MULTI-HAZARD RISK AND DECISION MAKING

INTRODUCTION

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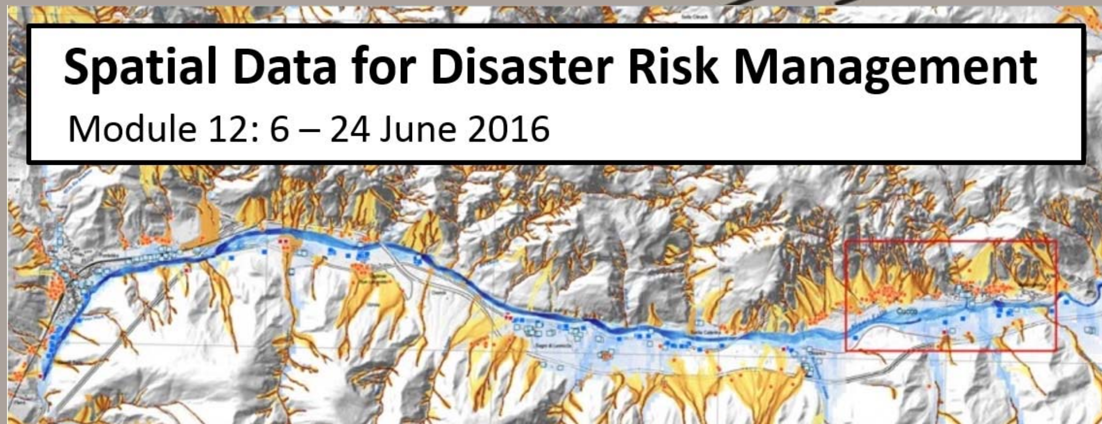


CONCEPTS : HAZARD , VULNERABILITY AND RISK

Risk = Probability of losses / estimated losses per time period in a given area

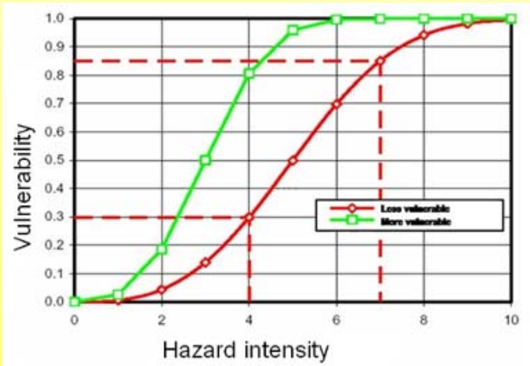
Hazard	*	Vulnerability	*	Elements-at-risk
Temporal probability of hazard scenario	*	Degree of loss given the hazard scenario	*	Quantification of exposed Elements-at-risk

Hazard

Hazard Type
Duration
Onset time

Hazard intensity: spatial distribution of damaging effects

Vulnerability



Elements-at-risk

Type of elements-at-risk

Quantification of elements-at-risk

Temporal variation

Exposure

Spatial overlay of hazard footprints and elements-at-risk

RISK CHANGES

R = f (H, V, C)

R = Risk

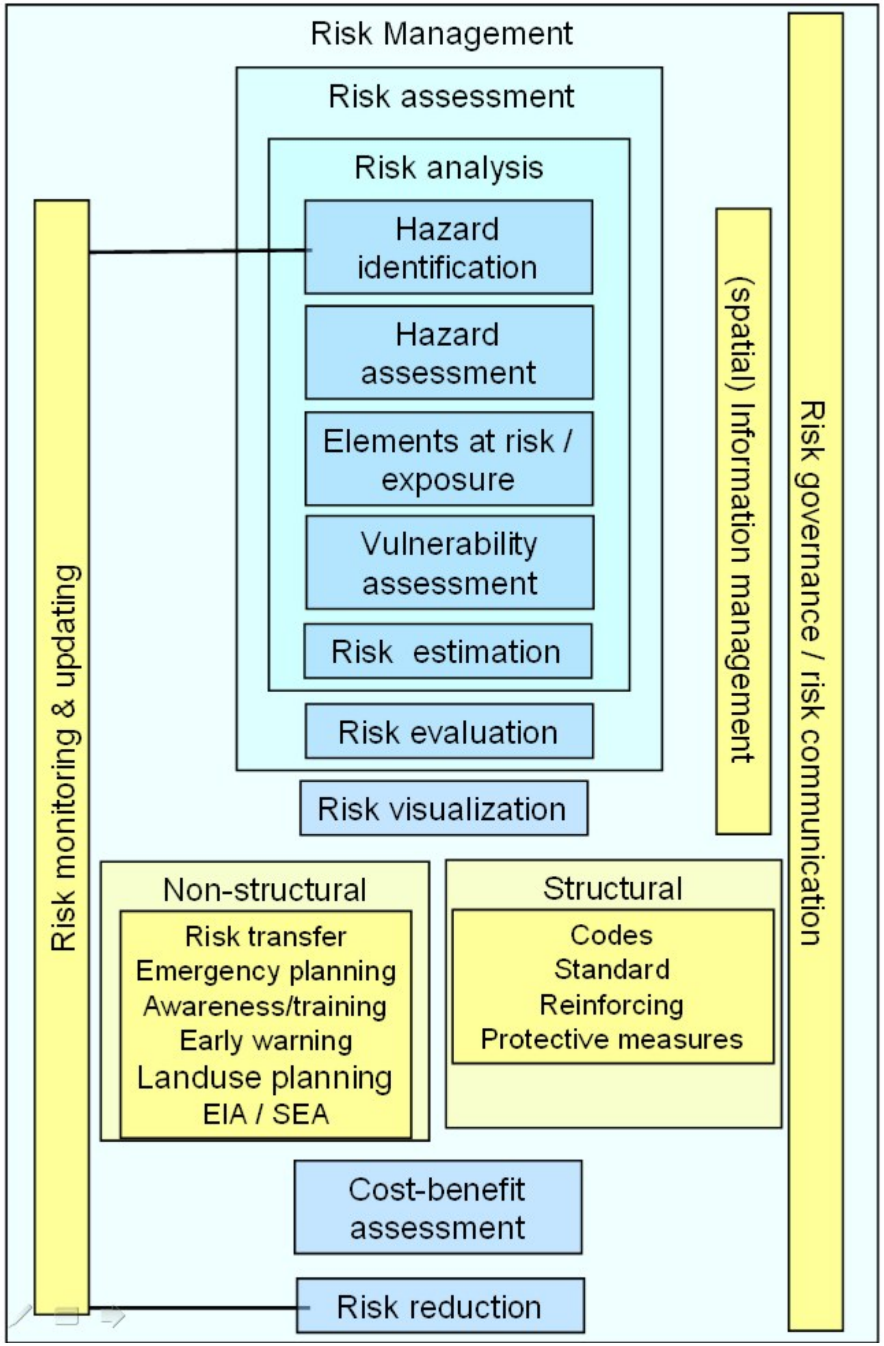
H = Hazard

V = Vulnerability

C = Coping capacity

Risk can change by:

- Changing the hazard
- Changing the vulnerability of the elements at risk
- Changing the amount of the elements at risk exposed
- Changing the coping capacity



