TARAS SHEVCHENKO NATIONAL UNIVERSITY OF KYIV

INSTITUTE OF GEOLOGY

DEPARTMENT OF GENERAL AND HISTORICAL GEOLOGY

GEOLOGICAL RISKS AND HAZARDS
GUIDELINES FOR PRACTICAL CLASSES

Kyiv-2021

Іванік О.М., Кравченко Д.В. Geological risks and hazards. Guidelines for practical classes (Геологічні ризики та небезпеки. Методичні вказівки до виконання лабораторних робіт). Для студентів спеціальності 103 - Науки про Землю. – К., 27 с.

Рецензент: **Меньшов Олександр Ігоревич**, докт. геол. наук, асистент кафедри геофізики ННІ «Інститут геології» Київського національного університету імені Тараса Шевченка

Рекомендовано до друку Вченою Радою ННІ «Інститут геології» Київського національного університету імені Тараса Шевченка, протокол № 12 від 10 лютого 2021 року.

Aim of the discipline "Geological risks and hazards" is acquaintance with characteristics of natural hazard processes according to various structural, tectonic, landscape and climatic areas, classification features, modern methods and technologies of investigation of these processes and assessing their impact on the functioning of the natural and man-made systems.

Main objective is introduction of students with:

1) classification and main types of geological hazardous processes in various structural and tectonic areas;
2) main methods of the field investigation of the natural hazardous processes;
3) methods of laboratory investigation of the natural hazardous processes;
4) functional ability of special software for modelling of geological hazards; interpretation of modelling results; main approaches to the assessment and mitigation of geological risks and elaboration of preventive actions;

Practical classes description: natural hazard assessment, spatial modelling of hazardous geological processes in GIS, mathematic modelling of impact of geological processes on critical infrastructure, susceptibility mapping of geological hazards, risk assessment.

Table of Contents

Class№1.Comparative analysis and criteria of classification of natural hazards

Students should have knowledge of basics of geology and main geological processes including their peculiarities and distribution.

Concepts goals for this activity: Become more familiar with geological hazards and their distribution.

Task:

Compare main criteria of natural hazards classification:

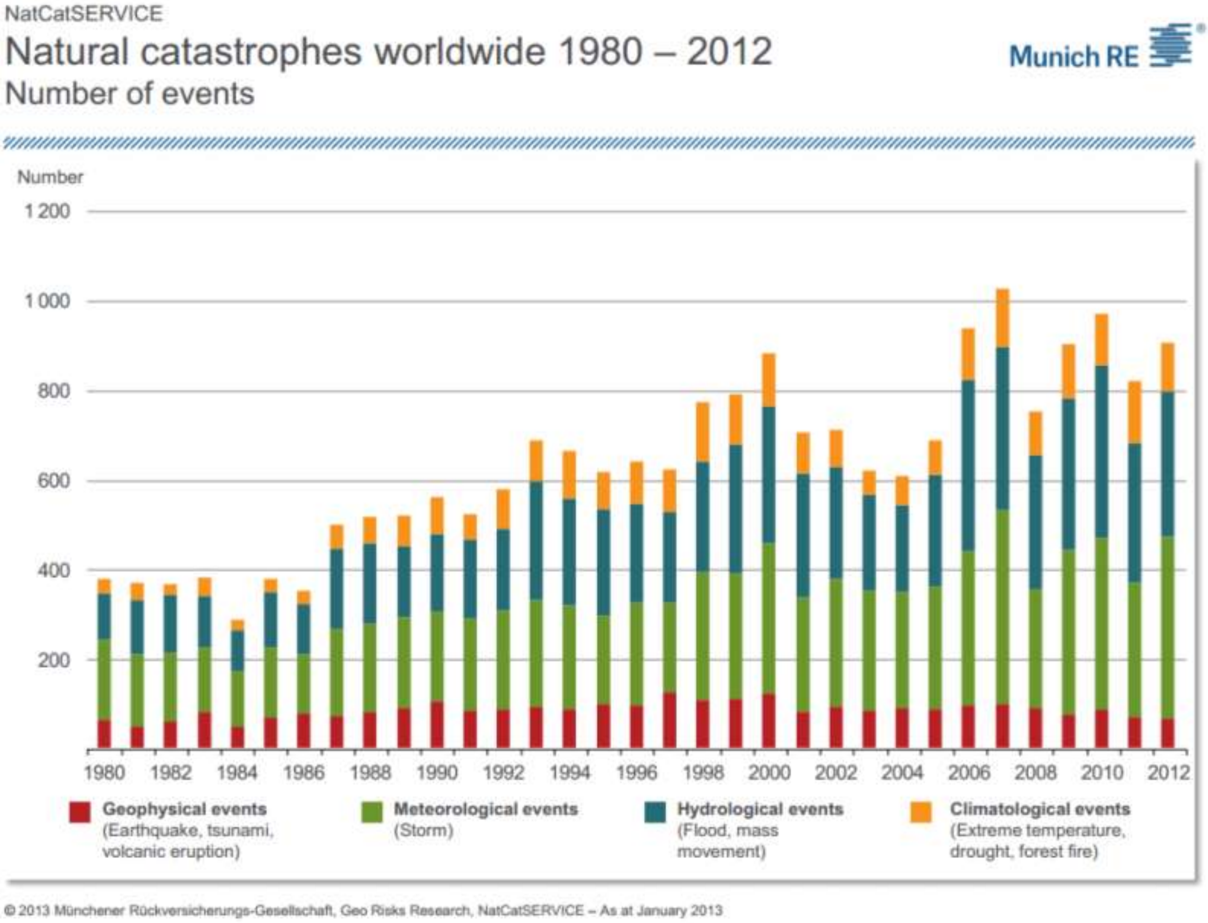
1. What makes an event a hazard or disaster based on information in the images.





2. What does the graph appear to show? Look at the detail on types of hazard. See the trends

Source:http://www.preventionweb.net/files/24476_20120104munichre.pdf



Questions for students:

1. What are the main criteria of natural hazards classification?

2. What makes an event a hazard or disaster?

3. Which geological hazards are the most devastating?

References:

1. Waterhttp://img.ehowcdn.com/article-new/ehow/images/a06/f9/r2/natural-hazards-disaster-management-800x800.jpg.
2. Internal displacement:http://www.internal-isplacement.org/8025708F004BE3B1/(httpGraphics)/B303AB7D46DFD5ECC12578D2005B9C8E/$file/nd-01-big.jpg.
3. Haiti earthquake: http://www.bing.com/images/search?q=haiti+earthquake&view=detail&id=CE5C433C1836E995E6DF12FF00689F877DA2DF3F&FORM=IDFRIR.
4. Guatemala's Volcano of Fire: http://www.bing.com/images/search?q=volcanic+eruption+diasaster&view=detail&id=D62AC286BAA6030CE1A08A8E7D78AFC1DB0139E2&FORM=IDFRIR
5. Fault Rupture source: http://www.teara.govt.nz/files/p4411gns.jpg; http://www.preventionweb.net/files/24476_20120104munichre.pdf

Class№2.Global distribution and main factors of seismic hazards

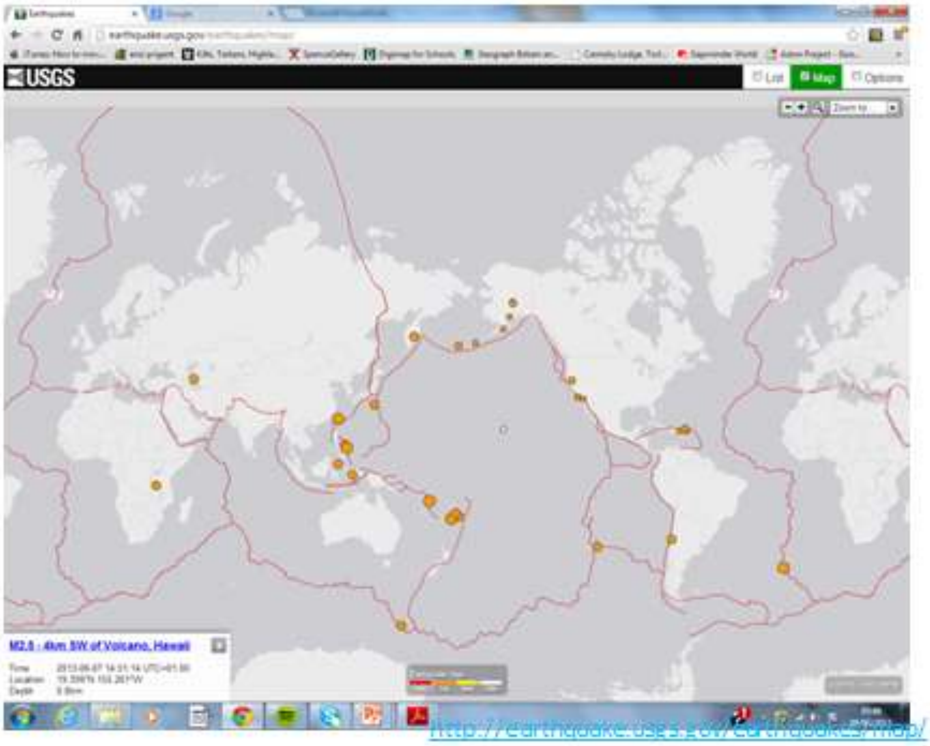
Students should have knowledge of basics of geology, geophysics, tectonophysics, structural geology.

Concepts goals for this activity: Become more familiar with geological hazards, global distribution and main causes of seismic hazards.

Task:

Describe the pattern of earthquakes (linear belts, around the edge of the Pacific Ocean, etc.).Are there variations in the concentration and spread of earthquakes within the linear belts? Where are most of the earthquakes clustered?

