Tutorial on the use of GIS for quantitative multi-hazard risk assessment

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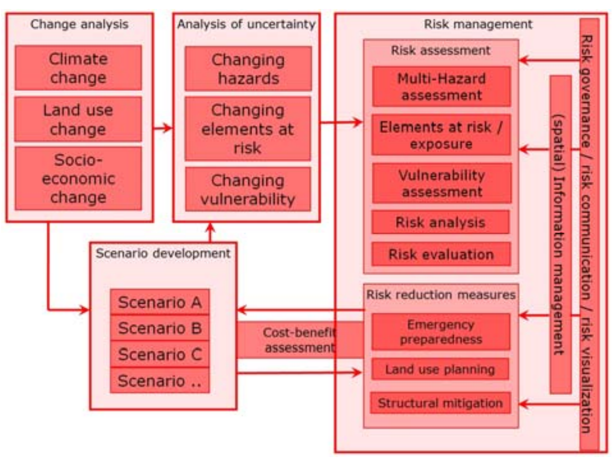
OUR MAIN FLOWCHART

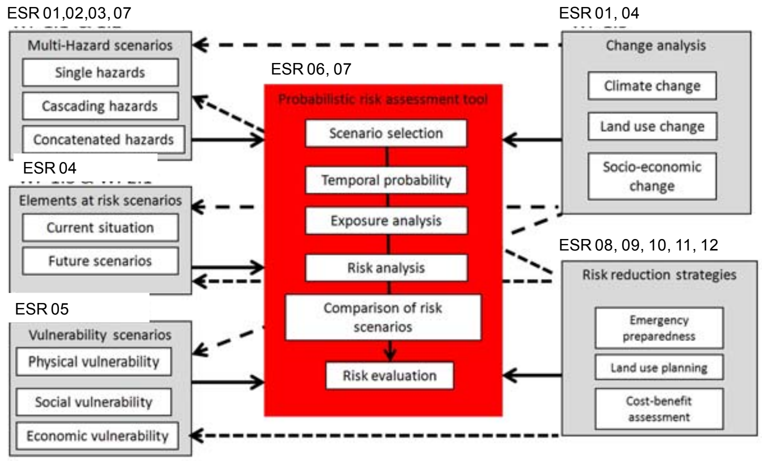


How easy is it to calculate the present risk?

Not so easy….

So how difficult will it be to calculate the future risk

HOW DOES THIS TRANSLATE TO YOUR RESEARCH?



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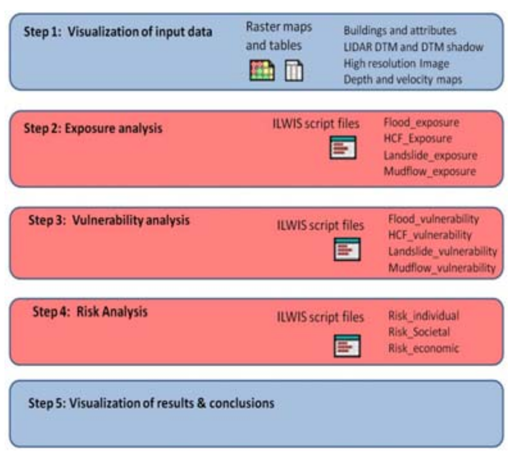
WHAT ARE WE GOING TO DO THIS AFTERNOON ?

- GIS practical
  - Input data
  - Exposure
  - Vulnerability
  - Risk analysis
    - Individual risk
    - Societal risk
    - Economic risk
- Evaluation session



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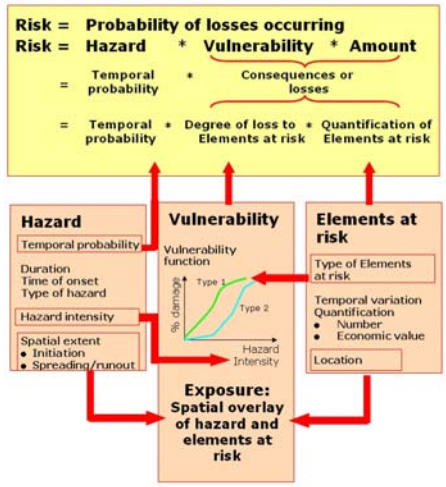
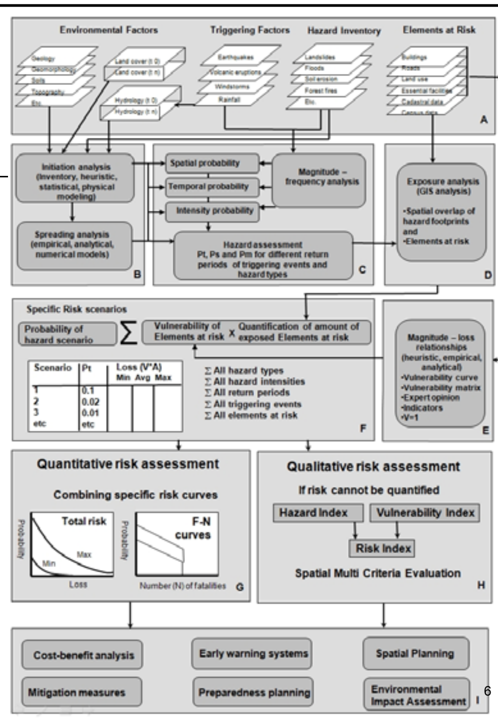
RISK CONCEPT