Multi-hazard risk assessment at the local level for decision making

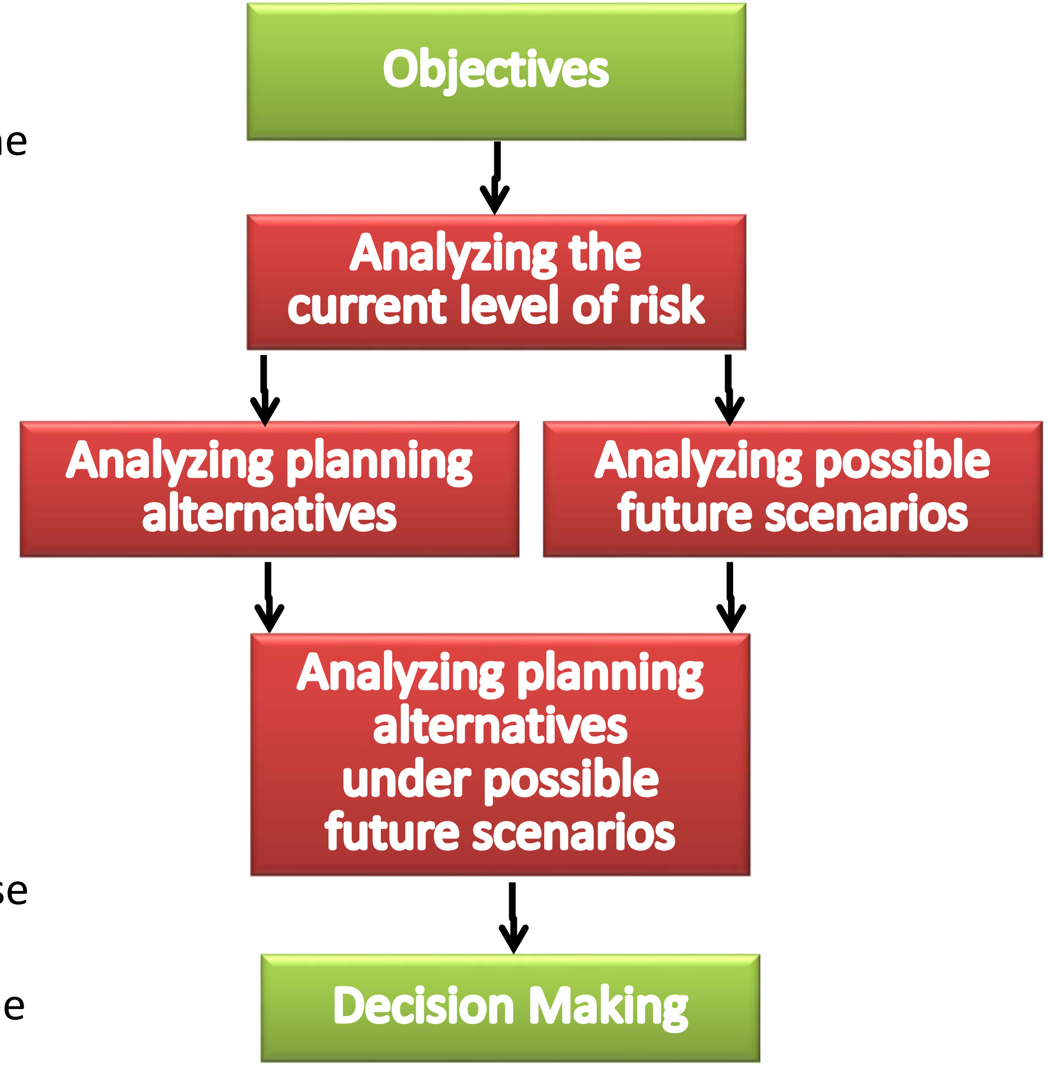
Risk maps are not static.

As everything changes constantly, also the level of hazard, vulnerability and risk might change.

This could be due to planned interventions, which we call planning alternatives.

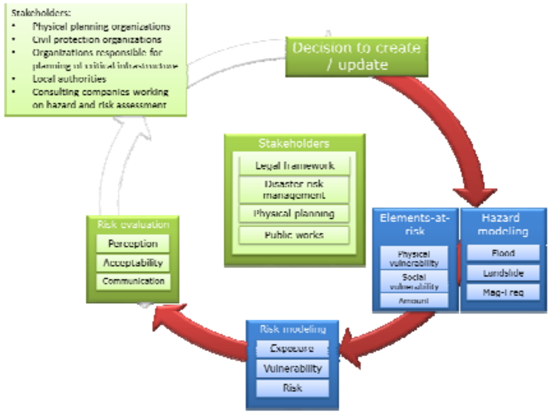
It could also be due to possible future changes related to climate change and land use change.

We call these possible future scenarios. Or to a combination of both. This use case analyses these situations using a hypothetical example of a mountain slope on an island.

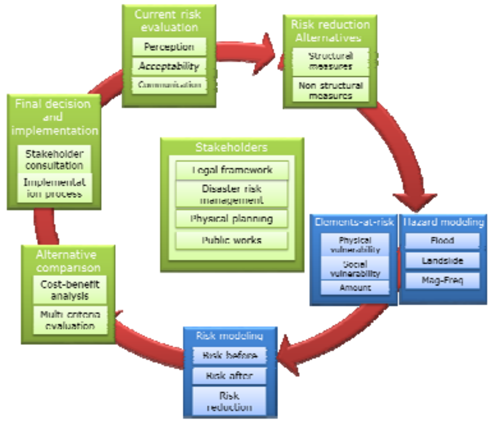


Structure of the project

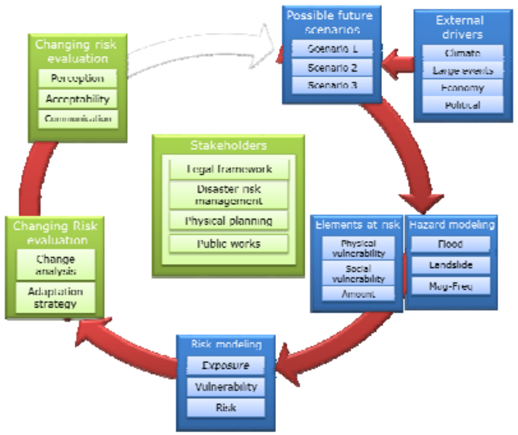
Part B: Analysis of current multi-hazard risk



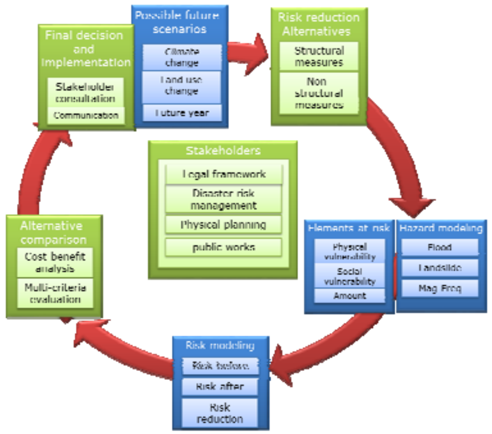
Part C: Analysis of risk reduction alternatives



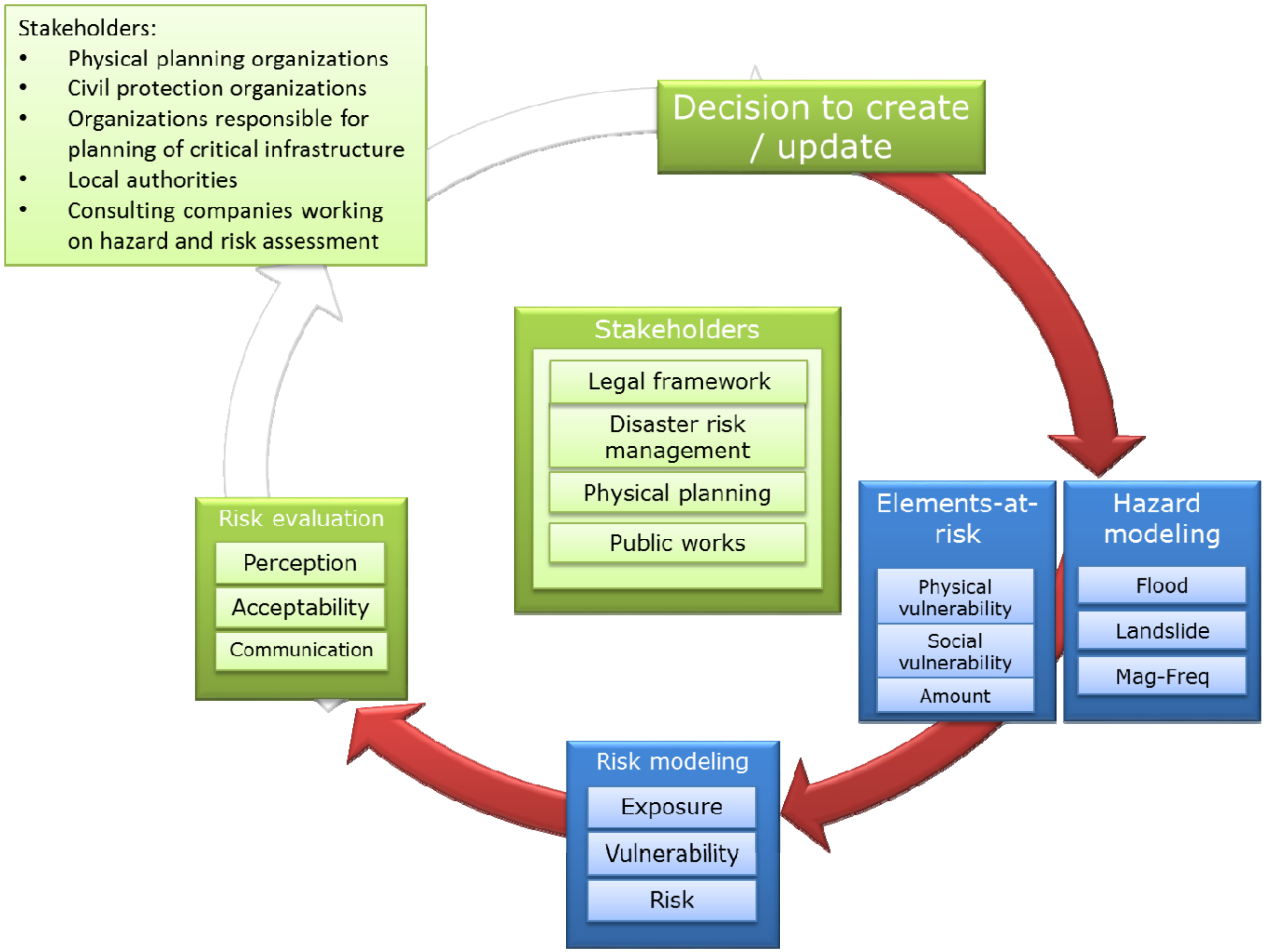
Part D: Analysis of changing risk for possible future scenarios



