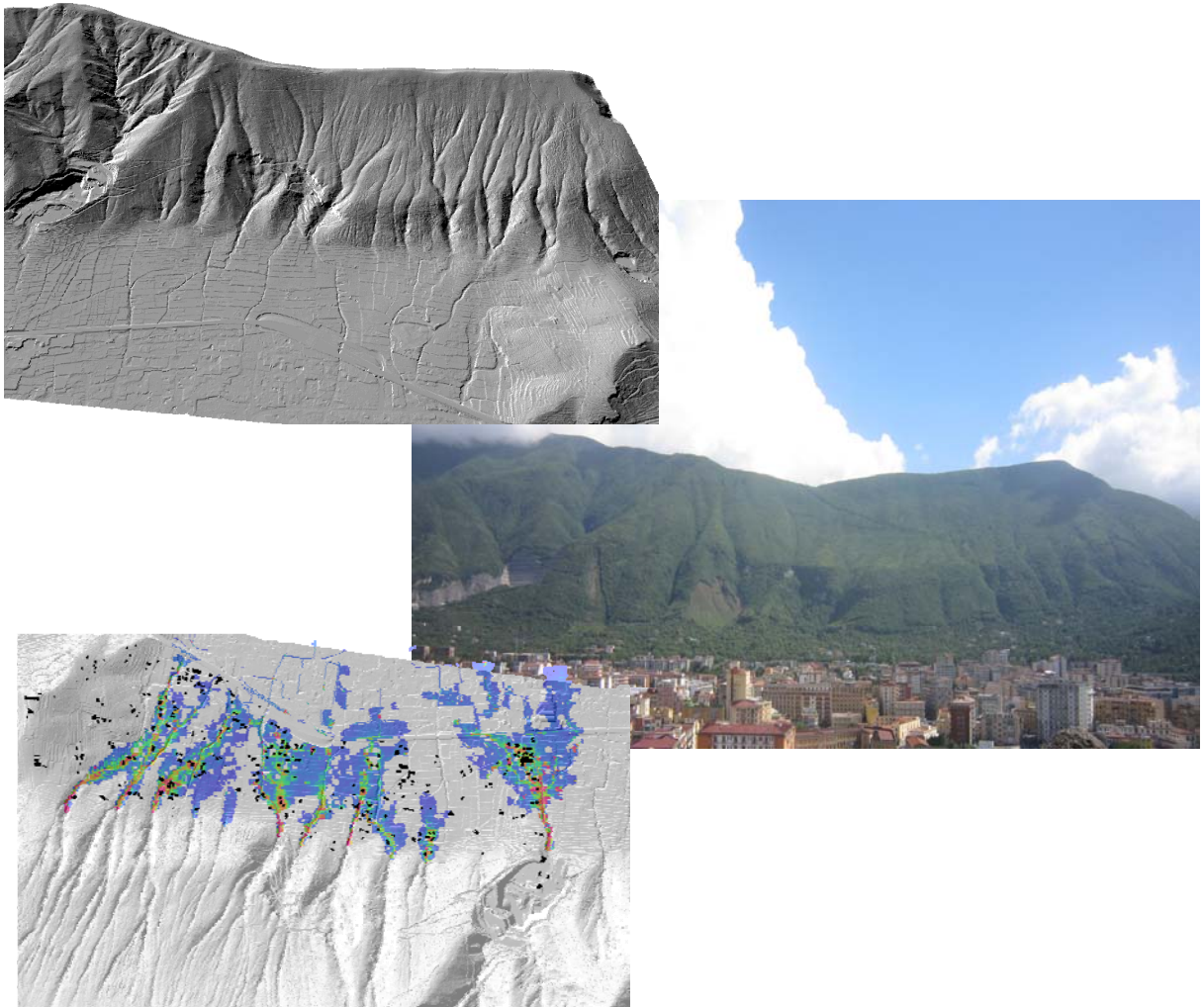# CHANGES SMCE-Exercise Nocera

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Objectives

This exercise deals with Spatial Multi-Criteria Evaluation to examplify the use of SMCE to analyse and evaluate spatial information for risk assessment from natural hazards in a mountainous environment. The exercise will guide you through the steps of SMCE using the a case study from Italy near the city of Nocera (Salerno Provence. Given the limited time it is not possible to go in depth into all the steps of SMCE and the aim of this exercise therefore is to serve as an introduction to SMCE as a useful tool in analyzing risk.

