst is the person that is mostly involved in the GIS analysis, based on the requests made by the planner. He/she will provide the information to the communicator.
- **Task 3: Communicator**. The communicator is responsible for preparing small reports with the answers to the questions posed by the emergency managers of RiskCity. It may also be required to provide some map information in the reports. The reports should be mailed to a given e-mail address in time.

> In the distance education course you have to play to perform all 3 tasks. In a classroom situation it is possible to divide the tasks and work in groups of 3 people.

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The role of supervising staff is twofold during the simulation exercise:

- One of the supervising staff members will evaluate the reports submitted by the groups in real time, and communicate back when the information is missing. Note that the score given each time depends on both the accuracy and the speed of the response.
- Two other supervising staff will be available to provide support during the simulation, by giving hints on how to solve particular GIS problems.

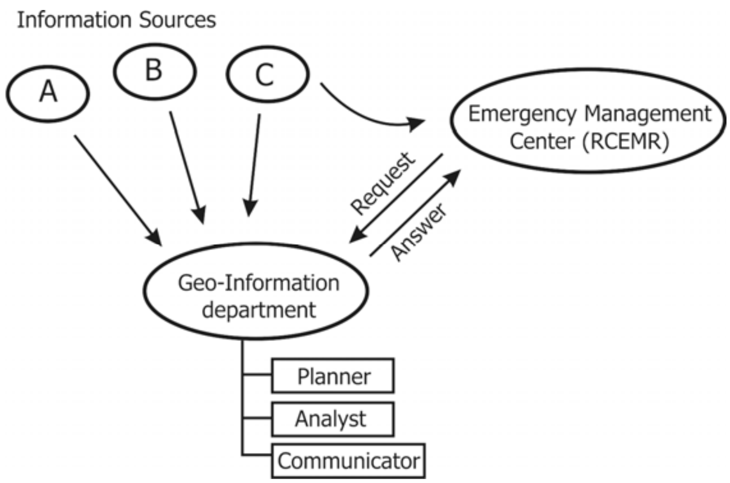

Figure 1. Overview of organisational setup of the RiskCity emergency management.

Input data

This simulation case study uses a large amount of data, related to hazards, elements at risk and expected losses for earthquakes, flooding, landslides and technological hazards. This simulates the real situation where you do not know when and what may happen, and therefore all available information might be useful.

The table below gives a list of the most important data

Name	Type	Meaning
Elements at risk		
Mapping_units	Raster	Building blocks of the city. The accompanying table containing general statistical information on the number of buildings and people per building block.
Building_map_1998	Raster Map	Building map of the city showing the situation after the disaster of 1998. The accompanying table contains information on: the landuse, the number of floors, the floorspace, the building types, and the daytime and nighttime population within the buildings in RiskCity.
Earthquake data		
Seismic_risk	Table	Table that links to the map **Mapping_units**, which containing expected building losses and population losses for earthquakes with intensities ranging from VI to IX (Modified Mercalli Intensity)
Earthquakes_country	Point	Point map of the earthquake catalogue and accompanying table with historical earthquake information.
Flood data		
Flood_risk	Table	Table that links to the map **Mapping_units**, which containing expected building losses and population losses for floods with 5, 10, 25, 50 and 100 year return periods
Flood_05year to Flood_100_year	Polygon	Polygon maps with modelled flood extend of floods with 5, 10, 25, 50 and 100 year return periods
Flood_10y, flood_50y and Flood_100y	Raster	Raster maps with flood depth for floods with 10, 50 and 100 year return periods
Landslide data		
Landslide_risk	Table	Table that links to the map **Mapping_units**, which containing buildings and population located in high, moderate and low landslide hazard zones
Landslide_susceptibility	Raster	Raster map of the landslide susceptibility
Landslide_ID	Polygon map	Landslide inventory map with a table containing relevant landslide information.
Technological risk data		

Technological_risk		Table that links to the map **Mapping_units**, which containing buildings and population located in zones close to the main hazardous industry.
Main_industry	Point	Point map with location of the main industrial site in RiskCity.
Other data		
High_res_image	Raster	High resolution image of the study area.
Country_anaglyph	Raster	Anaglyph map of the entire country.
City_center	Point	Location of RiskCity within the country
Real time data		
Rainfall_data		Daily rainfall data is given to the participants at regular intervals during the simulation
Situation reports		The participants will receive regular updates on the emergency situation.
Information requests		The team will receive regular requests from emergency managers related to information they

Preparing for the simulation

In the distance education course everyone could start the simulation exercise at a different time of the day, depending where you are in the World. In order to be able to carry out the exercise, you need to inform the course coordinator at which time exactly (GMT time) you are going to start the simulation exercise. You also have to indicate which e-mail you are going to use for receiving the messages.