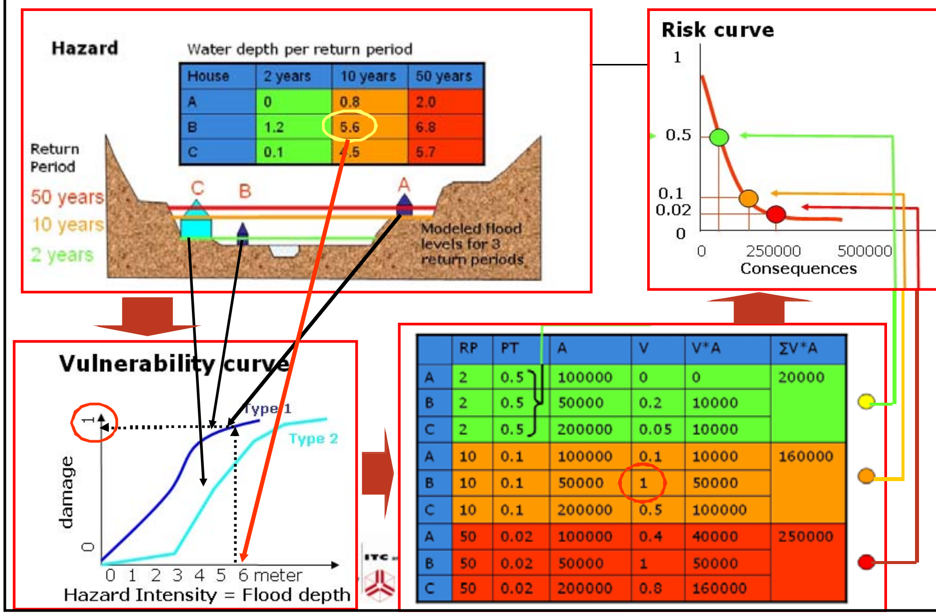


RISK ASSESSMENT

A: Input data
B: Susceptibility assessment
C: Hazard assessment
D: Exposure analysis
E: Vulnerability assessment
F: Risk assessment
G: Quantitative risk
H: Qualitative risk
I: Risk reduction



Generation of the Risk Curve

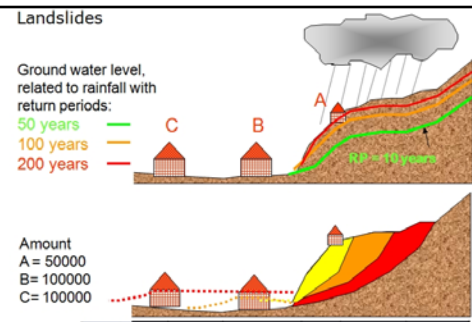


House	2 years	10 years	50 years
A	0	0.8	2.0
B	1.2	5.6	6.8
C	0.1	4.5	5.7

	RP	PT	A	V	V*A	ΣV*A
A	2	0.5	100000	0	0	20000
B	2	0.5	50000	0.2	10000	
C	2	0.5	200000	0.05	10000	
A	10	0.1	100000	0.1	10000	160000
B	10	0.1	50000	1	50000	
C	10	0.1	200000	0.5	100000	
A	50	0.02	100000	0.4	40000	250000
B	50	0.02	50000	1	50000	
C	50	0.02	200000	0.8	160000	

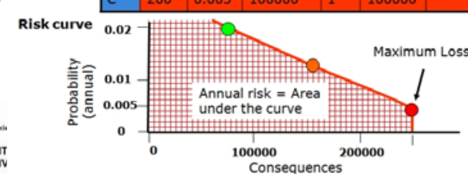
Landslide risk: very simplified example

What do we need to know:
- Temporal probability of triggering event
- Hydrological effect on slope
- Stability of slope / failure probability
- Volume of landslide
- Runout
  - Extent
  - Height
  - Velocity
  - Impact pressure
- Vulnerability of building
- Vulnerability of people in or outside
- Number of people
- Value of buildings



Risk calculation

	RP	PT	A	V	V*A	ΣV*A
A	50	0.02	50000	1	50000	70000
B	50	0.02	100000	0.2	20000	
C	50	0.02	100000	0	0	
A	100	0.01	50000	1	50000	150000
B	100	0.01	100000	1	100000	
C	100	0.01	100000	0	0	
A	200	0.005	50000	1	50000	250000
B	200	0.005	100000	1	100000	
C	200	0.005	100000	1	100000	



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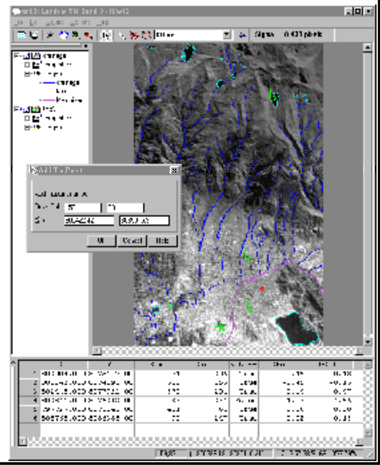
What is ILWIS?