Acknowledgements

The data for the Nocera area have been compiled by Prof. Leonardo Cascini, Dr. Settimio Ferlisi and their collegues of the University of Salerno within the SafeLand project http://www.safeland-fp7.eu/Pages/SafeLand.aspx

We wouldlike to thank Dr. Anna Scolobig and her colleagues from IIASA for coordinating the risk assessment process and for organising the stakeholders meetings that provided important input for the risk scenarios. This training package is also a contribution to the SAFELAND project.

Generation of hazard and vulnerability indices using Spatial Multi Criteria Evaluation

Expected time: 3 hours
Objectives: In this exercises you will generate two indices:
- A hazard index, which combines the source maps, runout maps, and inventories for the various hazard types
- A vulnerability index that combines the various elements at risk
- Both are standardized and weighted.
- The combination of the hazard index and the4 vulnerability index map is used as a tool for spatial planning and risk management.
- All procedures are based on 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. 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).
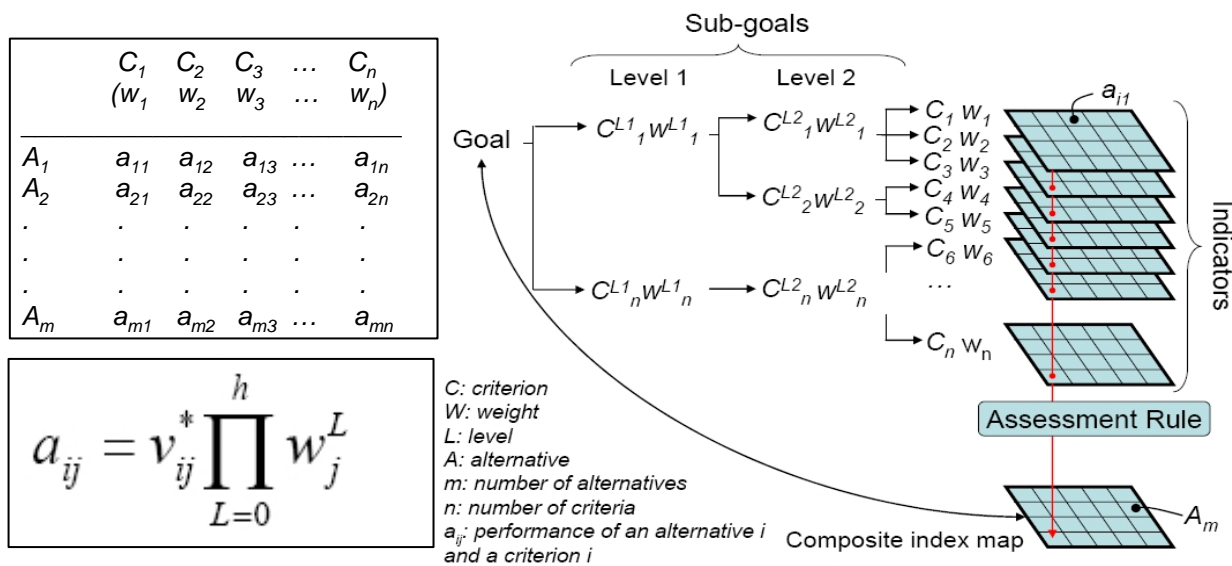

Figure 1. Schematic procedure for spatial multi-criteria evaluation based on the analytical hierarchical process

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.

From a decision-making perspective, multi-criteria evaluation can be expressed in a matrix as shown in Figure 6.8. The matrix A contains the criteria in one axis (C_1 to C_n), and a list of possible alternatives, from which a decision has to be taken on the other axis (A_1 to A_m). Each cell in the matrix (a_{ij}) indicates the performance of a particular alternative in terms of a particular criterion. The value of each cell in the matrix is composed of the multiplication of the standardised value (between 0 and 1) of the criterion for the particular alternative, multiplied by the weight (W_1 to W_n) related to the criterion. Once the matrix has been filled, the final value can be obtained by adding up all cell values of the different criteria for the particular alternative (e.g. a_{11} to a_{1n} for alternative A_1).