Source earthquake.usgs.gov



2. List reasons why Japan and Haiti are countries with the highest risk in the world to natural hazards. Why are they so **susceptible**, exposed to danger? **Compare and contrast** Haiti and Japan using disaster websites:

- **Prevention web** for risk profile: http://www.preventionweb.net/english/countries/statistics/risk.php?iso=hti
- International Disaster Database **EM-DAT** (www.emdat.be) and
- Centre for Research on the Epidemiology of Disasters, **CRED** (www.cred.be), for instance http://cred.be/sites/default/files/PressConference2010.pdf.

Questions for students:

1. *What are the main causes of seismic hazards?*
2. *What makes an seismic event a hazard or disaster?*
3. *Please describe the distribution of seismic hazards?*
4. *What are the implications for predicting major natural disasters in the future, not just earthquakes?*

References:

1. http://www.preventionweb.net/english/countries/statistics/risk.php?iso=hti
2. www.emdat.be
3. www.cred.be
4. www.earthquake.usgs.gov

Class№3. Disaster Risk Assessment

Students should have knowledge of basics geology, statistics.
Concept goals for this activity: measure hazard vulnerability.
Task:
Measures hazard vulnerability:
1. The Disaster Risk Formula measures hazard vulnerability:

$$\text{Disaster Risk} = \frac{\text{Natural Hazard} \times \text{Vulnerability}}{\text{Capacity of Societal System}}$$

Factors that decrease risk include:
- Effective warning and preparedness,
- Better planning and building practices,
- Development and insurance.

Source: FAO,

2. Draw a table to organise and capture your research for each case study using the prompts in the table. This template includes record of similar model.

Impacts	**Physical**	**Social**	**Economic**
Short term	Notable examples of natural and human-built landscape destroyed. Fires due to gas pipe explosions and electrical damage? Landslides and flooding?	Numbers of killed and injured, noting those in essential service professionals like doctors and policemen injured. Lack of food and health supplies? Damage or loss of homes, transport, communications, health care facilities, energy and water supply systems?	Note tangible losses due to the direct impact of property damage like destruction to shops and trade damaged or disrupted. Also, indirect losses resulting from social economic disruption, trade impacted by loss of communication, transport and water and energy supply infrastructure. Looting?
Long term	Intangible losses like the destruction of important natural and human landmarks and fertile lands.	Put here public health problems like disease (e.g., cholera due to contaminated water and lack of hygiene). Numbers of homeless and displaced people needing shelter and rehousing. Information on indirect impacts like stress and psychological damage.	Are settlements and shops being rebuilt and, if so, to higher standards? Settlements moved? People rehoused? Is there any positive impact in the form of aid, reconstruction and grants?

Questions for students:
1. How can we measure the geological hazards vulnerability?
2. What are the main factors that decrease the risk?

References:
1. http://www.fao.org/docrep/007/ae080e/ae080e01.htm
2. http://www.who.int/hac/techguidance/preparedness/emergency_preparedness_eng.pdf

Class№4.Development of quantitative algorithm and tools of debris flow impact on infrastructure

Students should have knowledge of basics of geology, geomorphology, deterministic modelling and hydrodynamics.

Concepts goals for this activity: Become more familiar with algorithms and methods of modelling of geological hazards impact on infrastructure.

Task:

Assess the impact of debris flows density and runoff coefficient on the value of the hydrodynamic force, pressure and velocity provided these estimated parameters. Illustrate the calculated results using tables and graphs of Word and Excel. Analyze these dependencies.

Algorithm

Debris flow danger prediction and evaluation of factors for debris flow forming are quite difficult task, coping with which is impossible without quantitative theory of debris flow formation and effect based on the complex of mathematical models describing different stages of debris flow process. Development of such theory and its practical application are connected with monumental challenges, stipulated by complexity and multifactor debris flow phenomena, great number of changeable parameters, which determine the progress of debris flow processes, absence of physically substantiated with accurate description of these processes.

The below algorithm is based on empirical data of the Carpathian district and fundamental laws of hydrodynamics, in particular, Bernoulli distribution, using which an expression for shock hydrodynamic pressure is obtained. Assuming that motion of an ideal fluid is adiabatic and stationary, while mass forces are conservative, the following formula is executed on the flow lines

$$\frac{v^2}{2} + \Pi + \mathrm{P} = const,$$

that is called Bernoulli integral.

For homogenous uncompressed liquid $\rho = const$ and that’s why

$$\frac{v^2}{2} + \Pi + \frac{p}{\rho} = const \ .$$

If mass forces are gravity forces ($\Pi = gz$), then

$$\frac{v^2}{2g} + z + \frac{p}{\rho g} = const,$$

where $\frac{v^2}{2g}$ – velocity head; z – elevation (levelling) head; $\frac{p}{\rho g}$ – piezometric head.

If to consider two cross sections of stream, indicating them 1 and 2 and via $p_1, v_{1,} z_1, p_2, v_{2,} z_2$, to indicate the corresponding values of pressure, speed and height for each of these cross sections, we’ll have other form for recording Bernoulli integral:

$$\frac{v_1^{\ 2}}{2g}+z_1+\frac{p_1}{\rho g}=\frac{v_2^{\ 2}}{2g}+z_2+\frac{p_2}{\rho g}.$$

Choosing position of the second cross section on the wall of fixed obstacle (any engineering transport facility can be obstacle, for example, road, bridge, etc. will have obvious equations: $v_2=0, z_1=z_2$.

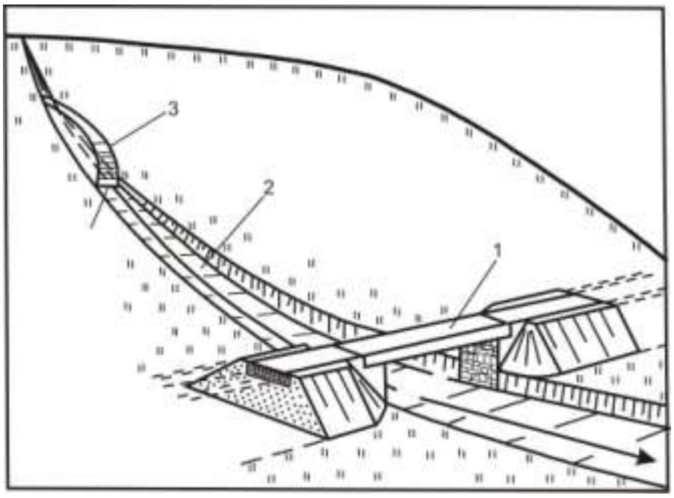
Hence

$$\frac{v_1^{\ 2}}{2g}+\frac{p_1}{\rho g}=\frac{p_2}{\rho g} \text{ or } \frac{p}{\gamma}=\frac{\left(p_2-p_1\right)}{\gamma}=\frac{v^2}{2g}.$$

Considering the most unfavourable scenario of flow collision with obstacle, when heavy lump of rock kicks the obstacle wall, the last formula may be rewritten in form:

$$\frac{p}{\gamma}=K\alpha\frac{v^2}{2g},$$

where K – coefficient, considering characteristics of bodies, experiencing knock; by the considered type of knock it is guessed to be equal to 2; α – evaluation speed coefficient by quantity of motion, it is guessed to be equal to 1-1.33.



Cross section of debris flow channel along the road:

1 – bridge; 2 – debris flow channel; 3 – debris flow formation

It should be noted that Bernoulli distribution, we assume that the flow acts like an ideal uncompressed liquid, although in reality it is a mixture with a great difference of densities of solid and liquid fraction.

Now we'll have formula for hydrostatic pressure. According to the hydrostatic Pascal's paradox we have the following formula for the main vector of fluid-pressure-induced force on the wall of obstacle with surface area S:

$$R=\gamma z_c S,$$

where z_c – vertical coordinate of gravity centre C of area S. Hence, for pressure we'll have:

$$p=\frac{R}{S}=\gamma z_c$$

or

$$\frac{p}{\gamma}=z_c=\frac{H}{2},$$

where H – flow depth.

Thus, making expressions for shock hydrodynamic and hydrostatic pressures, we obtain an expression for full pressure of the stream over obstacle:

$$p = \gamma \frac{H}{2} + \gamma K \alpha \frac{v^2}{2g} = \frac{\gamma}{g}\left(\frac{gH}{2} + K\alpha \frac{v^2}{2} \right).$$

Assuming that $g \approx 10$ in this formula, we'll have:

$$p = \gamma \frac{H}{2} + \gamma K \alpha \frac{v^2}{2g} = 0.1\gamma \left(5H + K\alpha \frac{v^2}{2} \right).$$

By $K = 2$ and $\alpha = 1$ we'll obtain the formula of I.I. Kherkheulidze:

$P_{повний} = 0{,}1\gamma_c \left(5H_0 + v_c{}^2\right)$

where $P_{повний}$ (t/m^2) – full pressure; γ_C (t/m^3) – average density (specific gravity) of debris flow; H_0 (m) – depth of debris flow; v_C (m/s) – speed of debris flow.

Calculated formulas for the maximum cost of rain floods are very diverse, based on different principles. Most of those who have received sufficiently wide application take into account area of water collection, intensity of shower and run-off completeness, as well as less significant factors, whereof influence is transmitted by corrective factors.

The formula of D.L. Sokolovskyi considering run-off volume $Q_c = \frac{0.28\alpha\ H_t F_v}{t} f_h$,

where Q_C (m^3/s) – flow cost; H_t (mm) – rainfall determined as product of average rain intensity and its duration; α – run-off factor; t (h) – time of flood raise; F_v (km^2) –- water collection area; f_h – coefficient of hydrograph form.