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- Inform the course coordinator 2 days before at which time (GMT time) you want to start this exercise, and indicate the e-mail address to which the messages related to this exercise will be send.
- The answers to the exercises should be mailed to the following e-mail: DGIM@itc.nl.

In this exercise you will receive e-mails at certain time intervals of Technical organisations related to riskcity (National weather forecasting center, National earthquake center, Geological Survey etc.) with situation reports. You will also receive e-mails from the RiskCity Emergency Management Center (RCEMC) with specific request for information, which you have to provide based on the GIS data available for this exercise. You have to provide the answers by e-mail to DGIM@itc.nl in time. We will evaluate whether you give the right answers and whether you did this in time. The total duration of the simulation is 3 hours.

As you know that there will be an event that might take place during the simulation, but do not know what and when, it might be best to use the time before you receive any message to become further acquainted with the data. The most important dataset is the map of the buildings, called **Building_map_1998**.

Pixel Information

One of the most important tools for querying information is the Pixel Information window. You can open this and add the most important data layers, and keep this “always on top” during the simulation

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- Open the **High_res_image** and add the segment map **Building_map_1998**.
- Open Pixel Information, and add the maps: **Building_map_1998**, **Mapping_units**, **Wards**, **Landslide_susceptibility**, **Slopecl** and other ones if needed. Select Options, Always on Top
- Keep this window open during the simulation. It will allow you to make rapid consultations of the data.

While you still have time, it is important to identify the main emergency centers. You can find the buildings and number of people related to the fire-brigades, policestations and hospitals.

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- Open the domain **Landuse** and check the names and codes.
- Open the table **Building_map_1998** and create a column using the following formula:

Emergency:=iff((landuse="ins_p")or(landuse="ins_f")or(landuse="ins_h"),landuse,?)

- Display the raster map **Building_map_1998** with the attribute **Emergency** that you just made. Overlay the segments of Building_map_1998.
- Check out where the fire stations, hospitals and police stations are.

Be aware that you may receive situation reports and scientific information through email.

Good luck…. And wait for the e-mails

Exercise 7b. Analysis of costs & benefits of risk reduction scenarios.

Expected time:	3 hours
Data:	data from subdirectory: RiskCity_exercises/exercise07b/answers
Objectives:	After calculating the expected losses for the different return periods, and the average annual risk, we would now like to analyze the various options that the municipality has to mitigate the risk, using a basic cost/benefit analysis.

In the previous exercise we have calculated annual losses in monetary values (for direct losses to buildings and contents only). These were made for flooding, seismic, landslides and technological hazards scenarios occurring at different time intervals. The table below gives a summary of these values. These will be the basis for the cost-benefit analysis in this chapter.

Return Period	Annual Probability	Flooding	Seismic	Landslides	Technological
		Direct monetary building losses in € .10 ^{6}			
5	0.2	19.34			
10	0.1	34.4			
15	0.0667		8.493		
25	0.04	100			
35	0.0286		85.85		
50	0.02	199	231.0	0.1519	44.96
60	0.0167		338.3		
100	0.01	510		2.016	
200	0.005			16.49	
300	0.0033			33.99	
400	0.0025			61.93	
500	0.002				249.3

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- Open Excel and create in a worksheet the same setup as above.
- Plot the risk curves
- What can you conclude on the individual hazard types? Which one would cause the highest losses?

The municipality of **RiskCity** has made a study and the report came up with the following possibilities for risk reduction. The following table shows a number of possible risk reduction measures, including also a very general indication of the costs that these measures would take. In the following section we will evaluate some of these in more detail.

	Measure	Estimated risk affect
Flooding	Evacuation of buildings in flood hazard zone with 10 year return period	Reduces risk in the 10 year RP flood zone by 100 %
	Flood retention basin	Reduces the probability of flooding per zone by 1 RP.
Seismic	Seismic retrofitting	Reduces losses by 40 percent,
Landslides	Evacuation of highest hazard zones	Reduces risk in these zones by 100 %
	Slope stabilization measures	Reduces risk by 90 percent
Technological	Relocation of chemical industry	Reduces risk by 100 percent

In the coming sections we will first evaluate the options for flood risk reduction. We will first look at the scenarios, define how they will reduce the risk, then calculate the investments of risk reduction measures and finally make a cost benefit analysis.