For implementing this matrix according to the AHP, three principles steps need to be considered. The first one decomposes the problem (and the weights) into a hierarchical structure. The second one considers the weighting process, employing the pairwise comparisons of the criteria, and the synthesis is related to the multiplications among the hierarchical levels. Additionally, in the spatial implementation of this procedure, every criterion (C_j) becomes a raster layer, and every pixel (or set of pixels) of the final composite index map eventually becomes an alternative Aj. The goal (risk index) has been decomposed into criteria levels C_{L1} and C_{L2}. The intermediate levels are often indicated as sub-goals or objectives (e.g. in level 1, the sub-goals are a 'hazard index' and a 'vulnerability index'). Each criterion of each level will also have an assigned weight. Therefore, the values for the layers of the intermediate levels are obtained through the summation of the performance for the alternative at lower levels. As the criteria consist of raster maps, their spatial performance (a_{ij}) and the alternative (A_i) will be identified for particular raster cells.

The composite risk index map is obtained by an assessment rule (sometimes also called decision rule), which is calculated by adding up the performance of all cell values of the different criteria (a_{ij}) for the particular alternative. However, the performance of every element in the matrix (a_{ij}), is obtained in a different way:

In this equation, v_{ij} refers to the standardised value of criterion (C_j) for alternative (A_i), and weight w^L_j refers to the weight of criterion (C_j) for level L (0–h levels). During the analysis, it could be desirable (and sometimes necessary for a better definition of the weights w^L_j) to produce the intermediate criteria maps.

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 2 gives an overview of the final criteria tree for the hazard index that could be used for this exercise.

One main goal is obligatory for any criteria tree. The main goal is also called the main root

The **Standardization** method will be indicated here.

Here will be the input maps (or tables and columns) that contain the data related to the factor

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.

A **Subgoal** is directly under the main goal, it defines the main groups that together define the overall goal. Each subgoal also has a weight value.

One subgoal can consist of one or more factors. These can be spatial or non spatial. They are all having a weight (value in front) and a standardi-zation method (e.g. Std: Goal)

a **Benefit**: contributes positively to the output; the *more* you have (the higher the values), the contributes to the main goal.

Criteria Tree

Hazard - as the combined impact of multiple hazards   Hazard_final
- 0.00 Overall hyperconcentrated flow hazard   Hazard_HCF_overall
  - 0.00 Type 1 - Low viscosity, most fluid type
    - 0.00 HCF_sc1 Depth in meters
    - 0.00 HCF_sc1 Velocity in m/s
  - 0.00 Type 2 - Medium viscosity, medium fluid type
    - 0.00 HCF_sc2 Depth in meters
    - 0.00 HCF_sc2 Velocity in m/s
  - 0.00 Type 3 - High viscosity - least fluid type
    - 0.00 HCF_sc3 Depth in meters
    - 0.00 HCF_sc3 Velocity in m/s
- 0.00 Overall flood hazard   Hazard_Flood
  - 0.00 Flood 20year return period
    - 0.00 20 year flood - Max flood depth in meters
    - 0.00 20 year flood - Max flow velocity in m/s
  - 0.00 Flood 100 year return period
    - 0.00 100 year flood - Max flood depth in meters
    - 0.00 100 year flood - Max flow velocity in m/s
- 0.00 Overall Debris Flow Hazard   Hazard_Debrisflow
  - 1.00 Mudflow flow velocity
- 0.00 Overall landslide hazard   Hazard_Landslides
  - 0.00 Runout of landslides - distance affected by landslid...
  - 0.00 Historic landslides - past events
  - 0.00 Landslide safety - slope stability classes