Run-off coefficient of rainfall floods depends on rainfall and on previous soil moisture and infiltration regime. Intensity of infiltration is one of the main factors of the substrate surface, which is determined by the nature of soil and vegetation. In the early stages, infiltration intensity of can be quite high, after filling pores with water, it decreases and asymptotically approaches the established value of filtration.

As for connection of run-off layer with rainfall layer, according to the date of Valdai branch of the State Hydrological Institute, although for 114 floods it is quite clearly expressed, but has a significant scatter of points stipulated by soil moisture. Its significance for high rain floods is marked by relative stability over geographic zones and is determined by analogy with previously studied pools. In the Carpathian region, run-off coefficient in dry period varies from 0 to 0.2, in wet - it increases to 0.4 - 0.5, and in particularly rainy periods it reaches 0.7.

Effectiveness of the formula of D.L. Sokolovskyi in the calculation module is decreased by inaccurate determination of t value and f_h. coefficient. Use to determine the last empirical formula:

$$f_h = \frac{12}{4 + v},$$

where v (m/sec) – the greatest speed by crossing flow, requires data as to more variable parameter – flux speed.

The phase of raising the flood schedule consists of a flat part, which reflects water run-off the nearest downpour slopes, and a corner part stipulated by water inflow from the biggest part of pool:

from the biggest part of pool:

$$t = \tau_n + t_{n.\partial},$$

Under the condition of known speed and if observations are absent:

$$\tau_n = \frac{L}{3{,}6\,v},$$

where L (km) – channel length to the calculated structure, v - average velocity of flood peak travel, which in its turn is equal to $v = 0.70 v_{max}$, where v_{max} – - maximum flow velocity in cross section (m/s); τ_n - time of peak flood travel, equal to shift time between rain peak and flood peak (h); $t_{n.\partial}$- duration of rain raise.

The estimated duration of the shower is determined by time of flood peak travel:

$$T = \mu\tau_n,$$

where T – estimated duration of rainfall; τ_n – time peak flood travel; μ – coefficient of slowing down of run-off.

By τ_n<10-15 h, $T=\tau_n$

The formula of N.E. Dolhov for full run-off is substantially easier for calculation prediction

$$Q_{\max} = k_p a\alpha F,$$

where k_p - coefficient of dimension; a – average intensity of shower; α – run-off coefficient; F - area of the pool. Defining $Q_{\max}$ in m^3/s, and– in mm/h, and F – in km^2, the preceding formula will look as follows

$$Q_{\max} = 0.28a\alpha F.$$

In general, rainstorms and rains considering the effect with regard to run-off are divided into several types: 1) rainstorms - short and intense rains lasting no more than 2-3 hours and with average intensity of a≥10-20 mm/h; 2) rain showers lasting from a few hours to several days with average intensity of a≥2-10 mm/h; 3) widespread rain, as a rule, with intensity of 3-5 days and more with a small average intensity of a<2 mm/h; Maximum debris flow effect is executed by rainstorms of the first type, although probability of debris flow occurrence due to other types is also high. It should be added that overall duration of the rains is not sufficient for their characteristics regarding the drainage effect, it is desirable to take into account duration of their effective part, within which rain intensity exceeds infiltration intensity, so-called water yield duration, during which drainage process takes place. It is clear that with increase in rain duration, its intensity decreases. Intensity of rainstorm is calculated by the following formula:

$$a = \frac{c}{1+bt},$$

where b and c – parameters, determined based on meteorological data for specific climatic district. By changing b parameter in a certain way, the ration of calculated intensity of short continuous rains may be varied. C parameter allows considering higher or lower intensity of rains of equal duration.

1 – average rain intensity; 2 – rain intensity by calculation formula.

For the Eastern European territory this formula looks as below (calculated on the basis of data of long-term meteorological observations over 28 meteorological stations in this region):

$$a = \frac{5}{1+0{,}06t}.$$

Since morphometric elements of the channel, in particular, depth and slope, included in Chezy formula, vary not less from velocity, what is more, with increase in depths, slopes, as a rule, tend to decrease, then the exactly velocity is often more stable value than its constituents. Nevertheless, he proposes the formula improved on the basis of investigative data:

$$V_{\max} = 17{,}0 J^{0{,}40} h_{cp}^{0{,}50},$$

where V_{max} – maximum velocity in cross section; J – channel slope; h_{cp} – average depth on effective cross section at maximum accumulation.

Based on Chezy formula other formulas were proposed to determine channel velocities. The above-mentioned formulas of M.F. Sribnyi, M.A. Mostkov, I.I. Kherkheulidze and others got widespread. M.M. Protodiakonov noting dependence of run-off velocity V m/sec on channel slope I ‰, from quantity of running-off water, which is measured by water discharges Qm^3/sec, as well as surface irregularities and channel cross-section, proposes to determine velocity of channel flow according to Chezy formula with coefficient by Manning:

$$V = k_1 Q^{\frac{1}{4}} I^{\frac{3}{8}};\ k_1 = 0{,}075\left(\frac{1}{n}\right)^{\frac{3}{4}} k^{\frac{1}{2}}$$

Here I –average channel slope, ‰; $\frac{1}{n}$ – coefficient of bottom irregularities; $k = \frac{R}{\sqrt{\omega}}$ – coefficient depending on form of channel cross-section; R – hydraulic radius, m; ω – area of effective cross section, m^2.

In calculations 1/n = 25 is usually taken (at extreme values for periodic flows - from 15 to 30), k = 0.30 (extreme values: from 0.15 to 0.40). Therefore, close to average value k_1 = 0.46.

Channels are proposed to be divided into three groups by peculiar channel length: 1) $L_1 < 1$ km; 2) $1 \le L_2 < 5$ km; 3) $L_3 \ge 5$ km. On the grounds of analysis of available data the following empirical dependences of rainstorm duration for each group considering change of intensity and critical velocities: $v_1 = 5\sqrt{T}$; $v_2 = 3\sqrt[4]{T}$; $v_3 = 2\sqrt[6]{T}$.

Thus, setting rainstorm intensity – H_t, its duration in hours – T, area of the territory, where it happened – F_V, soil ability to absorb water – α coefficient and expected channel length for this district – L, we calculate velocity and discharge of debris flow – correspondingly v_c and Q_c.

On the other hand, these values are connected with area of debris flow channel with the following ratio:

$$Q_c = v_c \cdot S,$$

where S – area of cross section debris flow channel. Then

$$S = \frac{Q_c}{v_c}.$$

Let's think that channel cross section has form of trapezium with a, b bases and H_0 height. Then

$$S = \frac{a+b}{2} \cdot H_0 .$$

Assuming that channel width on the bottom (a value) and angles of channel slope (φ_1, φ_2) are known, geometrically we have:

$$b = a + H_0\left(ctg\varphi_1 + ctg\varphi_2\right)$$

and

$$S = \left[a + \frac{H_0}{2}\left(ctg\varphi_1 + ctg\varphi_2\right)\right] \cdot H_0 .$$

We receive equation for finding out H_0 debris flow depth according to the set values of slope angles and flow width on the bottom as well as by early discovered debris flow discharges and velocity:

$$H_0^2\left(ctg\varphi_1 + ctg\varphi_2\right) + 2aH_0 - 2\frac{Q_c}{v_c} = 0 .$$

Hence

$$H_0 = \frac{-a + \sqrt{a^2 + 2\frac{Q_c}{v_c}\left(ctg\varphi_1 + ctg\varphi_2\right)}}{ctg\varphi_1 + ctg\varphi_2} .$$

When determining channel slope angles consideration must be given to the fact that they are usually irregular surfaces of changeable steepness. However, local decreases and increases of steepness are mutually compensated, which results in taking slope steepness constant, in other words, slopes are taken in form of bent planes with slope equal to average slope incline. This circumstance was considered when obtaining data as to slope incline angles both according to measurements during field works and when using GIS project data on the Carpathian field test site.

Thus, setting debris flow density and using the developed mathematical model, we can calculate a complete unstable (dynamic) debris flow pressure on the engineering facility.

Hydrodynamic force affecting the building is calculated according to the formula:

$$F = P_{\text{повний}} \cdot S \ .$$

The presented algorithm, based on empirical data on the Carpathian region and the fundamental laws of hydrodynamics, demonstrates the necessity of choosing calculation formulas and quantities, determination of which is possible under specific situations and in corresponding geological and geomorphological conditions. Based on the proposed algorithm, a software module was created for calculating loads transferred to the engineering structure under the influence of the external environment. This module allows to model influence of debris flows of the Carpathian region on transport objects of different purposes on the basis of the above-mentioned various calculation methods and, taking into account parameters both of the flows themselves and geological and geomorphological and hydrometeorological data.