- PC-based GIS & Remote Sensing package
- Developed by ITC
- A complete package:
  - image processing
  - spatial analysis
  - digital mapping
- Easy to learn and use:
  - full on-line help
  - extensive tutorials for direct use in courses
  - 25 case studies of various disciplines



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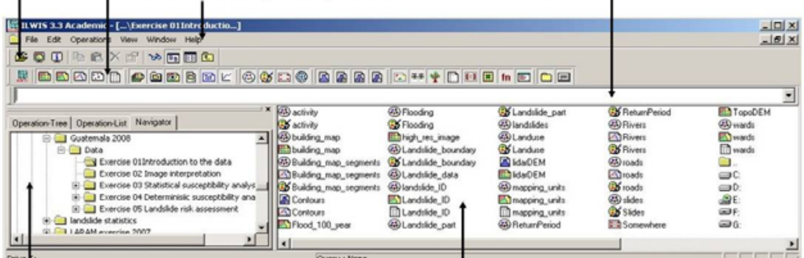
ILWIS Main window

Object selection
Defines which objects are visible in data catalog

Toolbar

Menu bar
Used for executing most operations

Command line:
Used for executing most of the calculations with maps



Navigation pane
You can also change it to operation-tree or operation list

Data catalog
with icons indicating different types of data.
Note: right-clicking on an icon gives the operations that are possible

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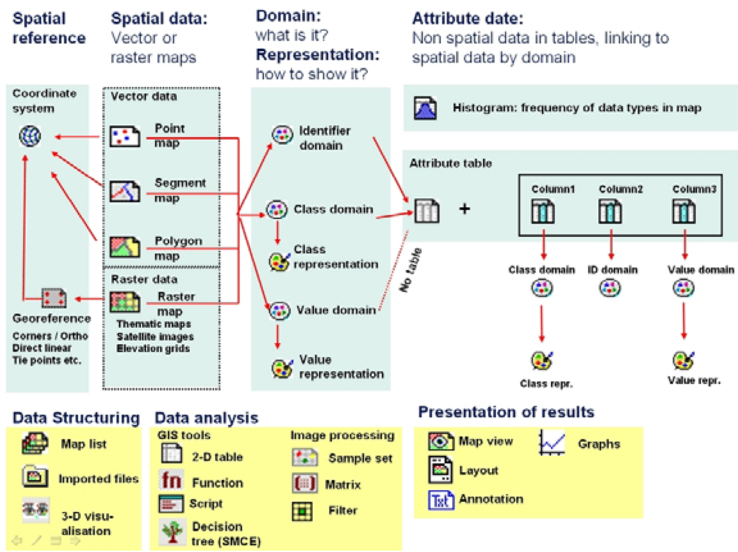
Main structure of ILWIS



How to use the data?

- Copy the directory T:\Changes to the D drive on your computer
- Create a directory D:\changes\nocera QRA\data
- Unzip the data (**exercise Nocera.zip**) into this directory
- Create a directory D:\changes\nocera QRA\software
- Unzip the zip file : **n52_ilwis_v3_08_beta_1.zip** in this directory
- Create a shortcut for the exe file ILWIS on the desktop
- Run the programme
- Go to directory: D:\changes\nocera QRA\data
- Follow the instructions in the text document

CASE STUDY: GIS FOR MULTI-HAZARD RISK ASSESSMENT MONTE ALBINO AREA, NOCERA INFERIORE

- Data collected by UNISA in framework of the SafeLand project (www.safeland-fp7.eu/)
- Method used is based on Deliverable 2.11 (QRA case studies at selected "hotspots"), prepared by UNISA
- Software used in ILWIS 3.08 (Open Source GIS) (http://52north.org/communities/ilwis/download)
- Shows entire procedure for risk assessment
- Using script files
- Short cuts & assumptions needed

52north exploring horizons

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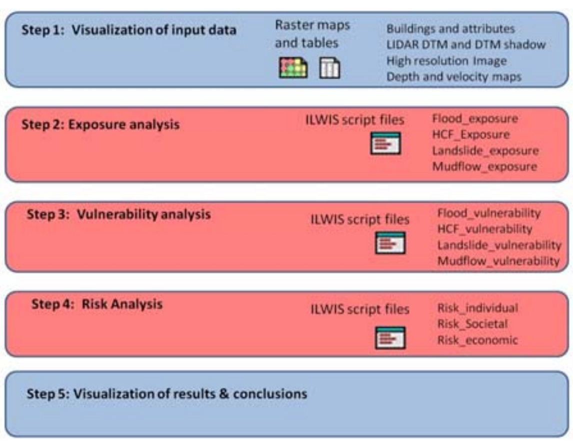
PROCEDURE: 5 STEPS EACH WILL TAKE ABOUT 20-30 MINUTES



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MULTI-HAZARD IN THE MONTE ALBINO, NOCERA AREA

- **Hyperconcentrated flows** related to erosion processes originated by heavy rains and affect the pyroclastic soils cover along rills as well as on the inter-rills areas.
- **Flashfloods** are originating from heavy rains as well, and they are having less sediment load than the hyperconcentrated flows.
- **Landslides** on the open slope sections, affect the triangular facets located at the base of the slope; they have similar characteristics to the phenomenon occurred on March 2005 (see figure) and are classifiable as "debris avalanches"
- **Mudflows** from flowslides that originate higher up in the catchment.

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Step 1: Visualization of input data

Raster maps and tables

Buildings and attributes
LIDAR DTM and DTM shadow
High resolution Image
Depth and velocity maps

Hazard type	Scenario	Return period	Hazard assessment	Files
Flooding	2 scenarios modelled	- 25 years - 100 years	FLO-2D	Flood_depth_020y Flood_depth_100y Flood_velocity_020y Flood_velovity_100y
Hyperconcen-trated flow	3 scenarios with different input parameters	- 17 years (before) - 200 years rainfall event used in the analysis	FLO-2D based on T=200 year rainfall	HCF_depth_sc1 to sc3 HCF_velocity_sc1 to sc3
Landslides	1 scenario	- 18.5 years	Empirical assessment of runout zones	Landslide_SF Landslide_distance Landslide_runout
Mudflows	1 scenario	- 200 years rainfall event	Safety factor analysis TRIGRS, runout with FLO-2D	Mudflow_depth Mudflow_velocity