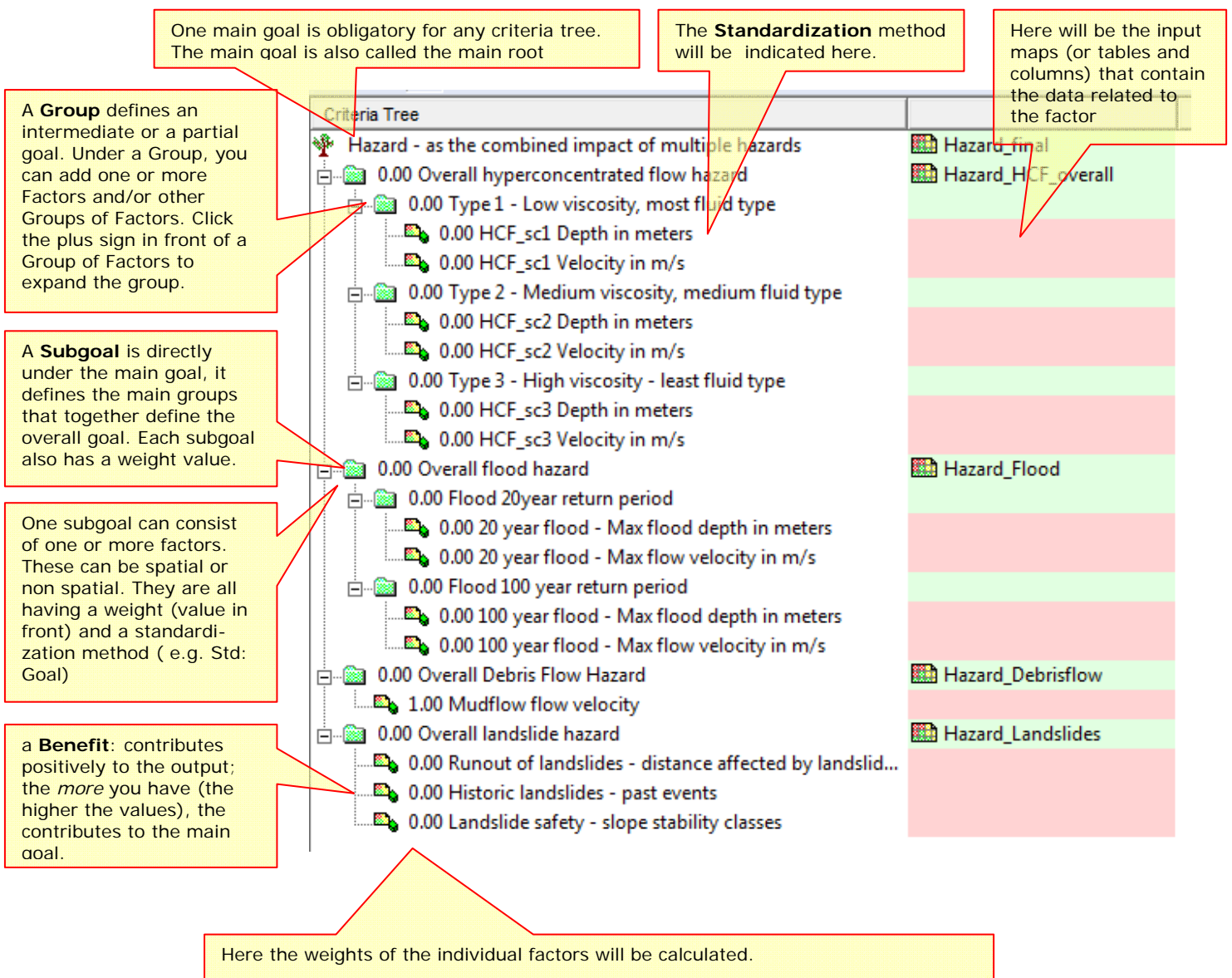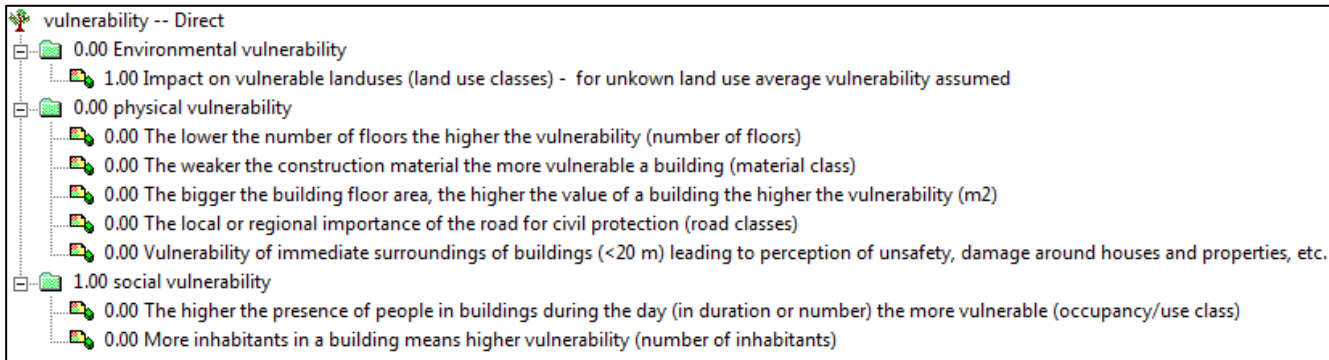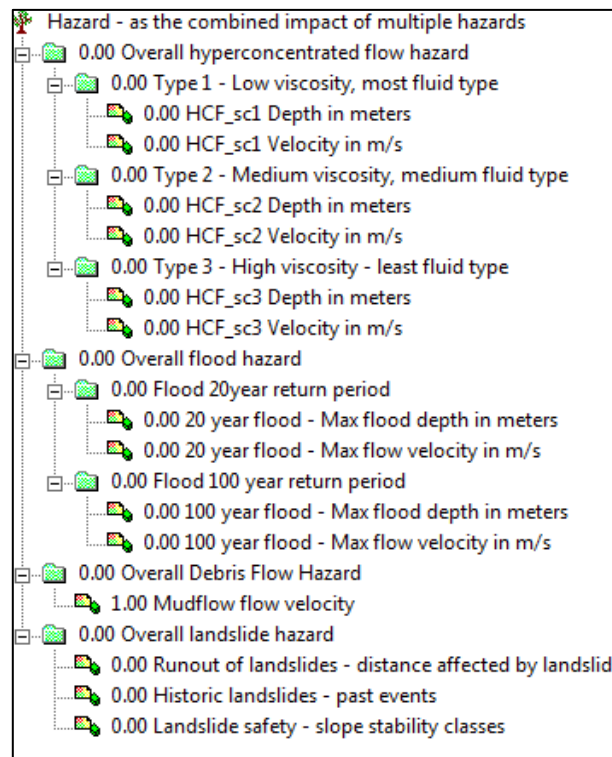Here the weights of the individual factors will be calculated.