Example

Rainfall - 50 min
The average size of stones - 0.10 m
Drainage area - 3.3 square kilometers
Density of rocks - 2.6 t/m^3
Length of channel - 2 km
Debris flows density - 1.5 t/m^3 through
Debris flows width - 2 m
The angle of the left slope - 30 º
The angle of the right slope - 35 º
Type of the soil saturation - saturated
Excess of relief of relief- 306 m
Length of projection - 2473 m

Rain-falls (mm)	**Duration of rain-fall (h);**	**Drainage areak m^2.**	**Channel length(m);**	**Run-off coefficient;**	**Mud-flow density (t/m^3)**	**Mud-flow width (m)**	**Left slope (degree)**	**Right slope (degree)**	**Debris flow velocity, m\s**	**Flow dis-charge, Qc, m^3/s**	**Hydrody-namic force (T)**
50	0,7	8.9	2	**0,05**	1,5	2	30	35	0,6	0,2	0,02
50	0,7	8.9	2	**0,1**	1,5	2	30	35	0,6	0,3	0,07
50	0,7	8.9	2	**0,2**	1,5	2	30	35	0,6	0,6	0,28
50	0,7	8.9	2	**0,3**	1,5	2	30	35	0,6	1	0,62
50	0,7	8.9	2	**0,4**	1,5	2	30	35	0,6	1,3	1,09
50	0,7	8.9	2	**0,5**	1,5	2	30	35	0,6	1,6	1,68
50	0,7	8.9	2	**0,6**	1,5	2	30	35	0,6	1,9	2,4
50	0,7	8.9	2	**0,7**	1,5	2	30	35	0,6	2,2	3,2
50	0,7	8.9	2	**0,8**	1,5	2	30	35	0,6	2,6	4,21

Questions for students:

1. What are the main geological causes of debris flows hazards?

2. What are the main formulas for assessment of debris flows impact on infrastructure?

References:

1. I.D. Bagrii, P.V. Blinov, P.F. Hozhyk, V.P. Kozhemiakin Activation of dangerous geological phenomena in Transcarpathia as a result of extreme floods. - K, 2004. - 210 p. (In Ukrainian)

2. O.M. Ivanik. The main features of interconnections of debris flows formation factors within the basin of the Abranka River // Bulletin of the University of Kiev. Series Geology. – Issue 43. - 2008. - p. 16-19. (In Ukrainian)

3. Cannon S., Gartner J., Rupert M., Michael J. A method for the rapid assessment of the probability of post-wildfire debris flow from recently burned basins in the intermountain west, U.S.A. / Geophysical Research Abstracts, Vol. 8, 02030, 2006.

4. V.V. Shevchuk, O.M. Ivanik, M.V. Lavreniuk Development of computer simulation tools of debris flow hazards within the Carpathian region // Theoretical and applied aspects of geoinformatics. K, 2009. - p. 307-318.

Class№5.Susceptibility mapping of Landslide hazards

Students should have knowledge of basics of geology and GIS modelling and be able to apply the spatial modelling for landslide hazards assessment.

Concepts goals for this activity: Become more familiar with methods of susceptibility mapping and landslide hazard assessment.

Task:

1. To assess the main factors of landslide hazards of the selected area.
2. To create the susceptibility map of landslide hazards of the selected area.

Short workflow

Susceptibility mapping and weighted overlay analysis.

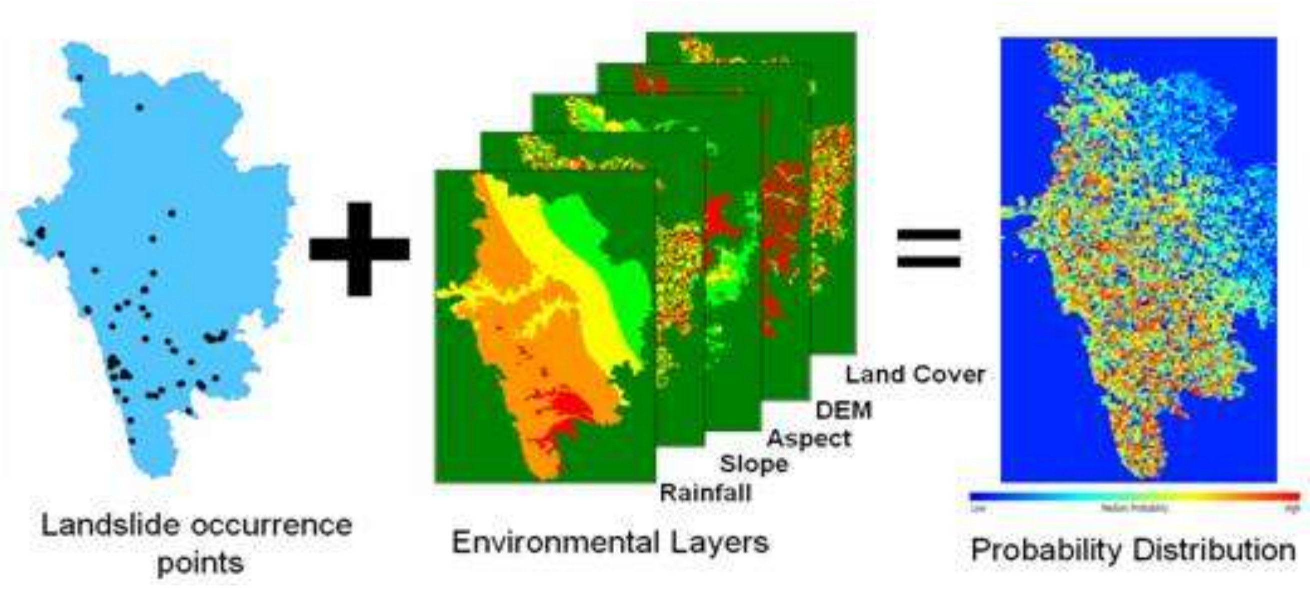
Landslide processes that occur on the slopes of different genesis and morphology are considered to be the most active factors of influence on natural and man-made systems and infrastructure objects. Each of the landslide processes requires special approaches to their modeling and forecasting, which are determined by geological models of the slope and the process. The development of this model is based on in-depth geological analysis of the geological environment and the determination of the parameters and characteristics of processes that differ depending on the rheological state of the geological environment and the corresponding geological structure of the slopes.

Susceptibility measures the degree to which a terrain can be affected by future slope movements. In other words, it is **an estimate of "where" landslides are likely to occur**. In mathematical language, susceptibility can be defined as the probability of spatial occurrence of slope failures, given a set of geo-environmental conditions. This was called "landslide analysis". Susceptibility does not consider the size e.g., the length, width, depth, area or volume of the landslides, but susceptibility assessments can be prepared for different-sized landslides (Carrara et al., 1995).

A **landslide susceptibility map** goes beyond an inventory map and depicts areas that have the potential for landsliding. These areas are determined by correlating some of the principal factors that contribute to landsliding (such as steep slopes, weak geologic units that lose strength when saturated or disturbed, and poorly drained rock or soil) with the past distribution of landslides.

These maps indicate only the relative stability of slopes; they do not make absolute predictions.

Landslide **susceptibility analysis**



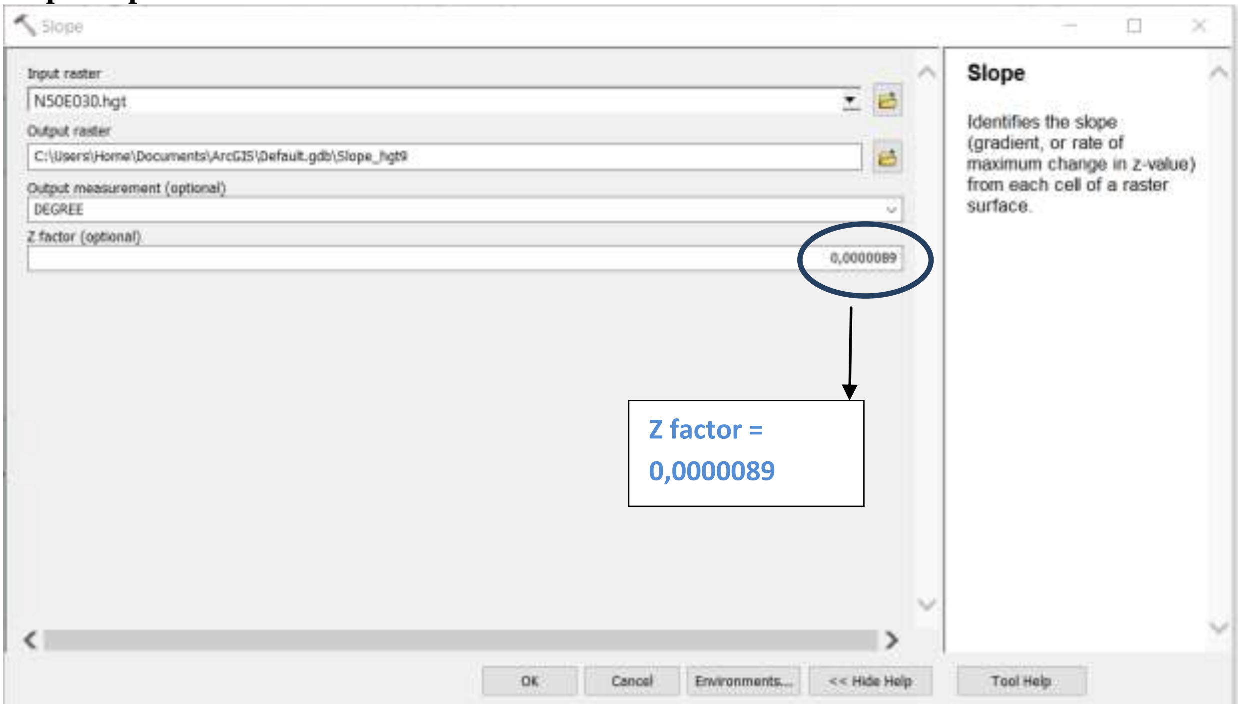
1) SRTM raster –>**Slope** (Spatial Analyst) –> **Reclassify** (Spatial Analyst): create 4 classes;

2) Faults layer–>**Multiple Ring Buffer** (Analysis): distance 500, 1000, 1500, 2000, 8000 –>**Spatial Join** (Analysis): target –Multiple Ring Buffer Output, join – landslide points –>**Feature to Raster** (Conversion): field – join_count–> **Reclassify** (Spatial Analyst): create 4 classes;