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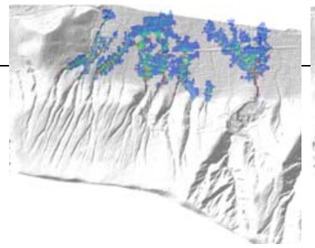
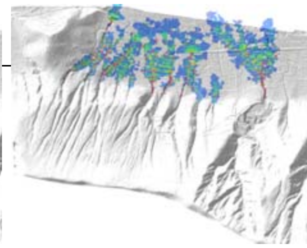
FLOOD HAZARD DATA

Flood depth:



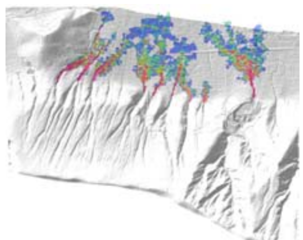
Flood Depth (20 years)



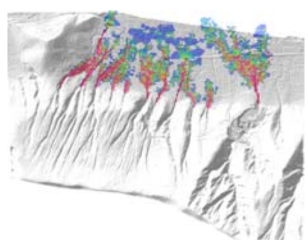
Flood Depth (100 years)

Depth (m)
0.01
0.08
0.16
0.23
0.30

Flow velocity:



Flow velocity (20 years)



Flow velocity (100 years)

Flow velocity (m/s)
0.00
0.10
0.20
0.30
0.40

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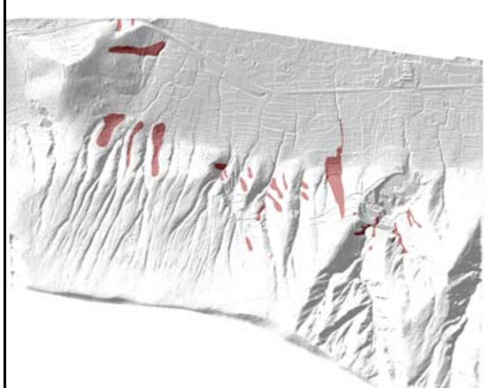
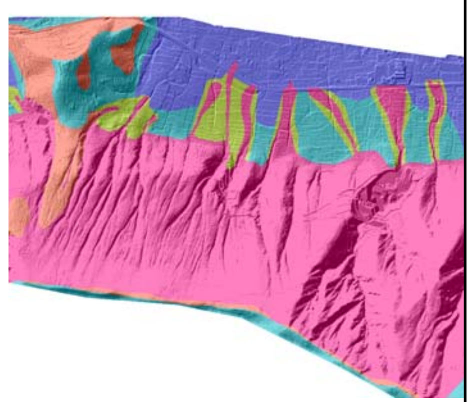
LANDSLIDE HAZARD DATA



Known landslides



Landslide hazard map

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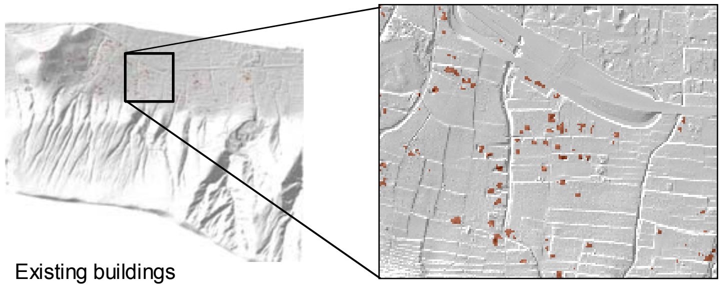
ELEMENTS AT RISK: BUILDINGS



Existing buildings

Attribute information :
- •Building materials (e.g. masonry)
- •Occupancy (e.g. residential)
- •Floors (number of floors)
- •Area (footprint area in sq meters)
- •People (maximum number of people at any time)
- •Value (economic value in Euros)

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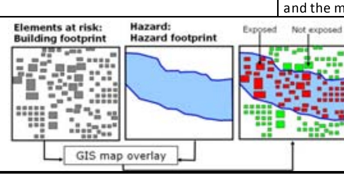
Step 2: Exposure analysis

ILWIS script files

Flood_exposure
HCF_Exposure
Landslide_exposure
Mudflow_exposure

Aim is: to make a spatial overlay between each of the hazard maps and the building map, and calculate the maximum depth and velocity of hyperconcentrated flows, floods and mudflows for each building.

Hazard and script file used.	Name of hazard maps	Description
Floods Flood_exposure	Flood_depth_020y Flood_velocity_020y	Flood depth & velocity modeled with FLO-2D with rainfall event that has a 20 year return period
	Flood_depth_100y Flood_velocity_100y	Flood depth & velocity modeled with FLO-2D with rainfall event that has a 100 year return period
Hyperconcentrated flow HCF_exposure	HCF_depth_sc1 to HCF_depth_sc3 HCF_velocity_sc1 to HCF_velocity_sc3	Depth and velocities modeled with FLO-2D with rainfall event of 200 year return period with 3 different sets of parameters for the model to represent the uncertainty.
Mudflow Mudflow_exposure	Mudflow_depth Mudflow_velocity	Depth and velocities modeled with TRIGGRS and FLO-2D with rainfall event of 200 year return period
Landslide Landslide_exposure	Landslide_distance	Emperically derived distance of the runout of landslides from 10 open slopes in between valleys
	Landslide_runout	File of the 10 runout areas with information in the attribute table on the relative stability of the slope above and the maximum runout.