There are of course many also many other risk reduction measures possible. You can broadly subdivide these in Structural and Non-structural measures. Structural risk reduction measures involve engineering measures and construction of hazard-resistant and protective structures and infrastructure. They can be quantified in monetary values. Non- structural risk reduction measures involve components related to land use zoning, early warning, awareness raising, disaster preparedness etc.

Flood risk reduction:

Two scenarios are mentioned for flood risk reduction:

- **Scenario I** involves the removal of housing in the 10-year Return Period flood zone (i.e. including the 2-year and the 5-year floodplain). The buildings should be demolished, new terrain should be bought, and new buildings have to be constructed in other hazard free zones, infrastructure should be constructed, and the 10 year RP flood zone is converted into green areas (park areas with recreational facilities). A strict supervision is made to avoid that these areas are invaded illegally by squatters. This requires the set-up of a vigilance group which involves costs over a larger period. The risk in the area that was formerly threatened by a 10 year Return Period flood will be reduced to 0, as a consequence of this risk reduction measure. The expected losses for the flood scenarios with return periods higher than 25 years will be basically the same. However, these will become also lower, because the losses for the 25 year event should be reduced from this.
- **Scenario II** involves the construction of an upstream storage lake. This basin is constructed in the upstream area of the city, and would not involve the removal of houses from the study area. However, the river channel should be made adequate and some engineering works have to be carried out to some of the bridges in the area. The flood retention basin and drainage also needs regular maintenance. The retention basin will reduce the flood losses. It will retain the discharge for 2 and 5 years, and reduce the risk to 0. For the other return periods the damage will reduce: the losses of a 10 year RP will be those of a 5 year RP flood in the original situation; those of a 25 year RP will be those of a 10 year RP etc.

In order to do a cost-benefit analysis of the various risk reduction measures we need to compare the present average annual risk with the future average annual risk of the two scenario's , to define the amount of risk reduction. In the table below the flood losses are indicated for the current situation.

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- Make an estimation of the reduction in flood losses based on the description of the scenarios given above, and fill in the values in the table below.