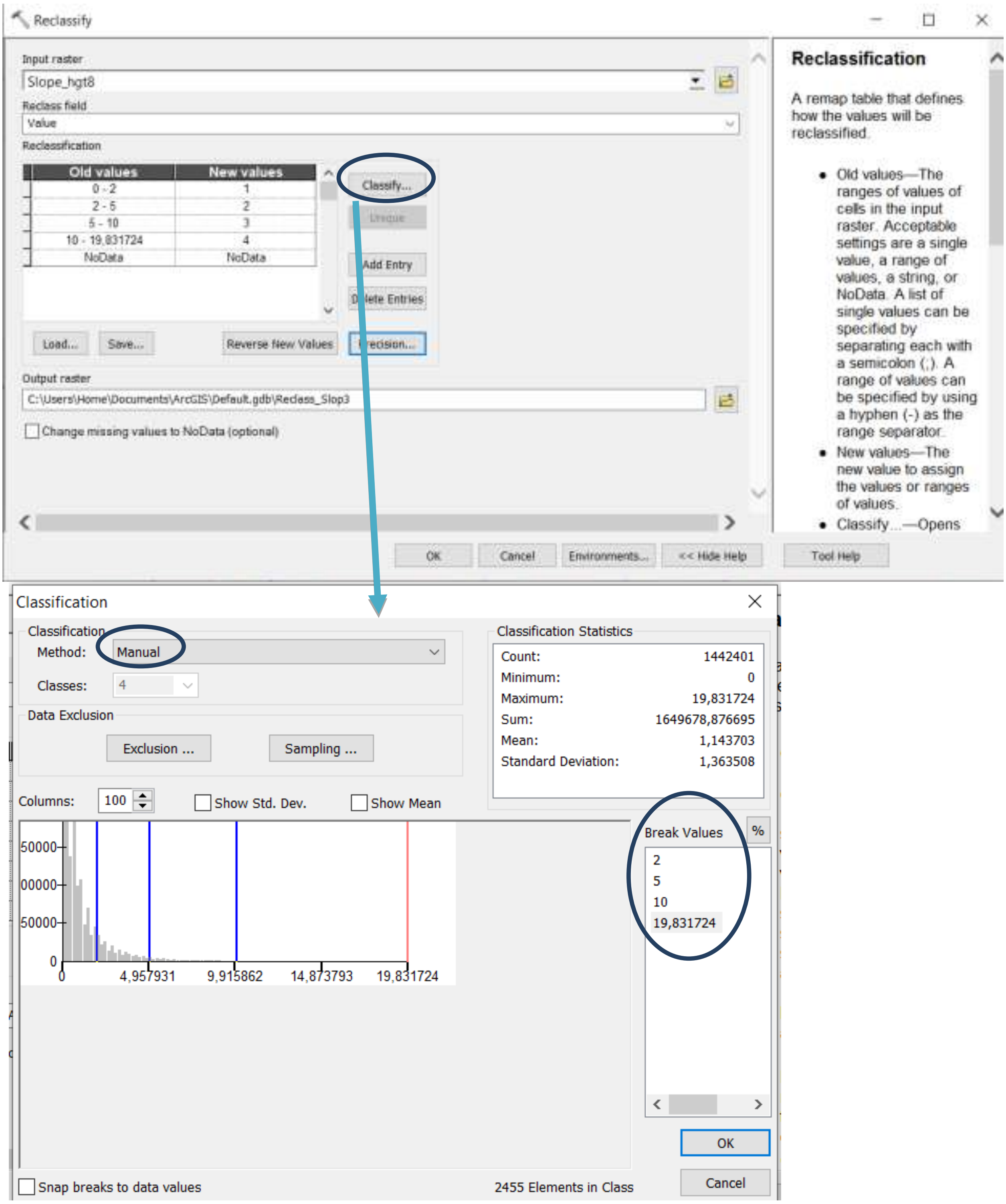
3) Geology layer –>**Spatial Join** (Analysis): target -geology, join – landslide points –>**Feature to Raster** (Conversion): field – join_count –> **Reclassify** (Spatial Analyst): create 4 classes;

4) Reclassify Output Slope + Reclassify Output Faults + Reclassify Output Geology–>**Weighted overlay** (Spatial Analyst): assign influence,% and the scale values (Note: 1 – the smallest influence of the particular value; the bigger the number, the higher the influence)

Slope map

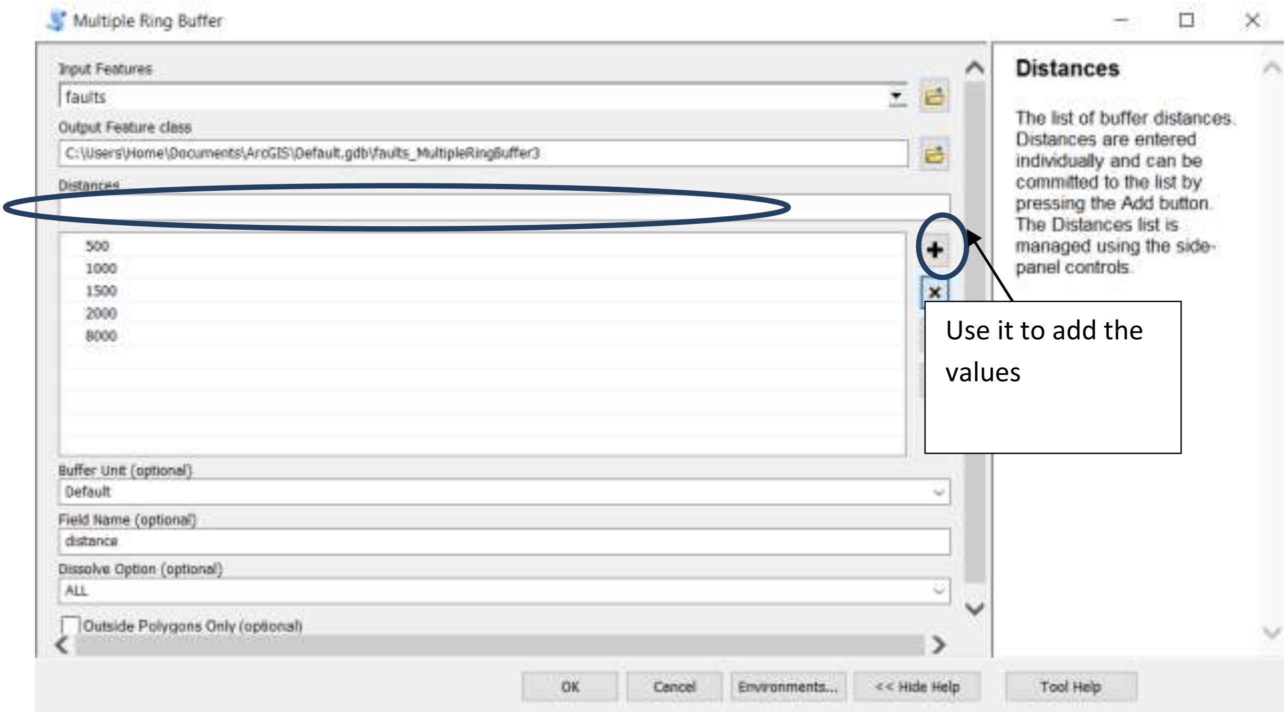


Slope map ->Reclassify (Spatial Analyst)