Part E: Which risk reduction measure behaves best under possible future scenarios



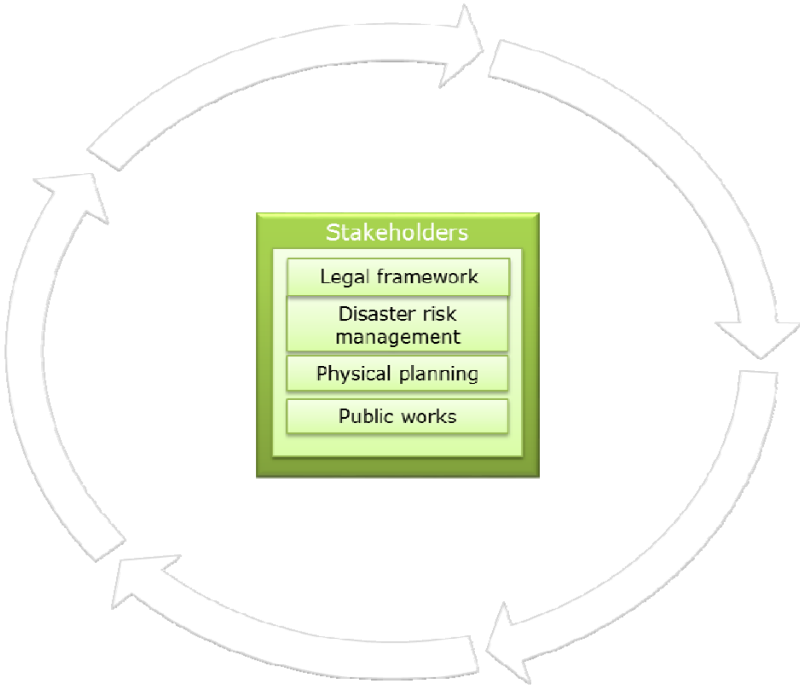
Analyse current risk level



Stakeholders

Central in the whole process are the stakeholders. These could be subdivided into:

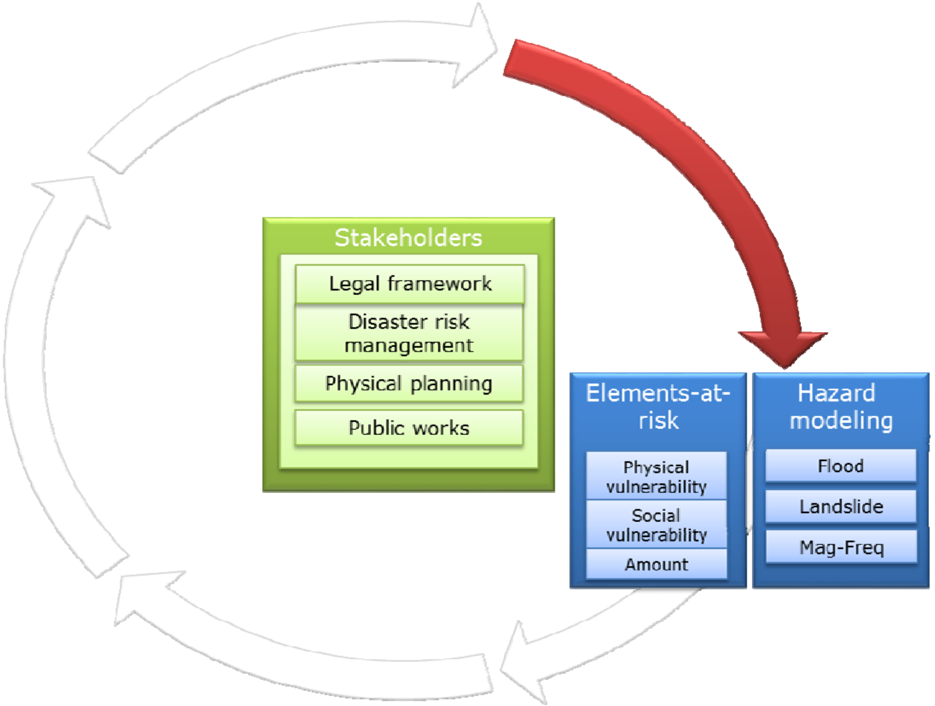
- Government departments responsible for the construction, monitoring, maintenance and protection of critical infrastructure (e.g. the Ministry of Public Works).
- Physical planning departments responsible for the with the mandate to make land development plans at different scales.
- National Emergency Management Organizations
- Local authorities
- Private sector
- Academics
- Non Governmental organisations



Hazard modelling and elements-at-risk mapping

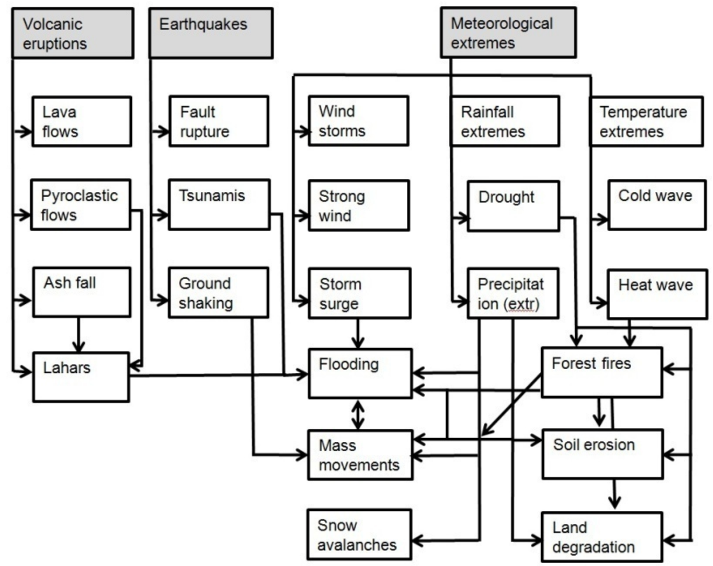
Stakeholders normally have a few persons capable of visualizing spatial data using GIS, but are not sufficiently capable of carrying out the actual spatial hazard and risk analysis required as the basis for their work.
Therefore they will work with external consultants that will carry out this type of analysis for them, and they have to specify the exact Terms of Reference of the work of the consultants.
These consultants may work on different topics:

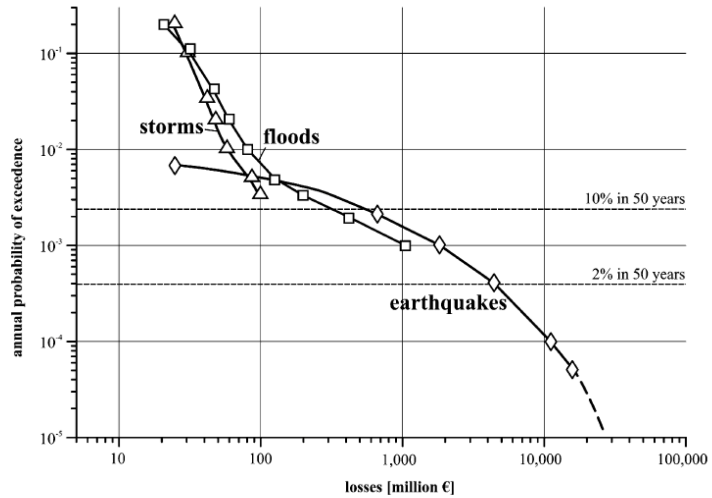
- Hazard modelling. Consultants provide the relevant information related to flood and landslide hazard for the required scales of analysis
- Elements-at-risk and vulnerability assessment