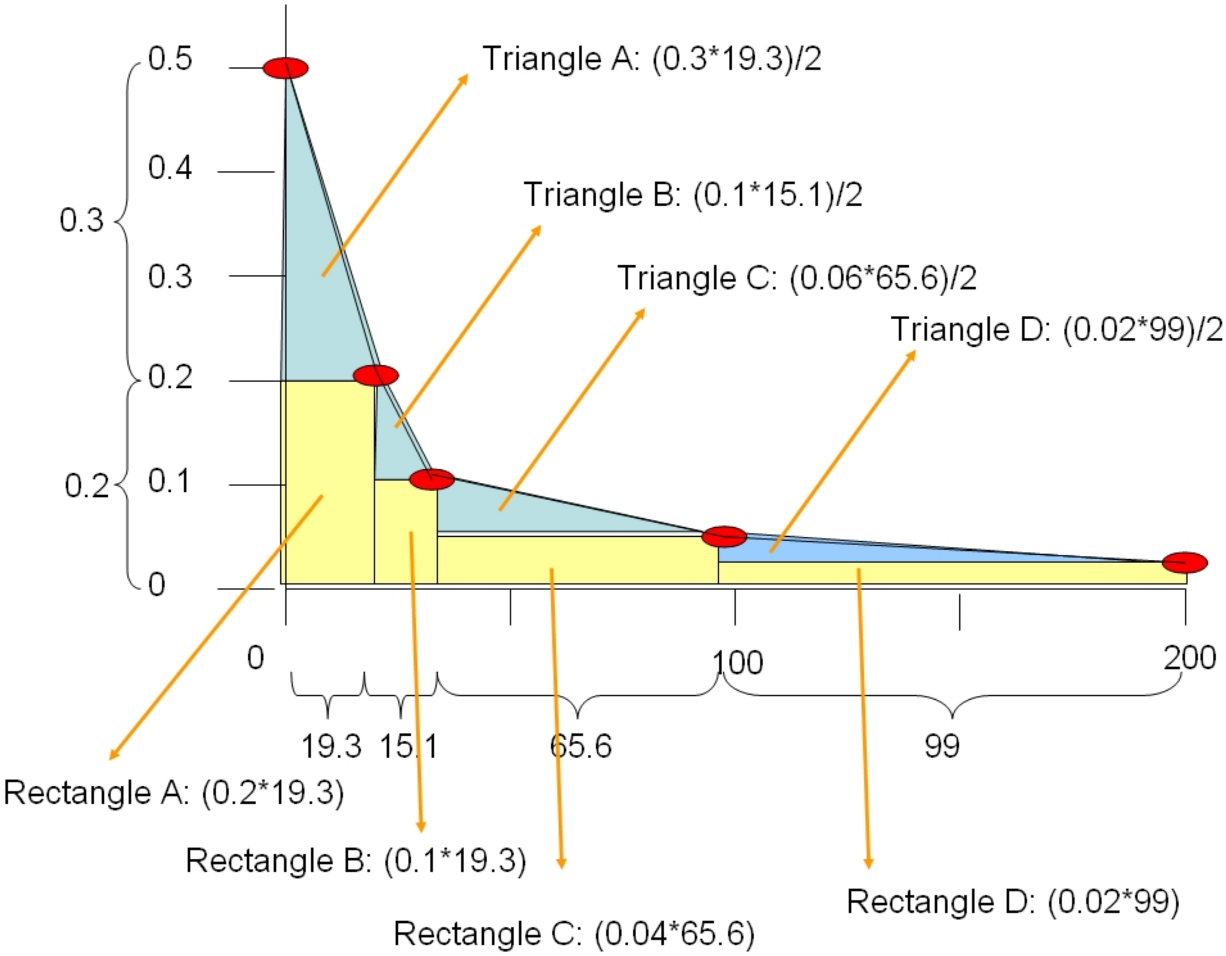
Flood recurrence in years.	**Flood Losses (without mitigation.) (in € .10 6))**	**Mitigation Scenario I Flood Losses (in € .10 6))**	**Mitigation Scenario II Flood Losses (in € .10 6))**
2	0	0	0
5	19.3	0	0
10	34.4	0	19.3
25	100	100	34.4
50	199	199	100
100	510	510	199
200	1134	1134	510

Calculating total annual risk from a risk curve

The first step in the cost-benefit analysis is to calculate the total annual risk for the present situation and the reduction in total annual risk given the various risk reduction scenarios. 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 the graph and table below.