Figure 3 gives an examples of the possible criteria trees for the hazard index and the vulnerability index that could be used for this exercise. You can of course deviate from this set-up and design your own criteria tree in a different way.

IMPORTANT: Work in a group and either work on the hazard Index or on the vulnerability Index.
Later on use the results from another group to combine them.

Part A: Creating the criteria tree for the Hazard Index / Vulnerability Index

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 hazard index. If you decided to make the vulnerability index, it works more or less the same way. We have used the hazard index as example, but you can also work on the vulnerability index.
Below we will take you through the procedure. Later on you can do it yourself for the other groups.

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 cannot 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.

Note: all parts indicated in red should be completed before you can make the output map.

☞

- 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: **Hazard_Index**, and the name of the output map (in the right side) to **Hazard_Index**.
- Click on **Hazard_Index** and click on the insert group icon 🖼️ or Right click on it and select *Insert group*. Add the groups: **HyperConcentratedFlow_Hazard, Flood_hazard**, **Debris_flow_hazard**, and **Landslide_hazard**
- Include the various spatial factors and groups for the individual criteria, as indicated on the previous page in the example by right-clicking on the individual criteria and inserting the spatial factors or click the insert spatial factor icon 🖼️.

You can of course deviate from the example if you think you should do it differently

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 maps or from tables associated to maps

Important: SMCE works only with raster maps, not with vector maps. You have to rasterize these first.