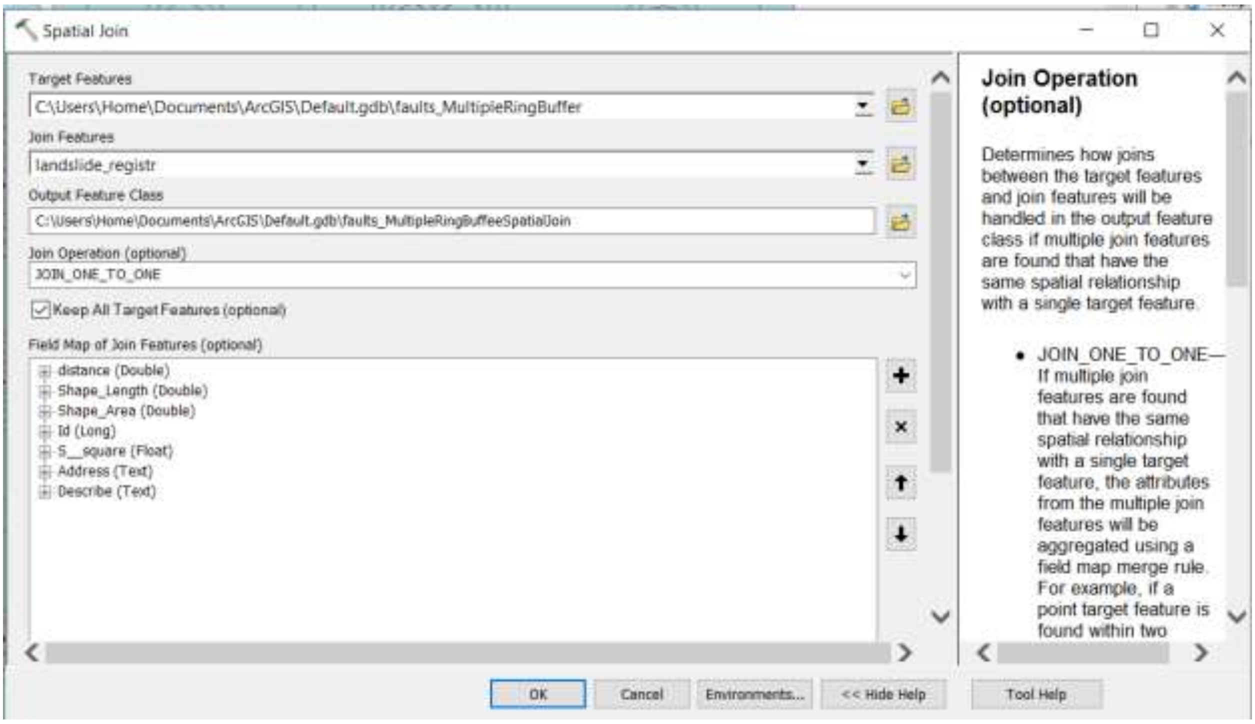


Faults

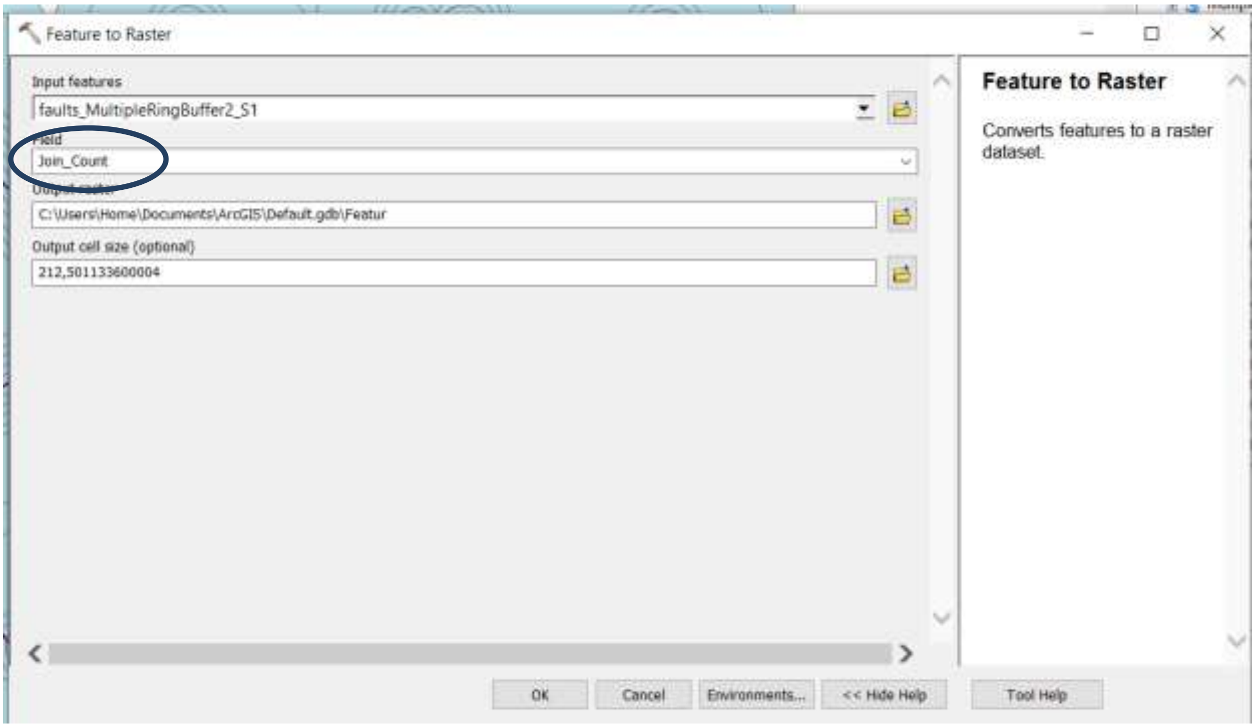
Faults –>Multiple Ring Buffer (Analysis)



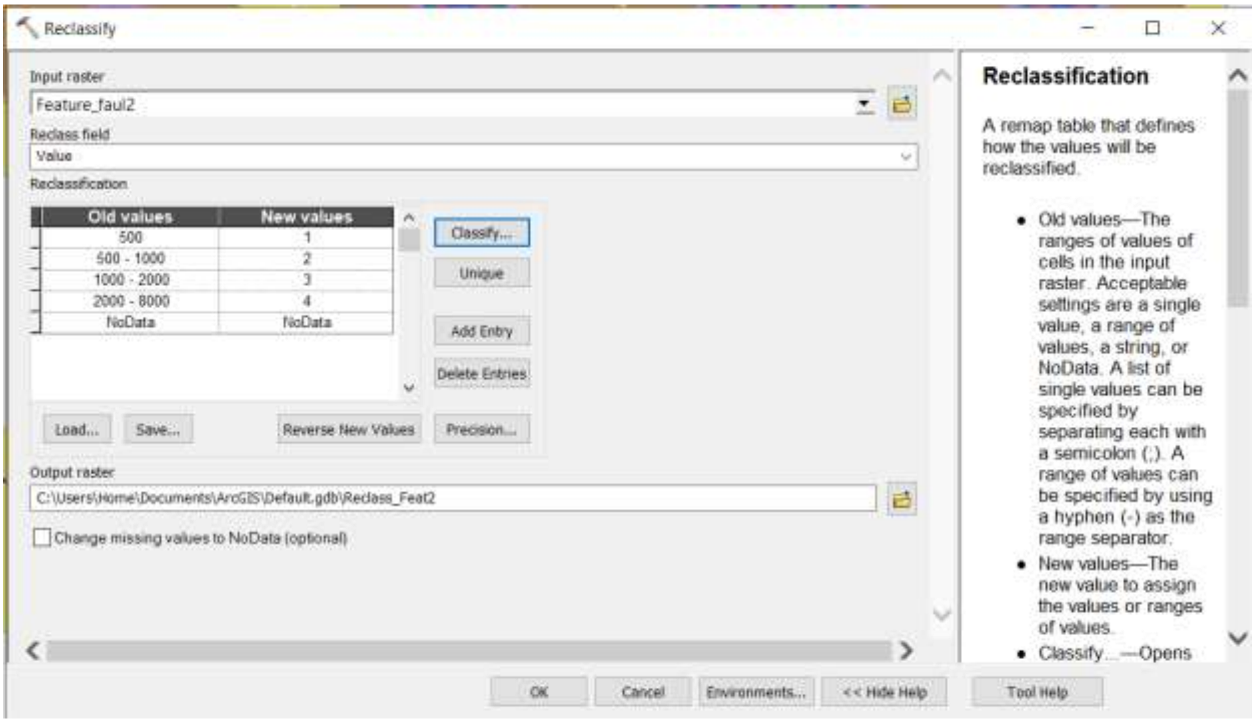
Multiple Ring Buffer Output ->Spatial Join (Analysis)