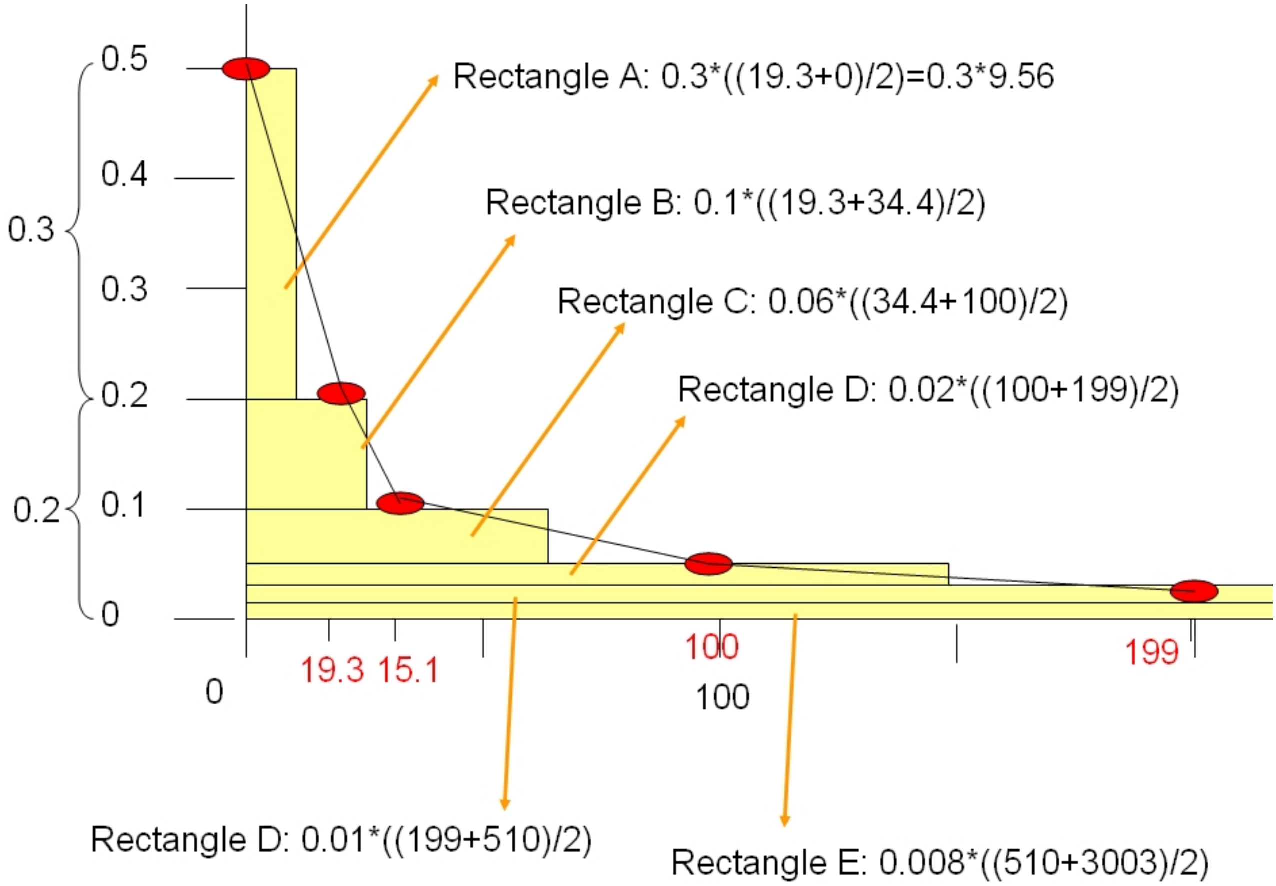


Part	Return Period	Annual Probability	Losses (in € .10 6)	Y-axis interval	X-axis interval (in € .10 6)	Triangle (in € .10 6)	Y-axis from	Rectangle (in € .10 6)
	2	0.5	0					
A				0.3	19.3	2.895	0.2	3.86
	5	0.2	19.3					
B				0.1	15.1	0.755	0.1	1.51
	10	0.1	34.4					
C				0.06	65.6	1.968	0.04	2.624
	25	0.04	100					
D				0.02	99	0.99	0.02	1.98
	50	0.02	199					
E				0.01	311	1.555	0.01	3.11
	100	0.01	510					
F				0.005	624	1.56	0.005	3.12
	200	0.005	1134			**9.723**		**16.204**
							25.927	

This is the annual risk, taking the sum of the triangles and squares in the graph

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 graph and Excel table below



Part	Return Period	Annual Probability	Losses (in € .10 6)	Y-axis interval	X-axis average (in € .10 6)	Losses (in € .10 6)
	2	0.5	0			
A				0.3	9.65	2.895
	5	0.2	19.3			
B				0.1	26.85	2.685
	10	0.1	34.4			
C				0.06	67.2	4.032
	25	0.04	100			
D				0.02	149.5	2.99
	50	0.02	199			
E				0.01	354.5	3.545
	100	0.01	510			
F				0.005	822	4.11
	200	0.005	1134			
G				0.00433333	1317	5.707
	1500	0.0006667	1500			
						25.964

Now that we know two method we can start calculating them in Excel

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- Open Excel and create in a worksheet the same setup as indicated in the first method. Calculate the total annual losses
- Then in the same workbook, make another worksheet and calculate the annual losses using the second method.

Since there is a large variation in probabilities and losses the graph doesn't show very nice. You might like to change the range of the X-axis and reduce it a bit more.
Now that we have calculated the annual loss for the existing situation, we can also now evaluate the reduction in total annual losses for the two scenarios.

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- Calculate in Excel in the same way the average annual risk for **Scenario I** and **Scenario II** (see earlier table with the losses for the two scenarios for the various return periods that you filled in yourself)
- Calculate the amount of risk reduction, comparing **Scenario 1** and **Scenario 2** with the original average annual risk. Fill in the table below.

	Average annual risk (in **€ .10** $^{6)}$	**Annual risk reduction** (in **€ .10** ^{6}**)**
Present situation		
Scenario 1		
Scenario 2		

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- Plot the three risk curves in one graph in Excel

We have now calculated the benefit, which is equal to the amount of risk reduction.