From single to multi-hazard risk

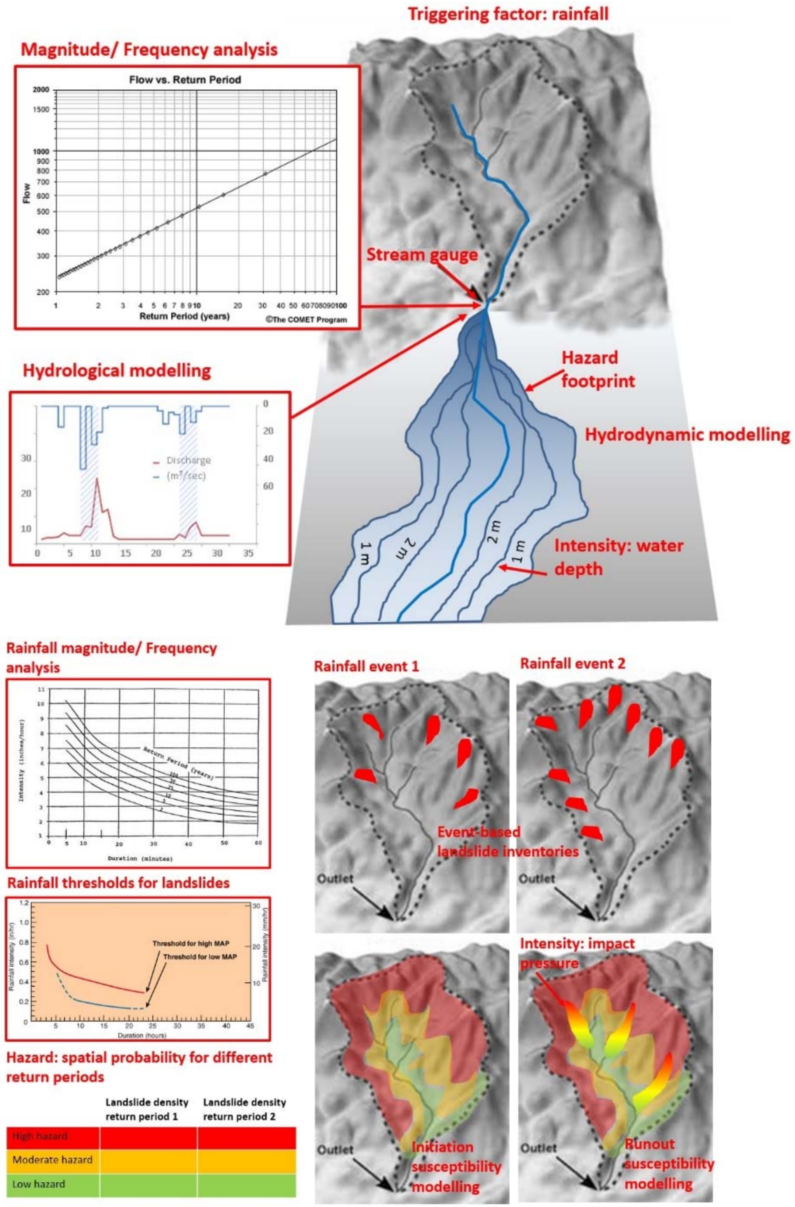
- **Independent events**
  - Triggering event do not interact
  - E.g. earthquake and floods
- **Coupled events**
  - same trigger, may affect same area
  - E.g. flashfloods and debrisflows
- **Conditional**
  - One hazard changes conditions for th
  - e.g. fire, landslide
- **Domino or cascading hazards**
  - First one, then next then third
  - e.g. earthquake, landslide, flood





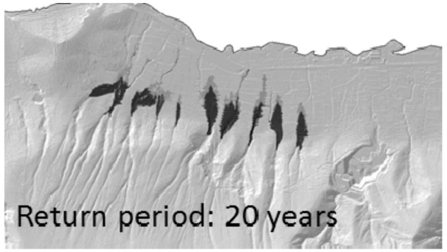
How these hazard maps are made

- Analysis of rainfall triggers ➔ return periods
- Collection of historical hazard data:
  - Where? When? How much? ➔ hazard extend maps
- Hydrological modelling:
  - Rainfall-runoff modelling ➔ discharge
  - Soilwater modelling ➔ ground water / soil water maps
- Slope stability modeling ➔ slope stability maps
- Hydrodynamic modeling ➔ flood / debrisflow maps
- Landslide runout modeling ➔run-out maps

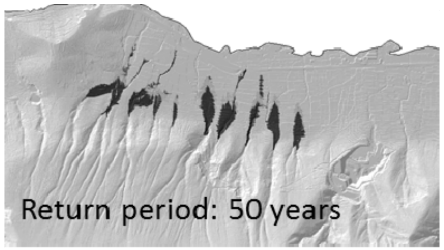


Hazard maps

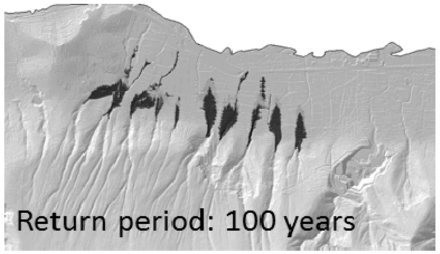
Debrisflow (DF) hazard
Impact pressure (IP)



DF_IP_20_A0

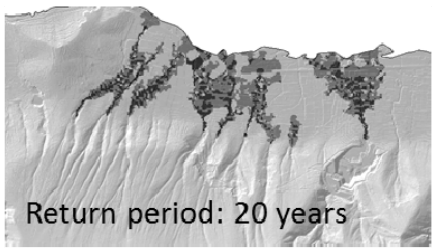


DF_IP_50_A0

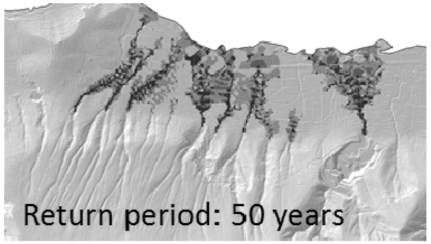


DF_IP_100_A0

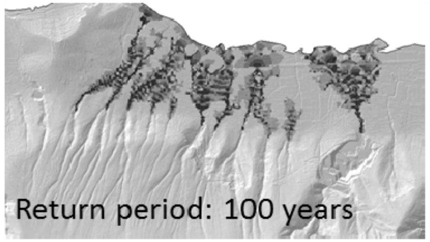
Flashflood (FL) hazard
Water depth (DE)



FL_DE_20_A0

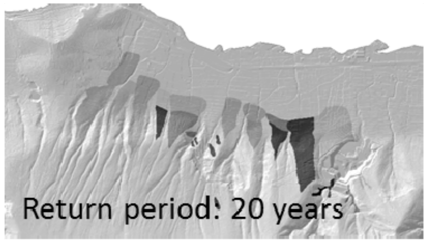


FL_DE_50_A0

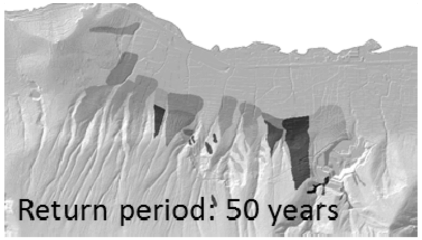


FL_DE_100_A0

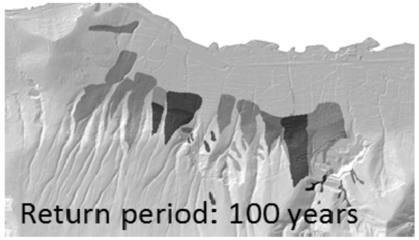
Landslide (LS) hazard
Spatial probability (SP)



LS_SP_20_A0

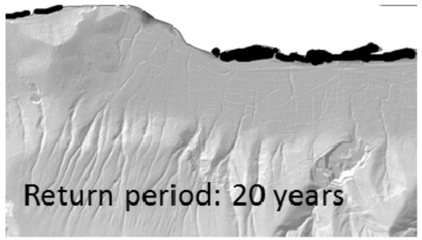


LS_SP_50_A0

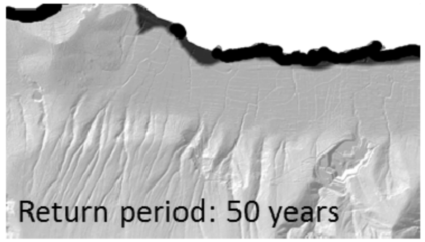


LS_SP_100_A0

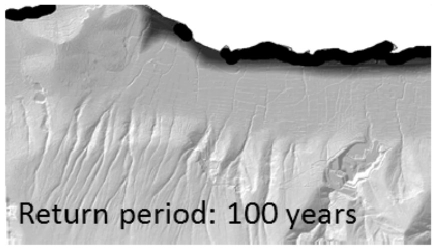
Tsunami (TS) hazard
Water Depth (DE)