Spatial Join Output ->Feature to Raster

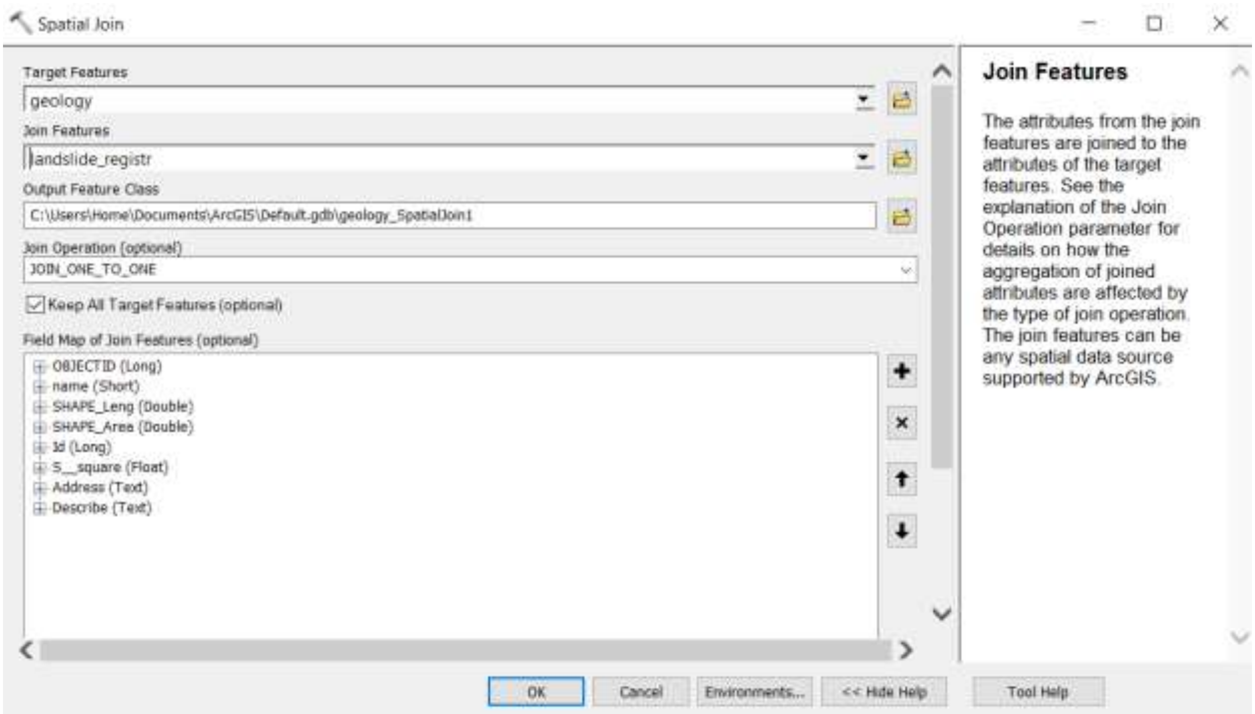


Feature to Raster Output ->Reclassify

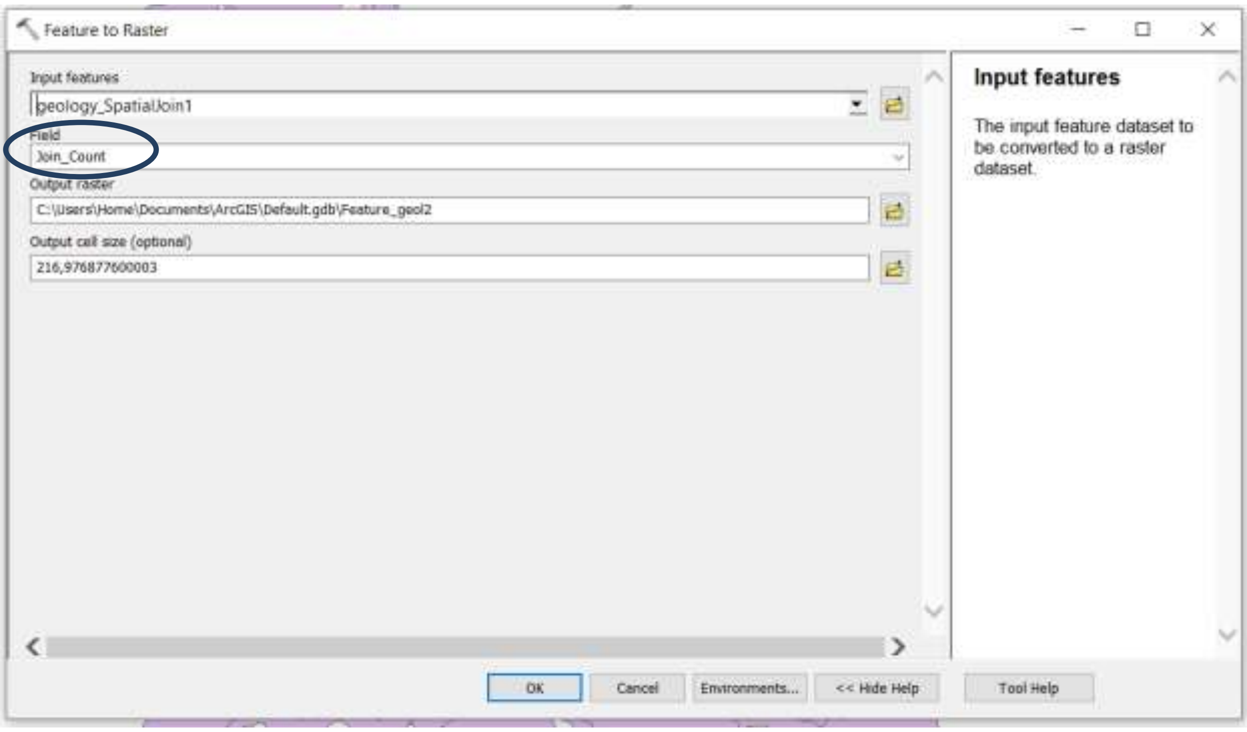


Geology

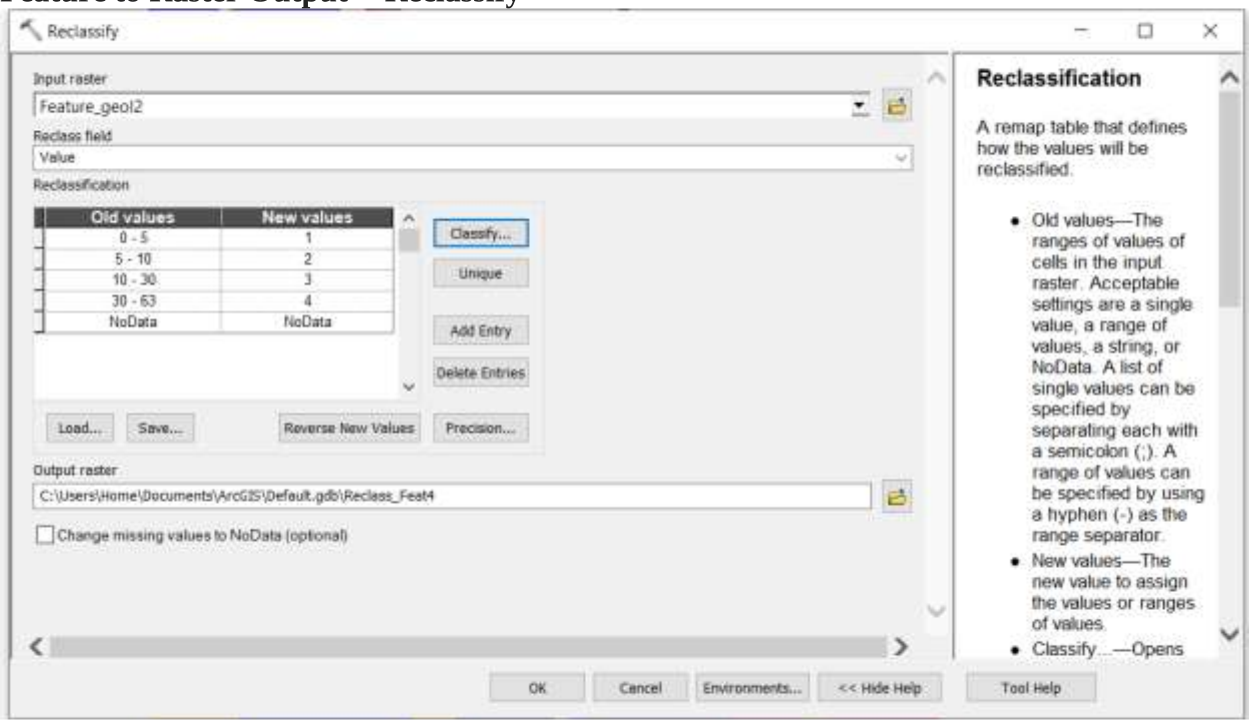
Geology->Spatial Join (Analysis)



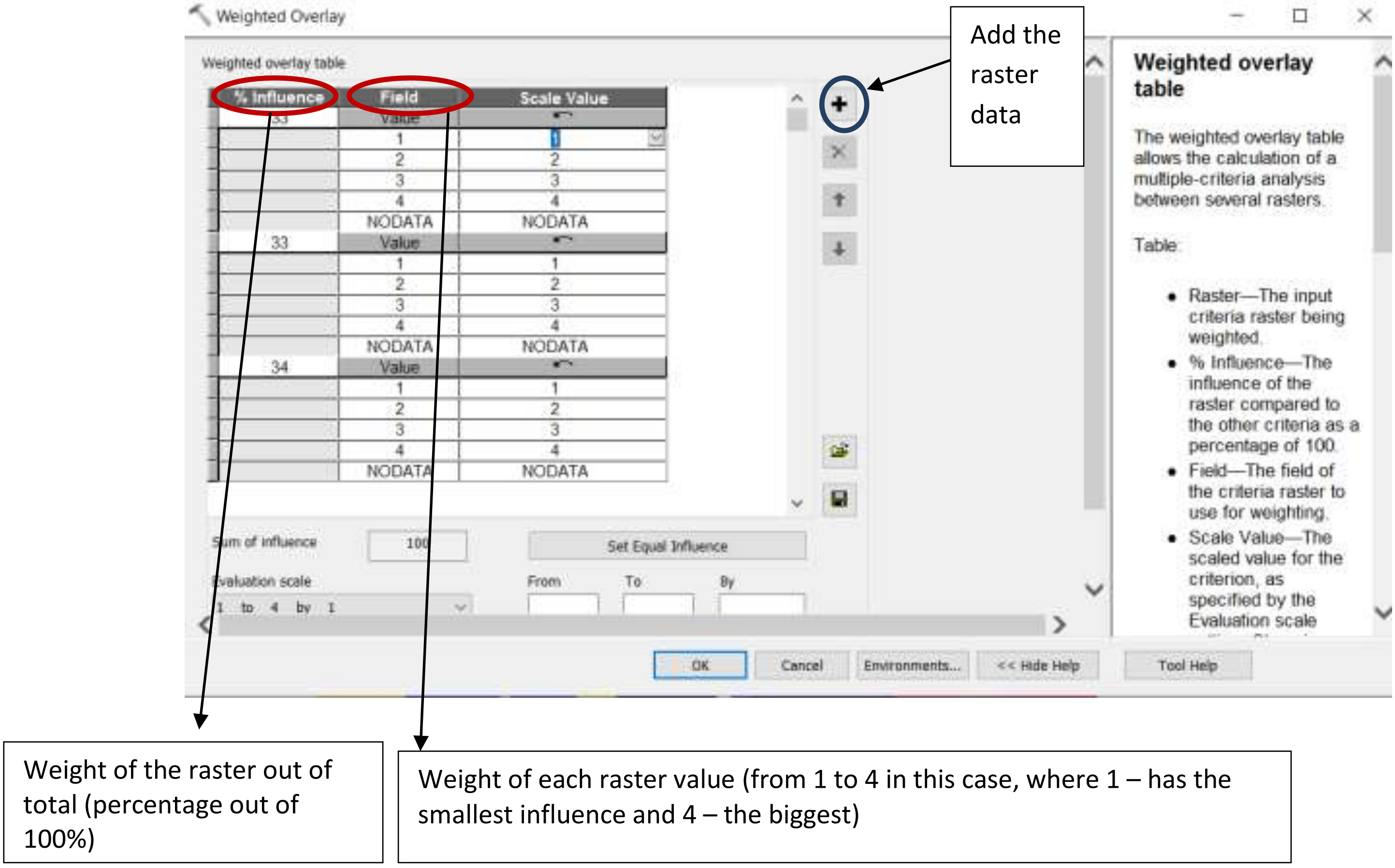
Spatial Join Output ->Feature to Raster



Feature to Raster Output ->Reclassify



Reclassified rasters -> Weighted overlay analysis



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2. Shahabi, H., Hashim, M. Landslide susceptibility mapping using GIS-based statistical models and Remote sensing data in tropical environment. SciRep **5,** 9899 (2015). https://doi.org/10.1038/srep09899
3. Roy, J., Saha, S. Landslide susceptibility mapping using knowledge driven statistical models in Darjeeling District, West Bengal, India. Geoenviron Disasters **6,** 11 (2019). https://doi.org/10.1186/s40677-019-0126-8Dekking, F.M. (Frederik Michel) (2005). A modern introduction to probability and statistics : understanding why and how. Springer. ISBN 1-85233-896-2. OCLC 783259968.
4. K. Poliakovska, O. Ivanik, V. Shevchuk.Spatial Modelling And Susceptibility Mapping Of Landslide Hazards Within The Middle-Dnipro Region Of Ukraine, **12th International Conference on Monitoring of Geological Processes and Ecological Condition of the Environment, DOI: 10.3997/2214-4609.201803157.**

Questions for students:

1. *What are the main factors of landslide hazards?*
2. *What are the main principles of susceptibility mapping and weighted overlay analysis?*

Class№6.Development of CAT model

Students should have knowledge of basics of geology, geomorphology and mathematic modelling

Concepts goals for this activity: Understand how a CAT model can be built.