The Rastermaps should all have the same georeference (the file defining the boundaries of the raster map and the pixelsize).
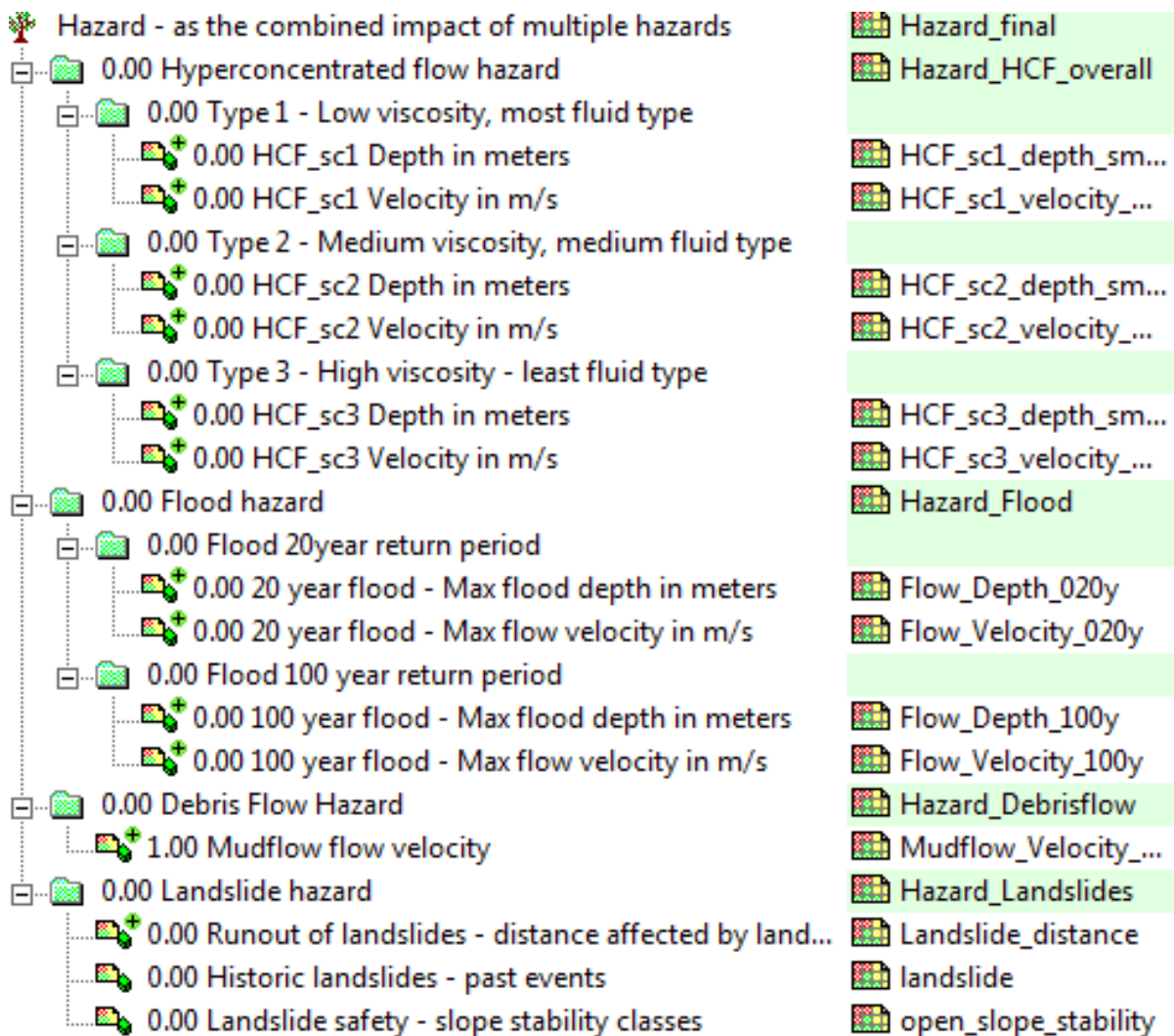
> ☞
> - Double click on the red area next **HCF_sc1 Depth in meters**. Select the map **HCF_sc1_depth_smce**.
> - Find also the relevant spatial information for the other criteria
> - Save the criteria tree as **Hazard_Index**.

> ☞
> - Adding output maps : Double click on the green area next to " Flood hazard" and fill in **Flood_hazard**. Press enter
> - Do the same for the other main subgoals.