TS_DE_20_A0



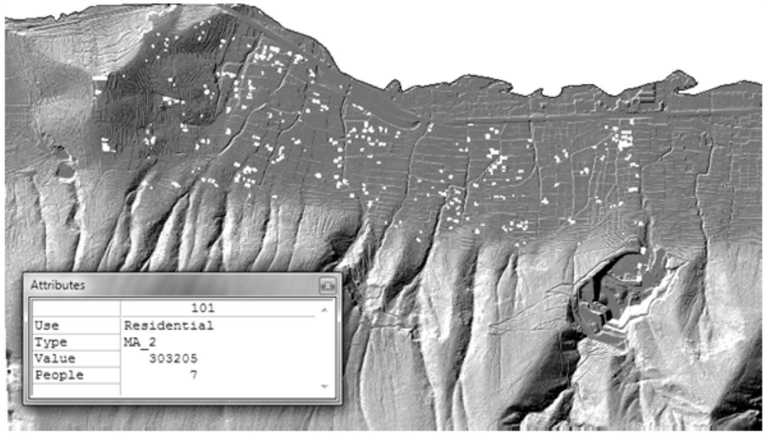
TS_DE_50_A0



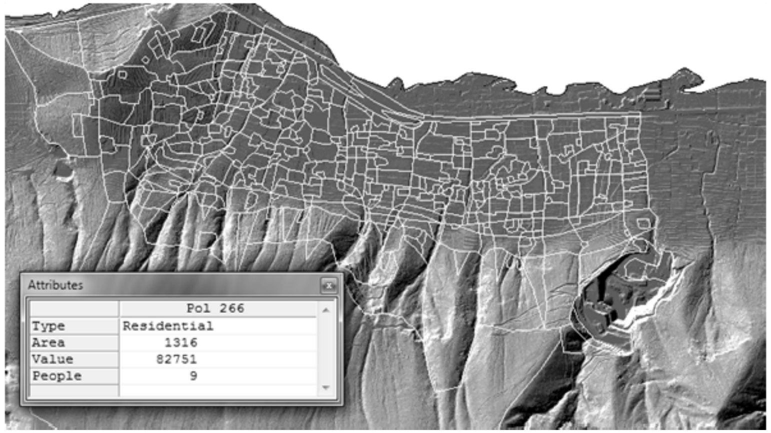
TS_DE_100_A0

Elements at risk

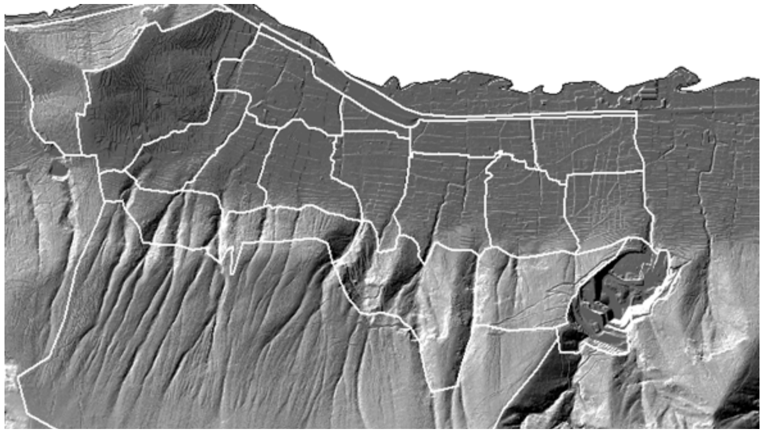
Building Footprints



Land parcels



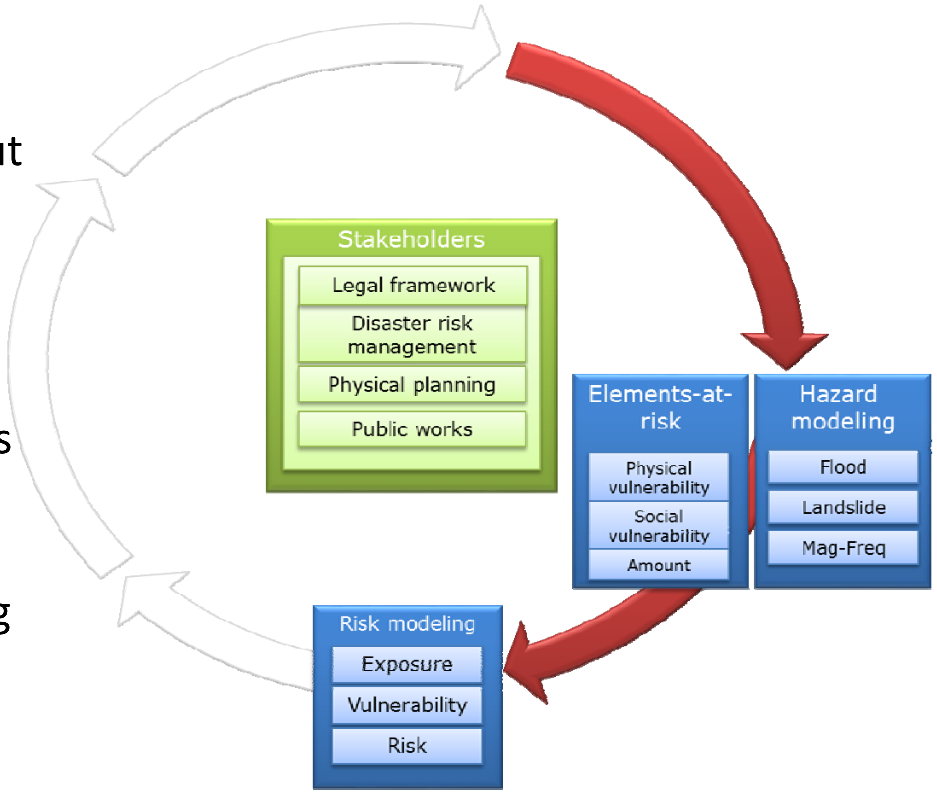
Administrative units



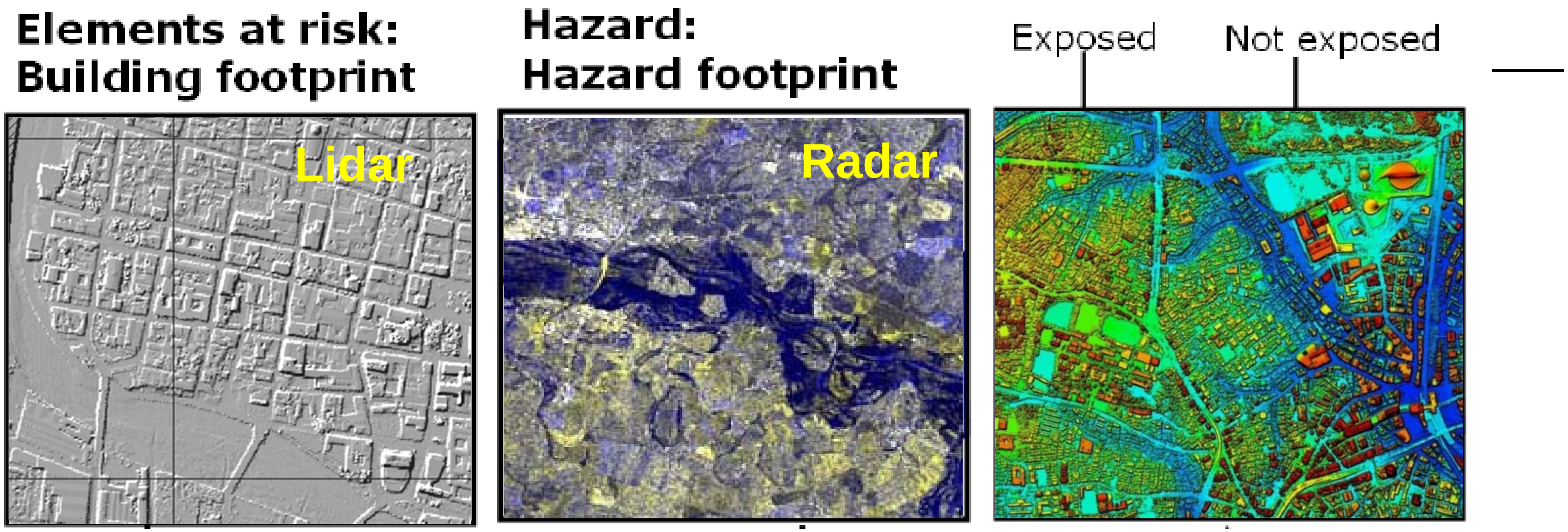
Risk analysis

The crucial stage in the evaluation of possible risk reduction strategies is the analysis of risk, which is defined as the probability of losses related to potentially hazardous phenomena. Also this type of work generally is not carried out by the government organizations themselves, but rather by consultants, that have the right expertise to carry out this type of analysis for one or more types of hazards, in combination with one or more types of elements-at risk. This work is done at the appropriate scale related to the objectives of the stakeholders. The risk assessment can be subdivided into the following components:

- **Exposure analysis** (overlay of hazard intensities and elements-at-risk)
- **Vulnerability assessment** (translate hazard intensities into expected degree of loss)
- **Risk assessment** (integrate losses for different hazards and return periods)



Exposure analysis



Spatial overlay of:

- a hazard footprint of a particular event;
- and elements at risk.

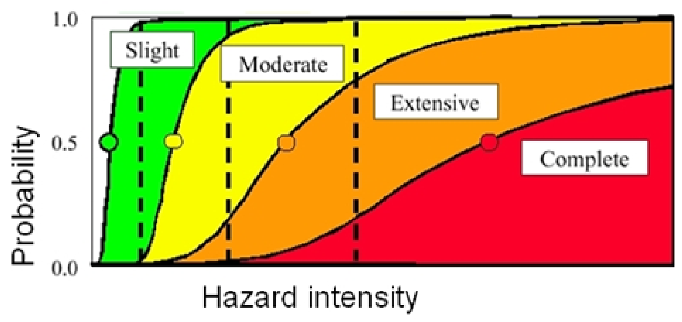
Gives the number of elements at risk affected.