Calculating the investment costs

After calculating how much the risk reduction is on an annual basis for the two different scenarios, we can now evaluate the benefits. The benefit is equal to the amount of risk reduction.
However, the two risk reduction scenarios also involve certain costs. The next table indicates the investment costs for implementing the two scenarios.

	Specific activities	How to calculate	Standard values	Values
Scenario 1	Buy the land of the privately owned buildings in the flood zone	Nr of building * standard land prince	Standard land price per building = 15000	A
	Demolition of buildings in flood zones with RP of 2,5 and 10 years	Nr of buildings * standard demolition costs	Standard demolition costs = 1000/building	B
	Acquisition of new land	Nr of buildings * standard costs for land per building	Standard costs for land per building = 10000	C
	Construction of new buildings for people removed from flood zones	Nr of buildings * replacement costs	Average Replacement costs = 50,000 / building	D
	Construction of infrastructure for people removed from flood zones	Nr of buildings * standard infrastructure costs	Standard infrastructure costs = 250 / building	E
	Adaptation of the zones where the buildings are	Area in hectares * standard adaption costs / hectare	Standard adaptation costs / m^2 = 20	F
Scenario 2	Construction of the flood retention basin	Estimated costs by contractor	10,000,000	
	Adaptation of the river bed	Estimated costs by contractor	10,000,000	25,000,000
	Adaptation of the bridges	Estimated costs by contractor	5,000,000	

For scenario 2 the costs of the investments for the risk reduction strategy are relatively simple. The mitigation works involve engineering works, which are calculated by a contractor and which amount at 25,000,000. However, for scenario 1, which involves the removal of a number of buildings in the highest flood hazard zones, we would still need to calculate the individual components.

IF you are not directly interested in calculating the investment costs for the removal of buildings and adaptation of the terrain you can skip this part of the exercise and move to the next part.

To calculate the A to D component costs from the table above, you need to know first the number of buildings in the flood zone of 10 years return period. For the component E you need to know the area of the 10 year flood zone.

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- You can find the number of buildings that are located in the flood zones with a return period of 10 year by crossing the raster maps **Flood_10_year** with the map **Building_map**

- You can find the area of the flood zone of 10 years by rasterizing the map **Flood_10_year** and then calculate the histogram.

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- Write the values in the table below and calculate the costs for the various components of Scenario 1.
- Calculate the total investment of scenario 1.

Scenario 1	Nr of buildings	Area of flood zone	Standard costs in €	Costs (in € .10 [6])
A				
B				
C				
D				
E				
F				
Total investments				

IMPORTANT:
We are considering only the economic aspects of executing Scenario 1. There are many more socio-economic aspects: the communities living in these areas will not be just willing to move out of these places. They have historic ties with the place where they live, they depend on the location where they live for their livelihood, etc. etc. These intangible aspects should also be taken into account apart from the purely economic ones.

For advanced ILWIS users:

For experienced ILWIS users: Calculating the number of destroyed buildings.

- The number of buildings that was calculated has an error: it includes also the buildings that were already destroyed by the disaster in 1998. Find a way to exclude those buildings. **Tip**: use the land use type **Vac_damaged** to mask out the buildings that are no longer there.
- The buildings that are in the 10 year flood zone are not only residential buildings. They have various land use types. You might like to improve the calculation of the demolition and reconstruction costs by differentiating building costs based on different land use types.
- The area of the flood hazard zone with a 10 year return period also includes the current river. Find a way to exclude the area of the current river.

Cost benefit analysis

After calculating the risk reduction (benefit) and the investment costs of the two flood scenarios we can now continue to evaluate the cost/benefits. The following table indicates the costs of the two scenarios.

	Costs: investment cost for the scenario	Benefits: Annual risk reduction
Scenario 1	50,000,000	8,762,000
Scenario 2	25,000,000	16.189,500

Maintenance cost and operational costs

Each of the two scenarios will also require long term investments.

- **Scenario 1** requires the set-up of a municipal organization that controls the illegal spread of housing in highly hazardous areas. It will require staff, office and equipment costs, which will rise over time depending on the increases of salary and inflation. The annual costs are estimated to be 250.000. We consider that these costs will increase with 5 % each year.
- **Scenario 2** also requires maintenance and operation costs. The flood retention basin contains a basin in which sediments are deposited. Annually the sediments from this basin have to be removed using heavy equipment. Also the drainage works needs regular repair. The costs for maintenance are considered to be 500.000 per year. We consider that these costs will increase with 5 % each year. See table below.