Once you have done this the decision tree might look like this. All the input and output maps have been defined.

|	
❀ Hazard - as the combined impact of multiple hazards	▦ Hazard_final
⊟ 📁 0.00 Hyperconcentrated flow hazard	▦ Hazard_HCF_overall
⊟ 📁 0.00 Type 1 - Low viscosity, most fluid type	
📊 0.00 HCF_sc1 Depth in meters	▦ HCF_sc1_depth_sm...
📊 0.00 HCF_sc1 Velocity in m/s	▦ HCF_sc1_velocity_...
⊟ 📁 0.00 Type 2 - Medium viscosity, medium fluid type	
📊 0.00 HCF_sc2 Depth in meters	▦ HCF_sc2_depth_sm...
📊 0.00 HCF_sc2 Velocity in m/s	▦ HCF_sc2_velocity_...
⊟ 📁 0.00 Type 3 - High viscosity - least fluid type	
📊 0.00 HCF_sc3 Depth in meters	▦ HCF_sc3_depth_sm...
📊 0.00 HCF_sc3 Velocity in m/s	▦ HCF_sc3_velocity_...
⊟ 📁 0.00 Flood hazard	▦ Hazard_Flood
⊟ 📁 0.00 Flood 20year return period	
📊 0.00 20 year flood - Max flood depth in meters	▦ Flow_Depth_020y
📊 0.00 20 year flood - Max flow velocity in m/s	▦ Flow_Velocity_020y
⊟ 📁 0.00 Flood 100 year return period	
📊 0.00 100 year flood - Max flood depth in meters	▦ Flow_Depth_100y
📊 0.00 100 year flood - Max flow velocity in m/s	▦ Flow_Velocity_100y
⊟ 📁 0.00 Debris Flow Hazard	▦ Hazard_Debrisflow
📊 1.00 Mudflow flow velocity	▦ Mudflow_Velocity_...
⊟ 📁 0.00 Landslide hazard	▦ Hazard_Landslides
📊 0.00 Runout of landslides - distance affected by land...	▦ Landslide_distance
📊 0.00 Historic landslides - past events	▦ landslide
📊 0.00 Landslide safety - slope stability classes	▦ open_slope_stability

Standardization of the factors.

Some of the factors used in the hazard index assessment are of the "value" type, and some will be classes which are stored as attributes in an attribute table linked to one map – this is especially the case for the vulnerability criteria tree.

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.

☞

- In the SMCE window, change the Mode from "*Problem Definition*" to "*Multi Criteria Analysis*". The entire left part of the tree will become red now, indicating that you still need to fill these in. Now you can start standardization.
- Double click on the red area indicating **0.00 HCF_sc1 depth in meters**. 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

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.
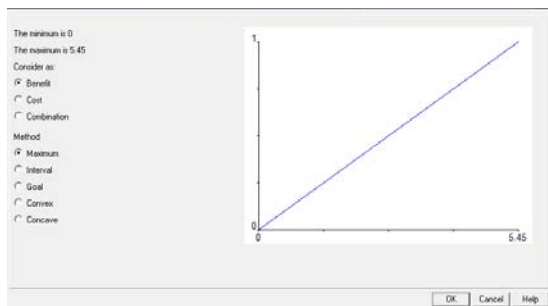
When selecting the boundaries for standardization, you always have to consider the aim of

the weighting and standardization procedure (in this case hazard assessment), and how this particular variable is related to that. In this case: the higher the flow depth, the higher the hazard: Flow depth is beneficial for hazard! You must decide if you want to apply a linear transformation relationship, or another shape. In other cases there will be a maximum value above which you will always find it high for instance if you believe any depth more than 2m contributes maximum to hazard and should be 1. In that case you select the Goal option, and you

can adjust the values manually. The aim of this step is to rescale all criteria to scale between 0 and 1.

☞

- Select the goal option and change the minimum X and the maximum based on your opinion of the importance of the given depth of the hyper-concentrated flow. For instance you could standardize between 0 and 2 meters, for all the HCF maps.
- Standardize in the same way the other variables.

After standardizing all factors, your criteria tree will have only red bars in the combination of the factors. The red bars are showing the places where still you need to indicate weights.

☞

- To see the result of the standardization: Right click on a name 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 **t**. Compare the original values to the standardized values.