Task:

The first step is to build the concept of CAT model development and second to implement on Matlab.

Create a map of 100 km by 100 km, distributing in an aleatory way dispensed buildings and a few cluster (cities or villages):

1. Use random point for dispersed buildings all over the map.
2. Distribute a few centre of clusters
3. Distribute more building close to the centre The function can *batiment ()* be used for that purpose:

function [x, y, nb_bat] = batiment (house)

This function needs to receive the number of cluster etc.:

```
%buiding distibution data
house.diperse=1000;          % housedispersed
house.village=3;             % 3 cluster house.rayon_village=10000;        %
radius of thevillage house.carte=100000;       % a 100 km2map
house.house_n=10;            % 10 house pervillage
```

Creating the frequency curve for earthquakes

Use 12 classes for intensity (III, …, XII) and a function of Gutenberg-Richter type such as:

$$F = a \times e^{-b \times I0}$$

To simulate the max intensity (I0) at the epicentre. It means that:

I0=(log(a)-log(rand(1,1)*(a-Fmax)+Fmax))/b;

Fmax is the value of F for I = XII.

Remember that intensities are not related to the magnitude directly there is the site effect, distance, etc. But it is convenient to use such exponential law. From the epicentre the intensity decrease by the following formula (proposed for this exercise) in the direction of the great axis of an ellipse:

$$I(\alpha, D) = I_0 \times e^{-D/(\alpha)}$$

I=I0*exp(D/R1);

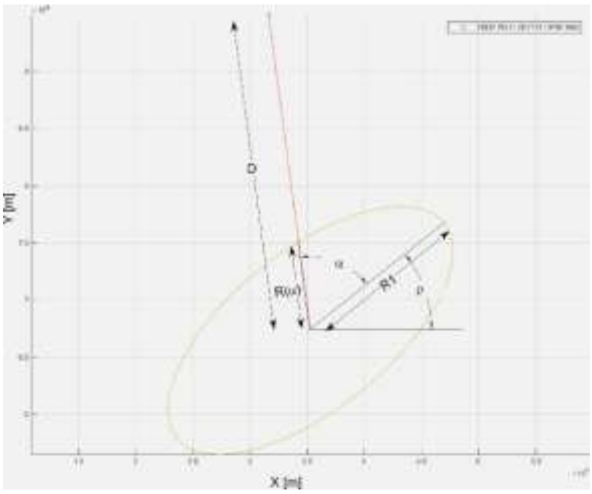
Where D is the distance to the epicentre and R1 (in meter). The value I (R1) = 0.36 I0 (in order to obtain the radius of the ellipse where I = IV, R1 can be multiply by (-log(4/I0)). The greater radius of the ellipse is related to the intensity by:

R1=C*exp(k*I0)*1000;

Where k = 0.633 and / C = 148.0 are constants. The small axis R2 is given by:

R2=R1*(.6-.3*rand());

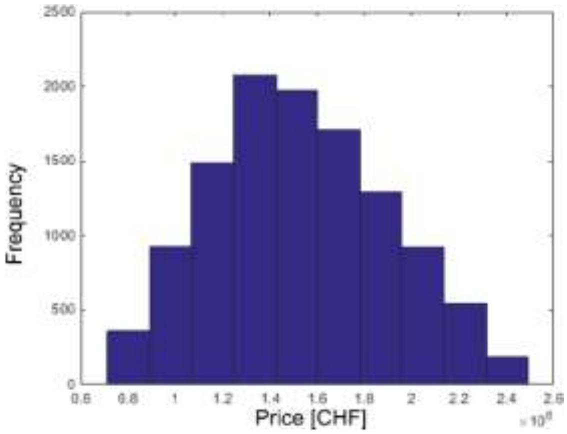
Which is an arbitrary choice. The centres of the ellipses are distributed randomly and their angles vary around a given value. i.e. the epicentres can be distributed aleatory on the territory or linked to a fault (line).They are rotated by α using a rotation matrix. The decay of the intensity varies in function of the ellipses R1 is replaced by the radius of the ellipse along the line joining the epicentre and a house R(α). α is the angle between the main axis and the line joining the epicentre and a building.



Variables used to describe the intensities.

Distribution of the house prices

The house prices can be simulated using triangular distribution with lower and upper limit of the prices and the most likely price.



Examples of simulated prices distribution for buildings.

Vulnerability function and uncertainty

The vulnerability function can be defined by a cumulative triangular distribution function. Using the lower limit for no damage and the maximum for full destruction. An uncertainty can be added by choosing 3 curves for the minimum, maximum and most likely vulnerability for the intensities. Then the simulation will use again a triangular distribution.

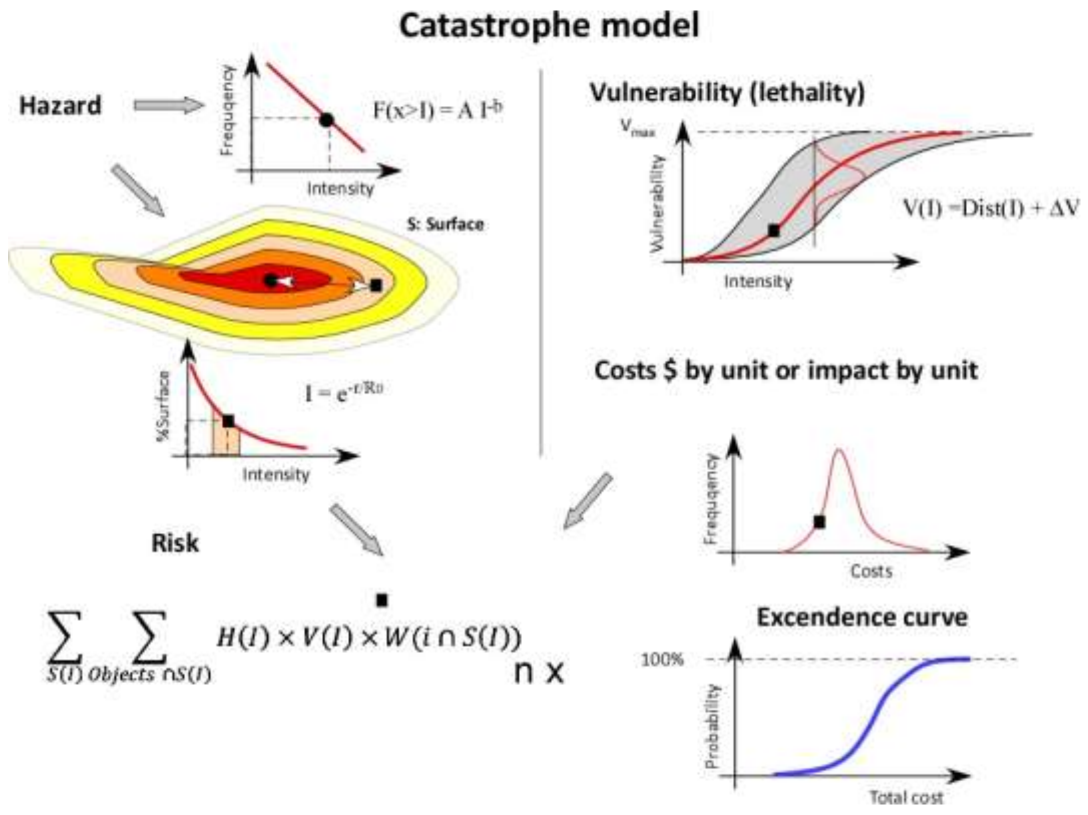


Illustration of the simulation of the vulnerability using a curve with most likely to occur and the lower limit or the upper limits of the triangular distribution. Simulated points are represented.

Model

Using all the above function it is possible to create a simple CAT model. The results will not be realistic, because the computation is time consuming, we are here simplifying. The model is built using the following steps:

1. Initializing all the fixed variables
2. Simulating the building positions
3. Simulate elliptical earthquakes using random epicentre and G-R law principle to simulate the intensity at the epicentre.
4. Use relationship between R1 and intensity.
5. Calculate R2
6. Rotate the ellipse
7. Calculate the angle between R1 and the line joining the epicentre and the building.
8. Calculate the intensity at the position of the building
9. Calculate the vulnerability and the damage costs
10. Create an exceedance curve
11. Provide graphics such as histograms.

Questions for students:

1. Describe the main concepts and stages of CAT model development.

2. How can we calculate the vulnerability and the damage costs.

References:

1. *Dekking, F.M. (Frederik Michel) (2005). A modern introduction to probability and statistics : understanding why and how. Springer. ISBN 1-85233-896-2. OCLC 783259968.*

2. PavKalinowski, "Understanding Confidence Intervals (CIs) and Effect Size Estimation", *Observer* Vol.23, No.4 April 2010.
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