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 other columns. 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_VI
	VII_collapse_max	Seismic_VII
	VIII_collapse_max	Seismic_VIII
	IX_collapse_max	Seismic_IX
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.

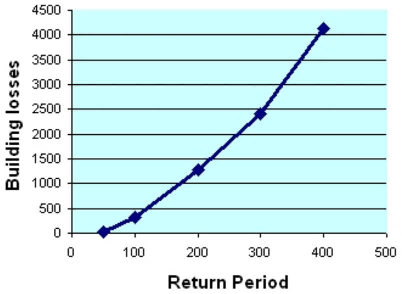
Question	Answer
Which scenario has the largest building losses?	
Compare scenarios with the same return period. Which one is the highest?	
Which mapping unit has the highest losses and in which scenario is that? (Hint: sort the table on the column with the highest losses in descending order)	
How many mapping units have no losses at all? (Hint: sort the table on the column with the highest losses in ascending order)	

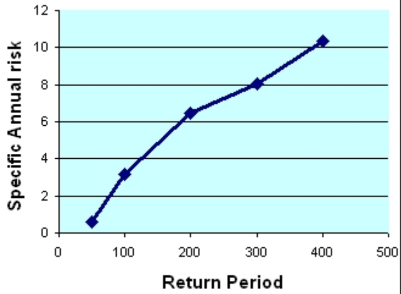
Step 2: Generating risk curves for building losses.

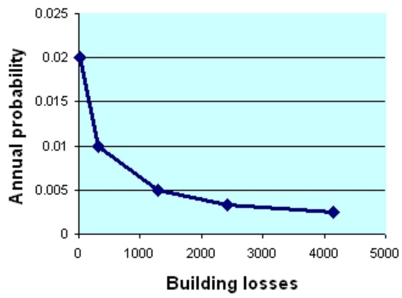
Now we have nearly all information to generate risk curves. The risk can be represented as a curve, in different ways:

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 type of curves for the other hazard types, and compare them.
- What can you conclude?

It is also possible to generate risk curves for individual mapping units. In principle you can make such curves at different levels of aggregation.

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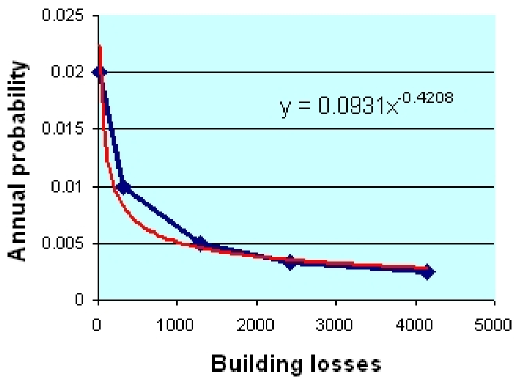
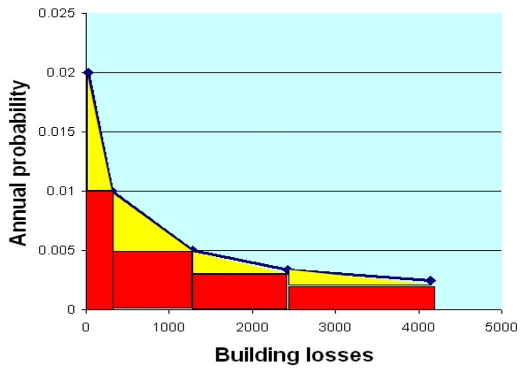
- Generate risk curves for mapping units Nr_998, Nr_149 and Nr_551
- Compare the results and determine which hazard are most important for each and which one has the highest level of risk.

Once you have obtained the Loss Exceedance curve you can also calculate the Annualized risk which is the total area under the curve. You can determine this in various ways:
- Determine in Excel a trendline for the curve and calculate the area under the curve.





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
- What is the average costs per mapping unit?
- 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 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 **Costs**. Multiply this with the building losses for each scenario.
- 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.

Step 4: Generating risk curves for population affected.