Investment period

The investments for both scenarios are not done within one single year. They are spread out over a larger number of years, because normally not all activities can be carried out in the same year.

- It is quite difficult to remove existing buildings. The municipality would like to buy the land of private owners, but they will resist, and there will be many lawsuits that might take a lot of time. Therefore we consider that the entire relocation of all building might take as much as 10 years. The investment costs are therefore spread out over this period.
- The construction of the engineering works for scenario 2 will take less time. Still it is considered that the costs are spread over a period of 3 years.

The benefits will start in the year that the investments are finished. For scenario 1 this is in year 11 and for scenario 2 it is in year 4.

Project lifetime.

The **lifetime** of the scenario 2 is considered to be 40 year. After that the structure will have deteriorated and it needs to be rebuilt. For the relocation scenario it is more difficult to speak about a life time, but we will also keep the same period of 40 years.

Each project has a certain **life time**, during which the investments of the projects should be paid off. The flood retention basin is constructed to exist for at least 40 years. Of course this life time is not very applicable to the scenario I: evacuation of houses from the high flood risk zone.

Table: Costs of the Flood Risk Reduction Scenario's (costs in € .10 [6]).

Year	Investments Cost Scenario I_F (in € $.10^6$)	Operational costs municipal squatter control (in € $.10^6$)	Investments Cost Scenario II_F (in € $.10^6$)	O&M costs Year Scenario II (in € $.10^6$)
1	10 % of 50=5	0.250	33 % of 25	0
2	10 % of 50=5	0.250 + 5%	33 % of 25	0
3	10 % of 50=5	0.263+ 5%	33 % of 25	0
4	10 % of 50=5	0.276+ 5%	0	0.5
5	10 % of 50=5	0.289+ 5%	0	0.500+ 5%
6	10 % of 50=5	0.304+ 5%	0	0.525+ 5%
7	10 % of 50=5	0.319+ 5%	0	0.551+ 5%
8	10 % of 50=5	0.335+ 5%	0	0.579+ 5%
9	10 % of 50=5	0.352+ 5%	0	0.608+ 5%
10	10 % of 50=5	0.369+ 5%	0	0.638+ 5%
11	0	0.388+ 5%	0	0.670+ 5%
12 -40	0	Etc..	0	Etc.

We are now going to put the avoided risk per year in a table as well as the cost and we will calculate the benefits over the 40 years period.

Flood Mitigation Scenario 1

9.02

year	risk reduction	invest costs	Maintenance	incre benefits
1	0	5	0.25	-5.25
2	0	5	0.263	-5.263
3	0	5	0.276	-5.276
4	0	5	0.289	-5.289
5	0	5	0.304	-5.304
6	0	5	0.319	-5.319
7	0	5	0.335	-5.335
8	0	5	0.352	-5.352
9	0	5	0.369	-5.369
10	0	5	0.388	-5.388
11	8.762	0	0.407	8.355
12	8.762	0	0.428	8.334
13	8.762	0	0.449	8.313
14	8.762	0	0.471	8.291
15	8.762	0	0.495	8.267
16	8.762	0	0.520	8.242
17	8.762	0	0.546	8.216
18	8.762	0	0.573	8.189
19	8.762	0	0.602	8.160
20	8.762	0	0.632	8.130
21	8.762	0	0.663	8.099
22	8.762	0	0.696	8.066
23	8.762	0	0.731	8.031
24	8.762	0	0.768	7.994
25	8.762	0	0.806	7.956
26	8.762	0	0.847	7.915
27	8.762	0	0.889	7.873
28	8.762	0	0.933	7.829
29	8.762	0	0.980	7.782
30	8.762	0	1.029	7.733
31	8.762	0	1.080	7.682
32	8.762	0	1.135	7.627
33	8.762	0	1.191	7.571
34	8.762	0	1.251	7.511
35	8.762	0	1.313	7.449
36	8.762	0	1.379	7.383
37	8.762	0	1.448	7.314
38	8.762	0	1.520	7.242
39	8.762	0	1.596	7.166
40	8.762	0	1.676	7.086

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- Create in Excel a new table: called **Flood Mitigation Scenario I** (see figure left).
- Column 1: **Years** (starting with 1 up to 40 year)
- Column 2 **Risk Reduction** (i.e. Risk avoided, or Benefit)
- Column 3: **Invest cost** for the risk reduction scenario.
- Column 5: **Maintenance**
- Column 4: **Incremental Benefits**
- Enter the values and calculate the incremental benefit over the 40 years period.