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ILWIS SCRIPT FOR EXPOSURE ANALYSIS

EXAMPLE: FLOOD_EXPOSURE

```
//FLOODING EXPOSURE
Del exposure_flood*.* -force
copy Buildings.tbt Exposure_flood.tbt
//cross building map with flood depth maps and read in the maximum values per building
Exposure_flood_depth_020y.tbt := TableCross(Buildings,Flood_depth_020y,IgnoreUndefs)
TabCalc Exposure_flood h020 := ColumnJoinMax(Exposure_flood_depth_020y.tbt,Flood_depth_020y,Buildings,1)
Exposure_flood_depth_100y.tbt := TableCross(Buildings,Flood_depth_100y,IgnoreUndefs)
TabCalc Exposure_flood h100 := ColumnJoinMax(Exposure_flood_depth_100y.tbt,Flood_depth_100y,Buildings,1)
// cross buildings with flood velocity maps and read in teh maximum values per building
Exposure_flood_velocity_020y.tbt := TableCross(Buildings,Flood_velocity_020y,IgnoreUndefs)
TabCalc Exposure_flood v020 := ColumnJoinMax(Exposure_flood_velocity_020y.tbt,Flood_velocity_020y,Buildings,1)
Exposure_flood_velocity_100y.tbt := TableCross(Buildings,Flood_velocity_100y,IgnoreUndefs)
TabCalc Exposure_flood v100 := ColumnJoinMax(Exposure_flood_velocity_100y.tbt,Flood_velocity_100y,Buildings,1)
Del exposure_flood_depth*.* -force
Del exposure_flood_velocity*.* -force
//Finally we will check how many building are flooded in each of the two scenarios taking a thresholds of 10 centimeters
TabCalc Exposure_flood Nr_building_flooded_020:=iff(h020<0.1,0,1)
TabCalc Exposure_flood Nr_building_flooded_100:=iff(h100<0.1,0,1)
Open Exposure_flood.tbt
```


RESULTS EXPOSURE ANALYSIS

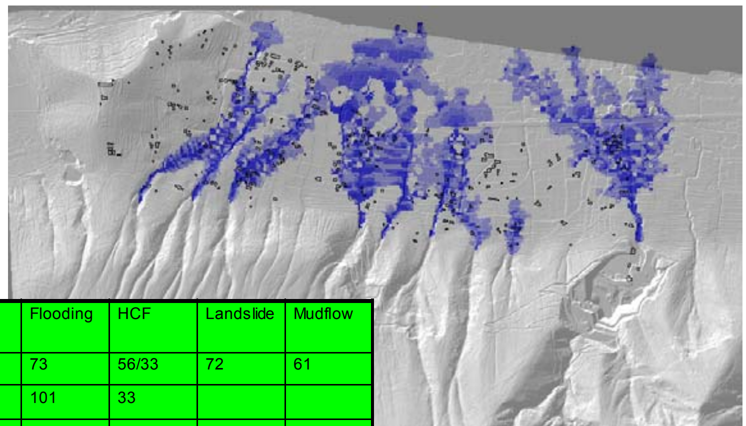
How many buildings are exposed?
Find out the results from the tables:

1. Exposure_flood
2. Exposure_hcf
3. Exposure_landslide
4. Exposure_mudflow

	Flooding	Hyperconcentrated flows	Landslide runout	Mudflow
Scenarios	020y	Sc1:		
		Sc2:		
	100y	Sc3:		

Exposure Analysis

Based on each Hazard map and the Building map:
- Calculation of maximum depth and velocity of Flows and Floods for each building
- Calculation of number of exposed buildings



Return period	Flooding	HCF	Landslide	Mudflow
20y	73	56/33	72	61
100y	101	33		

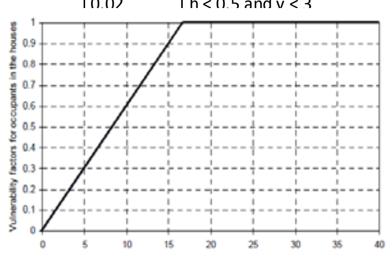
Step 3: Vulnerability analysis

ILWIS script files

Flood_vulnerability
HCF_vulnerability
Landslide_vulnerability
Mudflow_vulnerability

Flood		**Hyperconcentrated flow**		**Mudlfow**	
h ≥ 1 and v ≥ 5	0.1	h ≥ 1 and v ≥ 5	0.15	h ≥ 1 and v ≥ 7	1
h ≥ 1 and 1≤ v < 5	0.05	h ≥ 1 and 1≤ v < 5	0.1	h ≥ 1 and 3 ≤ v < 7	0.8
0.5 ≤ h < 1 and v ≥ 5	0.05	0.5 ≤ h < 1 and v ≥ 5	0.1	0.5 ≤ h < 1 and v ≥ 7	0.8
h ≥ 1 and v < 1	0.025	h ≥ 1 and v < 1	0.08	h ≥ 1 and v < 3	0.4
0.5 ≤ h < 1 and 1 ≤ v < 5	0.025	0.5 ≤ h < 1 and 1 ≤ v < 5	0.08	0.5 ≤ h < 1 and 3 ≤ v < 7	0.4
h < 0.5 and v ≥ 5	0.025	h < 0.5 and v ≥ 5	0.08	h < 0.5 and v ≥ 7	0.4
0.5 ≤ h < 1 and v < 1	0.01	0.5 ≤ h < 1 and v < 1	0.05	0.5 ≤ h < 1 and v < 3	0.2
h < 0.5 and 1 ≤ v < 5	0.01	h < 0.5 and 1 ≤ v < 5	0.05	h < 0.5 and 3 ≤ v < 7 0.4	0.4
h < 0.5 and v < 1	0.005	h < 0.5 and v < 1	0.02	h < 0.5 and v < 3	0.05

Landslides



How realistic are these?
For people?
For buildings?