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 "*HCF_sc1*" and "*HCF_sc2 year*" in the group "*Hyper Concentrated Flow*"), or the weights among the groups (e.g. "*Flood hazard*" versus "*Debris flow hazard*"). 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), See the example below left and
- **Rank ordering** (you indicate the relative ranking of the factors, and the software converts these in quantitative weights). See the example below, right.
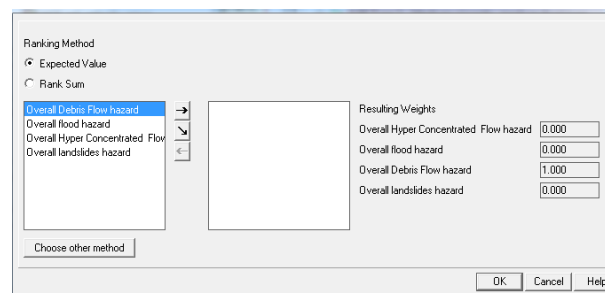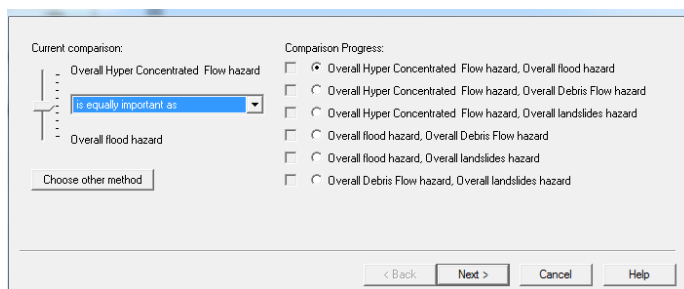
In this exercise we will work mostly with pairwise comparison.

☞

- Right-click the red indicated factor group "**Hyper Concentrated Flow**", and select Weight. Select the option: *Pairwise*

- Determine whether for the determination of flood hazard, the modeled flood in 100 year is more important than the modeled flood in 20 year, or equal, or less. Discuss this with your neighbors / group members.
- Double-click on the **Flood_Hazard** map name and generate the map. View the result.
- Generate also the weight for the other groups.

Determining the weights among groups

The fourth step in the procedure is to define the weights between among the groups (e.g. "*Flood Hazard*" versus "*Debris flow hazard*"). 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 *"Hazard Index "*, and select Weight. Select the option: *Pairwise*
- Determine for each combination the relative importance. Discuss this with your neighbors / group members.
- What information do you need to be able to fill this in properly?

Now all the parameters are given and it is time to calculate the output map.

☞

- Right-click the map icon "**Hazard_Index**", and select Generate selected item
- Also evaluate the individual hazard map for **Flood_hazard**, **Debrisflow_Hazard** etc.
- 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 different hazards?

What is your opinion on the method of combining the various hazard types?

You can also classify the output map, or the intermediate hazard maps in a few classes. For that we will use again a Class/Group domain. Remember that all the result maps have values between 0 and 1.

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- Classify the output map **Hazard_Index** in three classes (use Operations, Image Processing, Slicing). Name the output: **Hazard_Class**
- You can also classify the individual hazard maps for flood, debris flows, snow avalanches, rockfall and landslides.

> • Critically evaluate the result.

Creating the criteria tree for vulnerability index

You can also generate the criteria tree for the vulnerability index, or you can exchange the information with another group that did the vulnerability hazard.

> ☞
>
> • Generate the criteria tree for **the Vulnerability_Index** or exchange the information with another group that already made this.
>
> • 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. Due to the object oriented approach of ILWIS, one file is associated with several other files that are needed for displaying it. When you copy files with Windows explorer you will forget which files are linked, and then you run the risk that the file will not open anymore. So always copy files by clicking on it in the data catalog and then select from the menu: Edit, Copy Object To
>
> • Classify the **Vulnerability_Index** map, and also the intermediate maps (**Environmental, Physical, and social**) using the Class/Group domain **Vulnerability_Class**.

Combining the hazard and vulnerability maps

Once the various hazard maps (including the overall **Hazard_Index** and **Hazard_Class** maps) and the various vulnerability maps (including the **Vulnerability_Class** map) have been generated, you can now use them in many different ways. We will focus on the use of these maps in the last exercise. Here we will only make a very simple overall risk map to conclude. We do this using a two-dimensional table, called **Qualitative_risk**.
The table looks like this:

		Vulnerability		
		High	Moderate	Low
Hazard	High	High	Moderate	Low
	Moderate	Moderate	Moderate	Low
	Low	Low	Low	Low

> ☞
>
> • In the command line type the following formula:
>
> **Risk_Class:=Qualitative_Risk[Hazard_Class,Vulnerability_Class]**
>
> • Display the result and evaluate it. Also make a histogram and calculate the area and percentage that has low, moderate and high risk.