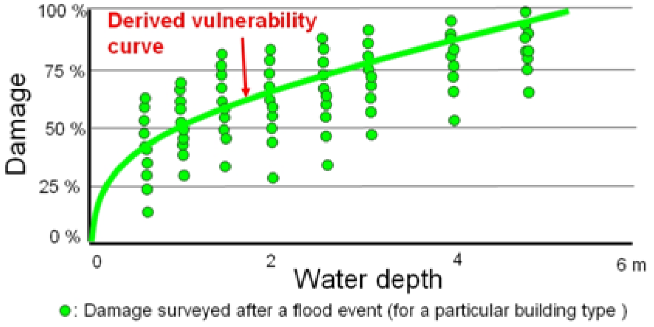
Useful first approach

Also a step in advanced risk assessment

EXPRESSING PHYSICAL VULNERABILITY

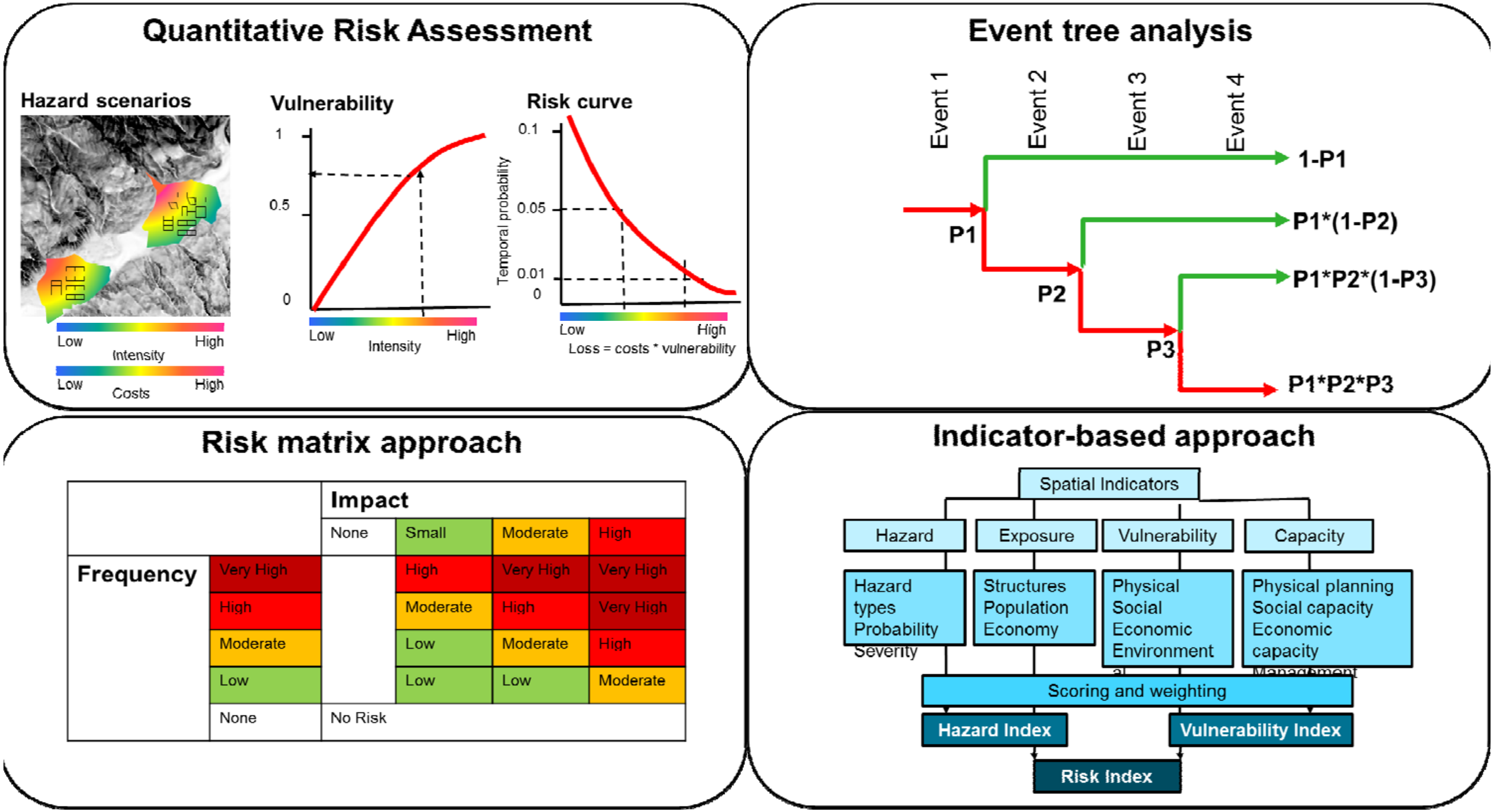
- **Vulnerability indices / tables**
- **Vulnerability curves:**
  - that are constructed on the basis of the relation between hazard intensities and damage data
  - Relative curves.
  - Absolute curves
- **Fragility curves:**
  - provide the probability for a particular group of elements at risk to be in or exceeding a certain damage state under a given hazard intensity.





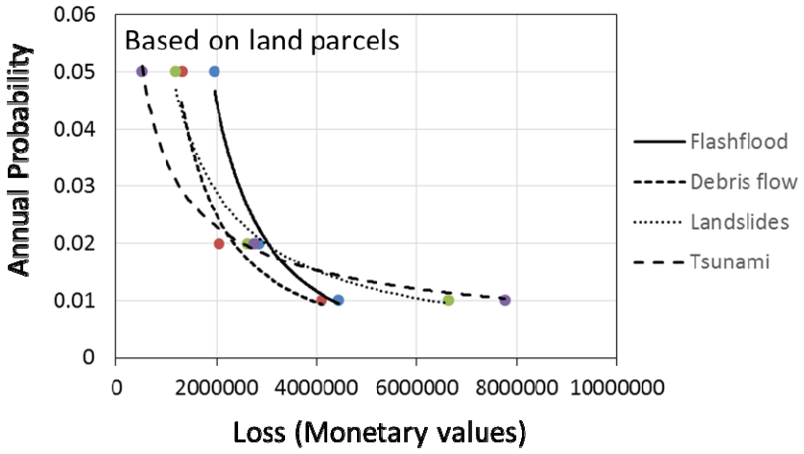
How are they obtained?

- **Empirical methods:**
  - **Analysis of observed damage**
  - **Expert opinion**
  - **Scoring and weighting**
- **Analytical methods**
  - **Physical modeling**
  - **Computer modeling**

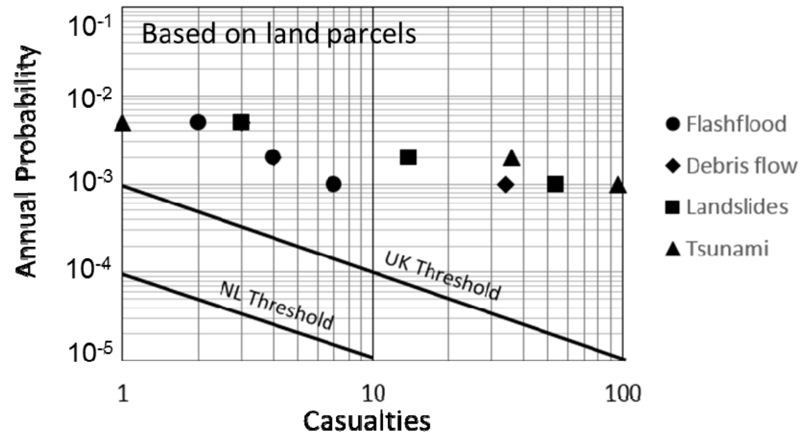

Quantitative Risk Assessment
Hazard scenarios
Low
High
Intensity
Low
Costs
High
Vulnerability
1
0.5
0
Low
Intensity
High
Risk curve
Temporal probability
0.1
0.05
0.01
0
Low
High
Loss = costs * vulnerability
Event tree analysis
Event 1
Event 2
Event 3
Event 4
1-P1
P1
P1*(1-P2)
P2
P1*P2*(1-P3)
P3
P1*P2*P3
Risk matrix approach
Impact
None
Small
Moderate
High
Frequency
Very High
High
Very High
Very High
High
Moderate
High
Very High
Moderate
Low
Moderate
High
Low
Low
Low
Moderate
None
No Risk
Indicator-based approach
Spatial Indicators
Hazard
Exposure
Vulnerability
Capacity
Hazard types
Probability
Severity
Structures
Population
Economy
Physical
Social
Economic
Environmental
Physical planning
Social capacity
Economic capacity
Management
Scoring and weighting
Hazard Index
Vulnerability Index
Risk Index