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SCRIPT: VULNERABILITY ANALYSIS
EXAMPLE: FLOODING

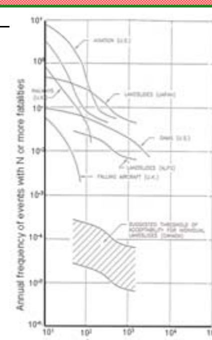
```
//FLOOD VULNERABILITY
//run flood_exposure.isl
opentbl Exposure_flood
TabCalc Exposure_flood  V020a:= iff(h020>=1,iff(v020<1,0.025,iff(v020<5,0.05,0.1)),0)
TabCalc Exposure_flood  V020b:=iff((h020<1)and(h020>=0.5),
iff(v020<1,0.01,iff(v020<5,0.025,0.05)),0)
TabCalc Exposure_flood  V020c:=iff((h020<0.5)and(h020>0.1),
iff(v020>5,0.05,iff(v020>1,0.01,iff(v020>0.1,0.005,0))),0)
TabCalc Exposure_flood  Vuln020:=max(v020a,v020b,v020c)
TabCalc Exposure_flood  V100a:= iff(h100>=1,iff(v100<1,0.025,iff(v100<5,0.05,0.1)),0)
TabCalc Exposure_flood  V100b:=iff((h100<1)and(h100>=0.5),
iff(v100<1,0.01,iff(v100<5,0.025,0.05)),0)
TabCalc Exposure_flood  V100c:=iff((h100<0.5)and(h100>0.1),
iff(v100>5,0.05,iff(v100>1,0.01,iff(v100>0.1,0.005,0))),0)
TabCalc Exposure_flood  Vuln100:=max(v100a,v100b,v100c)
Closetbl Exposure_flood
```

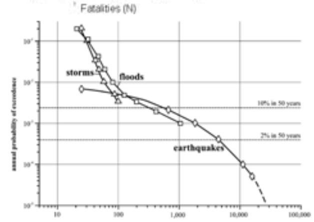

Step 4: Risk Analysis

ILWIS script files

Risk_individual
Risk_Societal
Risk_economic

- **Individual risk** = the probability of being killed by one of the types of hazard by a person that lives in one of the buildings in the exposed area.
- **Societal risk** = the number of people that might be killed in the area as a consequence of the natural hazards, and the associated probabilities of these losses.
- **Economic risk** = the expected losses to buildings expressed in terms of economic values (Euros) and the probability of these losses.





RISK ANALYSIS: INDIVIDUAL RISK

$$P_{LOL} = P_{(R)} * P_{(T:R)} * P_{(S:T)} * V_{(D:T)}$$

P_{LOL} = individual risk to loss of life of an individual exposed to one of the hazards
$P_{(R)}$ = the annual probability of occurrence of the hazard, calculated as 1/return period
$P_{(T:R)}$ = the probability that a landslide reaches the element at risk. As the models used do not consider this probability, we take this as 1.
$P_{(S:T)}$ = the temporal spatial probability of the element at risk. In order word, what is the probability that the person is actually in the building when the hazard strikes. For example, we could consider that people are in the building for 40% of the time, so than this factor is 0.4. In the first run we use a factor of 1.
$V_{(D:T)}$ = the vulnerability of the person in relation to the intensity of the hazard. This we have evaluated in the previous section, and are the vulnerability values calculated before.

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Individual risk

Cause	Probability / year	Cause	Probability / year
All causes (illness)	1.19E-02	Rock climbing	8.00E-03
Cancer	2.80E-03	Canoeing	2.00E-03
Road accidents	1.00E-04	Hang-gliding	1.50E-03
Accidents at home	9.30E-05	Motor cycling	2.40E-04
Fire	1.50E-05	Mining	9.00E-04
Drowning	6.00E-06	Fire fighting	8.00E-04
Excessive cold	8.00E-06	Police	2.00E-04
Lightning	1.00E-07	Accidents at offices	4.50E-06

- Individual risk can be calculated as the total risk divided by the population at risk.
- For example, if a region with a population of one million people experiences on average 5 deaths from flooding per year, the individual risk of being killed by a flood in that region is 5/1,000,000, usually expressed in orders of magnitude as 5×10^{-6}.

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SCRIPT FOR RISK ANALYSIS

ONE SCRIPT FOR ALL HAZARD TYPES: RISK_INDIVIDUAL

$P_{LOL} = P_{(R)} * P_{(T:R)} * P_{(S:T)} * V_{(D:T)}$

	$P_{(R)}$	$P_{(T:R)}$	$P_{(S:T)}$	$V_{(D:T)}$
Risk_flood_020:=(1/20)*Vuln020				Vuln020
Risk_flood_100:=(1/100)*Vuln100				Vuln100
Risk_HCF:=(1/200)*0.5*Vuln				Vuln
Risk_landslide:=(4/80)*(1/10)*Vuln				Vuln
Risk_mudflow:=(1/200)*Vuln				Vuln

- **Flood risk**
  - For two return periods: 20 years and 100 years
- **Hyperconcentrated flow risk**
  - Not all catchments will be affected by hyperconcentrated flows in the same event, so we apply a correction factor of 0.5
- **Landslide risk**
  - Not all catchments will be affected by landslide in the same event,we expect based on historical information that
  - 4 landslides are likely to happen over aperiod of 80 years ina total of 1p slope facets
- **Mudflow risk**
  - One triggering event with a return period of 200 years was modelled.