Net Present Value

We need to take into account that the same amount of money in the future will be less valuable today. We will need therefore to calculate the so-called net present value (NPV).

The Net Present Value (NPV) calculates the net present value of an investment by using a discount rate and a series of future payments (negative values) and income (positive values).

$$NPV = \sum_{i=1}^{n} \frac{values_i}{(1+rate)^i}$$

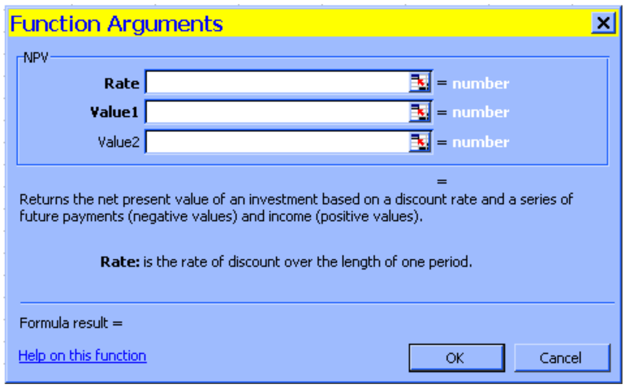
Rate: is the rate of discount over the length of one period
Value 1 value 2 ... are the "arguments" representing the payments and income.
NPV = the discounted benefits and costs at a given discount rate.
An example is given below:

	A	B
1	**Data**	**Description**
2	8%	Annual discount rate. This might represent the rate of inflation or the interest rate of a competing investment.
3	-40,000	Initial cost of investment
4	8,000	Return from first year
5	9,200	Return from second year
6	10,000	Return from third year
7	12,000	Return from fourth year
8	14,500	Return from fifth year
	Formula	**Description (Result)**
	=NPV(A2, A4:A8)+A3	Net present value of this investment (1,922.06)
	=NPV(A2, A4:A8, -9000)+A3	Net present value of this investment, with a loss in the sixth year of 9000 (-3,749.47)

☞

- In the Excel worksheet to the right of the table call a cell **NPV (Net Present Value)** ;
- In the cell next to it insert the name **Interest rate** (which is the same as discount rate) and enter the value o**f : 10 %.**
- In Excel: Click in your **"NPV" cell** and **Insert Function**; select **Financial Functions**.
- Select: **NPV**
- The Function Arguments Box opens (see figure below);
- Select for **Interest Rate** 10%
- For **value 1**: select the whole column down all the incremental benefits; starting at year 1 up to year 40.
- Click OK

Flood Mitigation Scenario 1						
	9.02					
year	**risk reduction**	**invest costs**	**Maintenance**	**incre benefits**	**NPV**	**Interest rate**
1	0	5	0.25	-5.25	-€3.10	10%
2	0	5	0.263	-5.263	**IRR**	
3	0	5	0.276	-5.276	9%	
4	0	5	0.289	-5.289		
5	0	5	0.304	-5.304		
6	0	5	0.319	-5.319		
7	0	5	0.335	-5.335		



- Repeat the NPV calculation, but now with a discount rate / interest rate of 5 and 20 %

Question:

- **Is the NPV still positive?**
- **What do you expect of the value of the Internal Rate of Return?**

Internal Rate of Return

Now we are going to calculate the Internal rate of return. The Internal Rate of Return is the discount rate/interest rate at which the NPV=0

- In Excel: Click Insert Function and select Financial Functions.
- Select: **IRR**
- The Function Arguments Box opens;
- **Read the HELP file**
- For values: select the whole column down all the incremental benefits; starting at year 1 up to year 40.
- Click OK.

Other flood scenario

Now we will compare the NPV and IRR values for the various flood risk reduction scenarios.

- Repeat the procedures for Flood Mitigation Scenario 2. Fill in the results in the table below.
- Remember that Flood Mitigation Scenario II has also Operation & Maintenance costs that have to be subtracted as well from the benefits, in order to calculate the incremental benefits. .

Flood Risk Reduction Scenario	NPV at 5 % interest rate	NPV at 10 % interest rate	NPV at 20 % interest rate	IRR
Mitigation Scenario I	€34.56	-€3.10	-€15.58	9%
Mitigation Scenario II	€195.80	€91.16	€27.32	42%

Question:
Which Mitigation Scenario would you advice the Municipality?