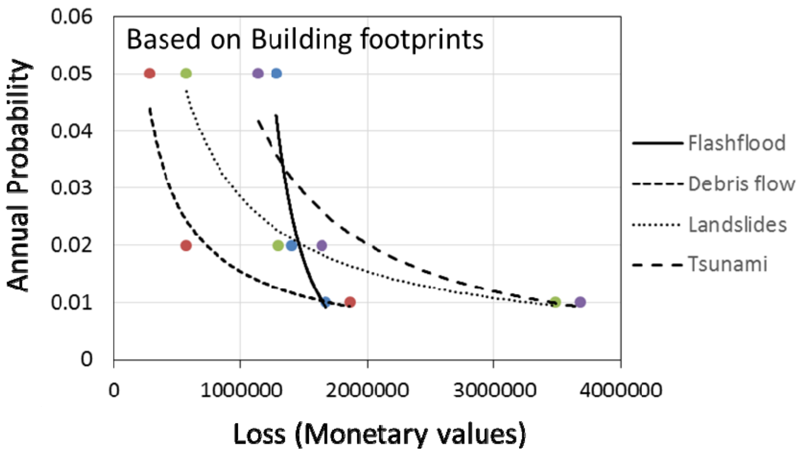
RISK RESULTS

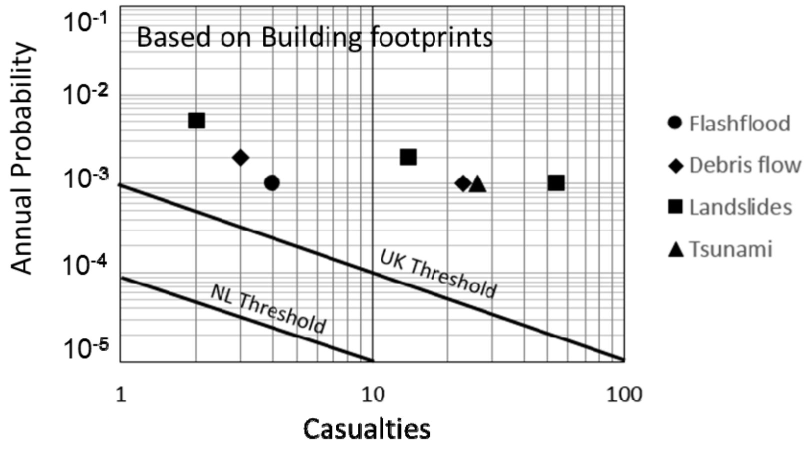
Monetary risk



Societal risk





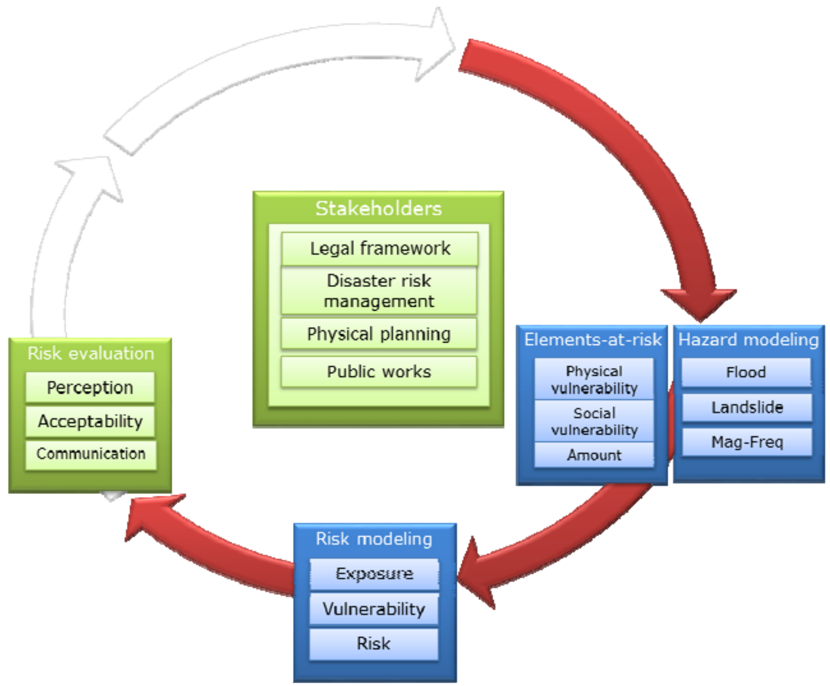


Risk evaluation

After analysing the risk it is important to determine whether the risk is too high, and where the risk is too high. This is called the risk evaluation stage, and is the stage at which values and judgements enter the decision process, explicitly or implicitly, by including consideration of the importance of the estimated risks and the associated social, environmental, and economic consequences, in order to identify a range of alternatives for managing the risks.

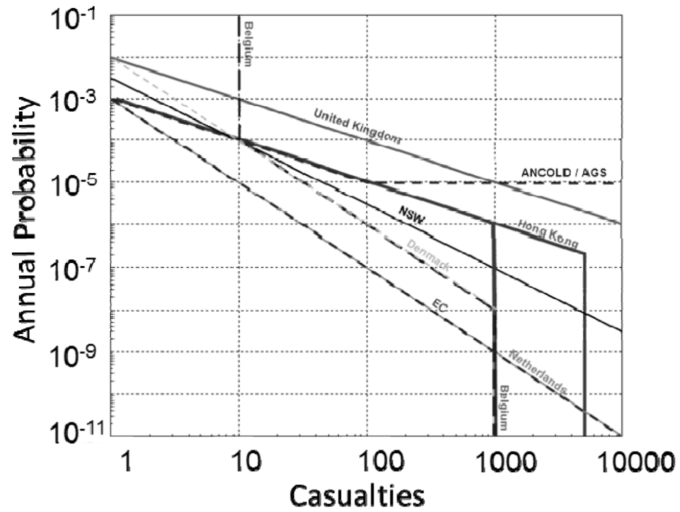
Important considerations in this respect are:

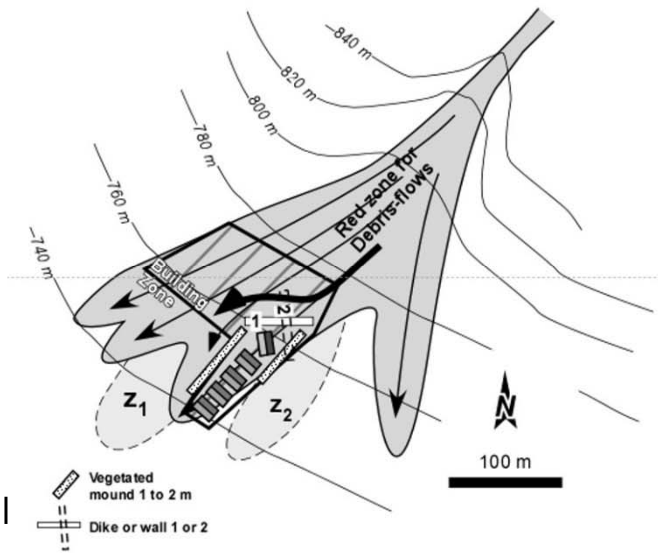
- Risk perception
- Risk acceptability
- Risk communication