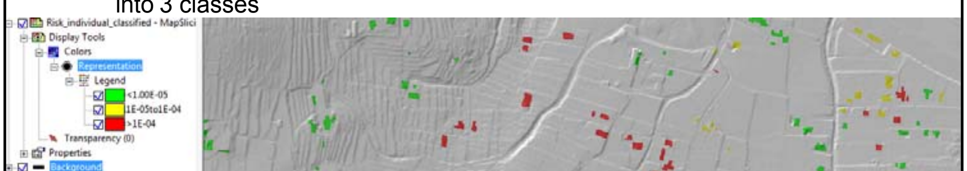
RESULTS INDIVIDUAL RISK ANALYSIS

The individual risks for flooding, HCF, landslide and mudflow are summed:

$R_{loltotal} = \sum (P_{(R)} * P_{(T:R)} * P_{(S:T)} * V_{(D:T)})$

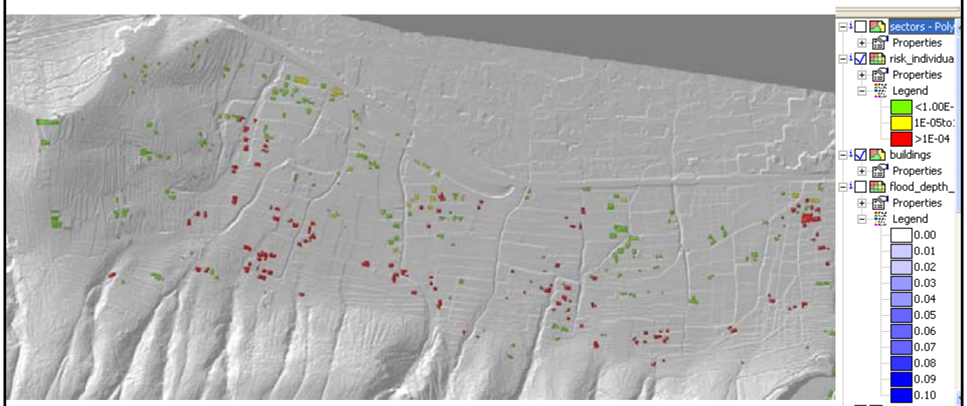
Question: **Is this allowed?**

The individual risks are then displayed in a map, and the map is classified into 3 classes



Risk Analysis- Individual Risk

Probability of being killed by one of the hazard types by a person that lives in one of the houses in the exposed area.



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RISK ANALYSIS: SOCIETAL RISK

$$P_{SOC} = P_{(R)} * (P_{(T:R)} * P_{(S:T)} * V_{(D:T)} * N_{(people)})$$

P_{soc} = societal risk

$P_{(R)}$ = the annual probability of occurrence of the hazard, calculated as 1/return period

$P_{(T:R)}$ = the probability that a landslide reaches the element at risk. As the models used do not consider this probability, we take this as 1.

$P_{(S:T)}$ = the temporal spatial probability of the element at risk. In order word, what is the probability that the person is actually in the building when the hazard strikes. For example, we could consider that people are in the building for 40% of the time, so than this factor is 0.4. In the first run we use a factor of 1.

$V_{(D:T)}$ = the vulnerability of the person in relation to the intensity of the hazard. This we have evaluated in the previous section, and are the vulnerability values calculated before.

N(People) = the number of people living in the building exposed to a certain level of hazard.

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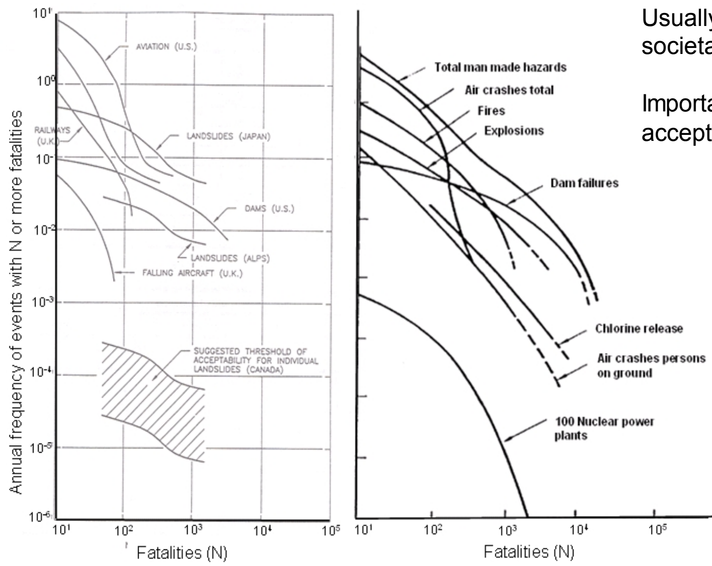
Societal risk: f-N curves

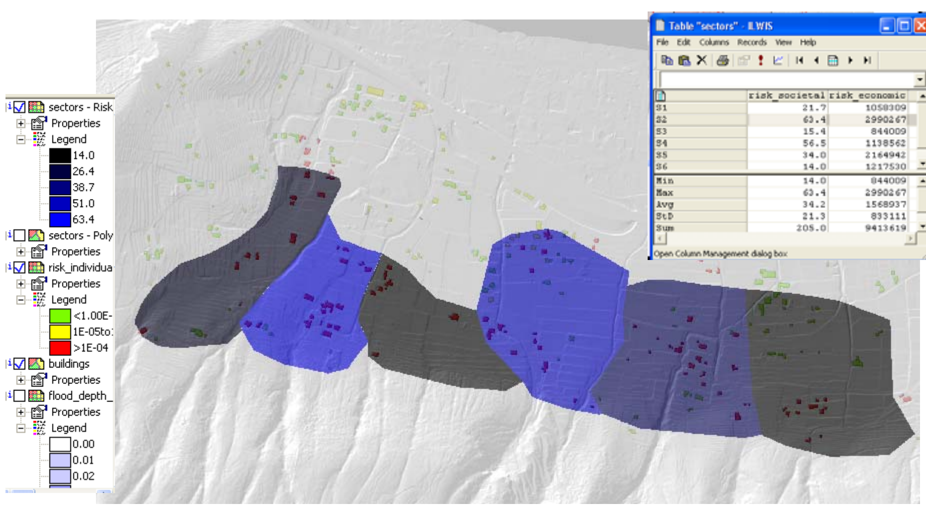


Usually used to express societal risk.

Important to define acceptable / tolerable risk

Left: f-N curves showing the number of Fatalities against annual frequency. For natural and man-made hazards

Prioritization: Societal Risk



	risk_societal	risk_economic
S1	21.7	1058309
S2	63.4	2990267
S3	15.4	844009
S4	56.5	1138562
S5	34.0	2164942
S6	14.0	1217530
Min	14.0	844009
Max	63.4	2990267
Avg	34.2	1568937
StD	21.3	833111
Sum	205.0	9413619

1. Priority: Sector 2
2. Priority: Sector 4
3. Priority: Sector 5

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RISK ANALYSIS: DIRECT ECONOMIC RISK

$$P_{eco} = P_{(R)} * (P_{(T:R)} * V_{(D:T)} * N_{(value)})$$

P_{eco} = economic risk

$P_{(R)}$ = the annual probability of occurrence of the hazard, calculated as 1/return period

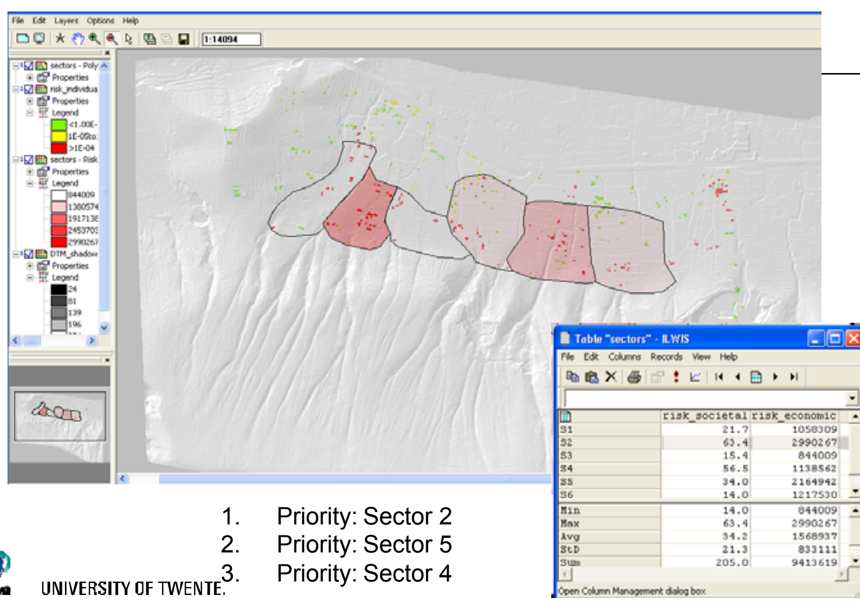
$P_{(T:R)}$ = the probability that a landslide reaches the element at risk. As the models used do not consider this probability, we take this as 1.

~~$P_{(S:T)}$ = the temporal spatial probability of the element at risk. In order word, what is the probability that the person is actually in the building when the hazard strikes. For example, we could consider that people are in the building for 40% of the time, so than this factor is 0.4. In the first run we use a factor of 1.~~

$V_{(D:T)}$ = the vulnerability of the person in relation to the intensity of the hazard. This we have evaluated in the previous section, and are the vulnerability values calculated before.

N(Value) = the total economic value of buildings exposed to a certain level of hazard. .

Priority Sector: Economic Risk



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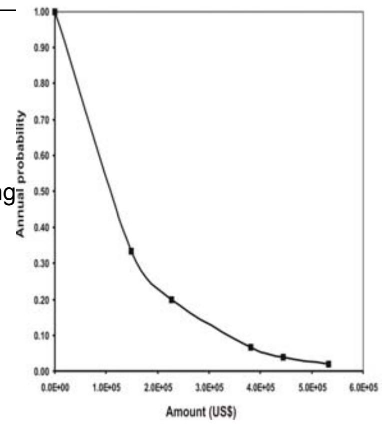
RISK CURVES

We need to have different scenarios
With different return periods
With different activities
We need to analyze vulnerability of building



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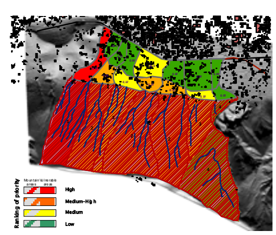
What next?
Prioritization of areas for risk reduction measures

- Questions
  - Which sectors of the study should get first/most attention?
  - Which risk reduction measures can be adopted?
  - For which types of hazard?
  - What do the stakeholders want?
  - How much would these measures cost?
  - How much will they reduce the risk?
- Which tools could be used?
  - Cost-benefit analysis: quantitative, looks only at costs
  - Spatial Multi-Criteria Evaluation: qualitative, can incorporporate all aspects. Decision support tool



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