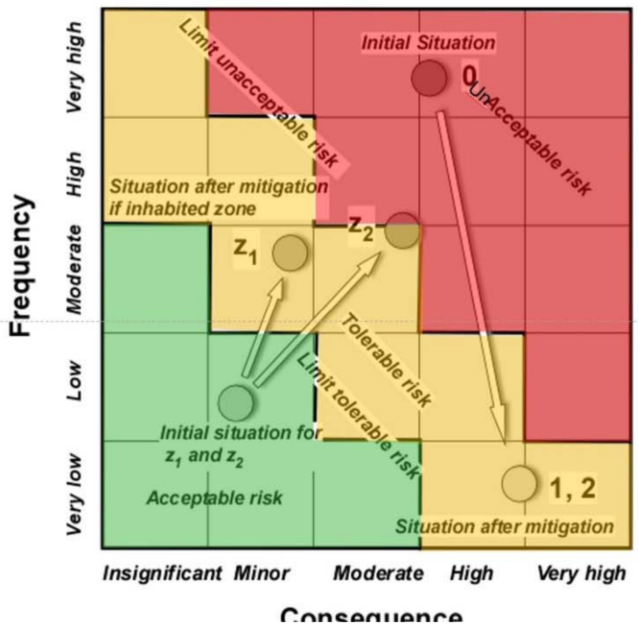


RISK EVALUATION

- Individual risk
- Societal risk
- Risk perception
- Risk evaluation criteria







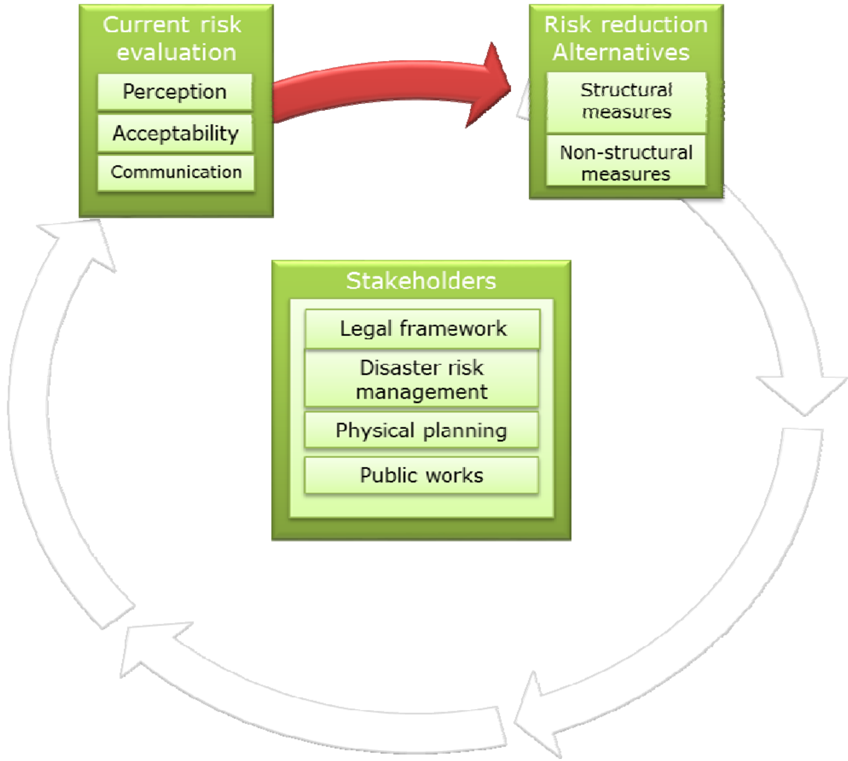
Analyse risk reduction alternatives

In this workflow the stakeholders want to analyze the best risk reduction alternative, or combination of alternatives. They define the alternatives, and request the expert organizations to provide them with updated hazard maps, elements-at-risk information and vulnerability information reflecting the consequences of these scenarios.

Once these hazard and asset maps are available for the scenarios, the new risk level is analyzed, and compared with the existing risk level to estimate the level of risk reduction. This is then evaluated against the costs (both in terms of finances as well as in terms of other constraints) and the best risk reduction scenario is selected.

The planning of risk reduction measures (alternatives) involves:

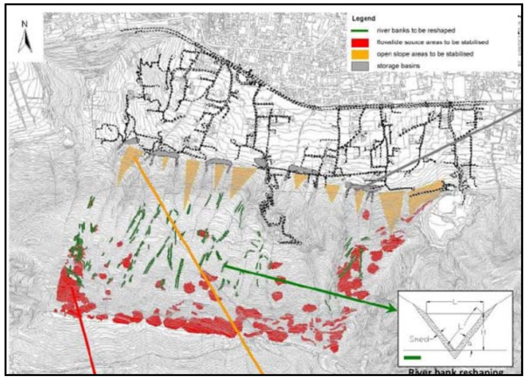
- **Disaster response planning**
- **Planning of risk reduction measures**
- **Spatial planning**

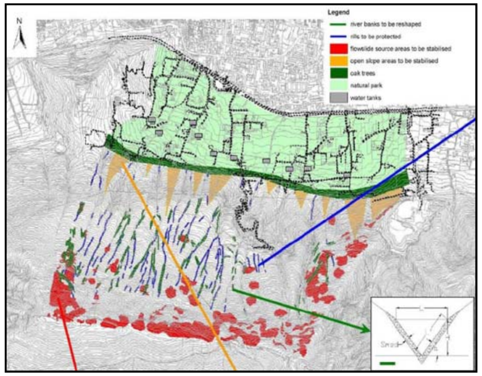


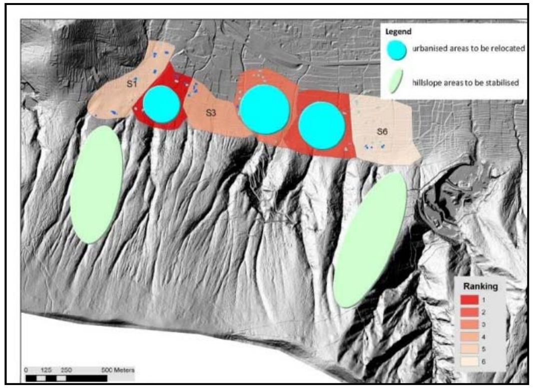
Possible planning alternatives

For example the following planning alternatives could be analyzed when considering an area prone to flashflood, debrisflows and landslides:

Planning Alternatives	Description	Codes
A0 (no risk reduction)	Do nothing	2014_A0_S0
A1 Engineering	Construction of engineering structures (e.g. flood walls, sotriage basins)	2014_A0_S1
A2 Ecological	Ecological disaster risk reduction measures (e.g. protective forest, bioengineering)	2014_A0_S2
A3 Relocation	Relocation of high risk elements-at-risk	2014_A0_S3





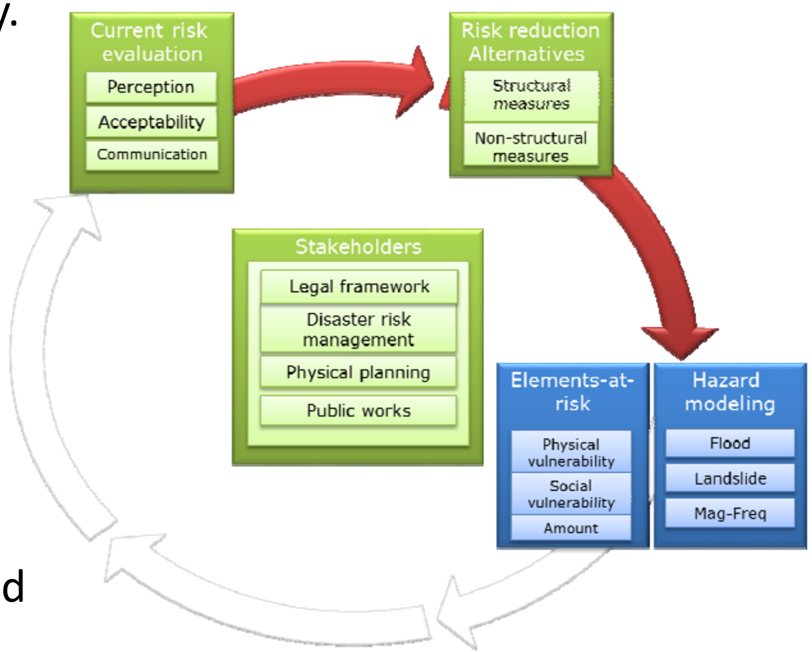


Update hazard & elements-at-risk

The implementation of certain structural or non-structural risk mitigation measures might lead to a modification of the hazard, exposure and vulnerability. Risk is a function of Hazard * vulnerability of exposed elements-at-risk * the quantification of the elements-at-risk. So there are several possibilities, that risk mitigation measures will influence

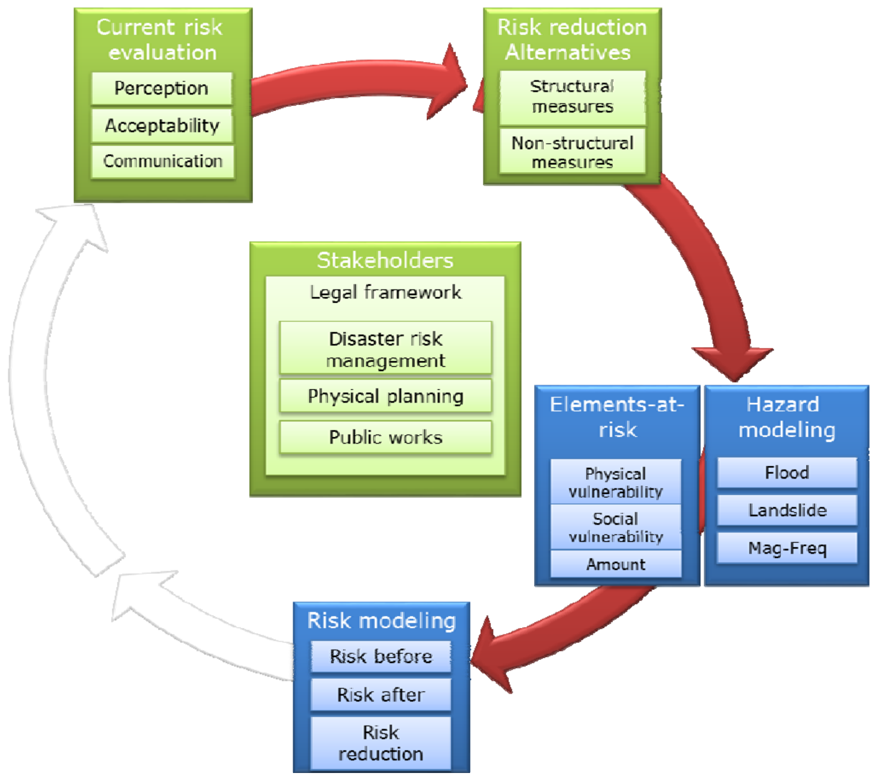
- **The hazard**
- **The exposure of elements-at-risk**
- **The vulnerability of elements-at-risk**
- **The quantification of the elements-at risk**

Therefore experts should evaluate together with the stakeholders what would be the effect of the proposed alternative on the hazard, elements-at-risk location and characteristics and the vulnerability. If needed new hazard modelling should be carried out, or new elements-at-risk maps should be made representing the new situation.

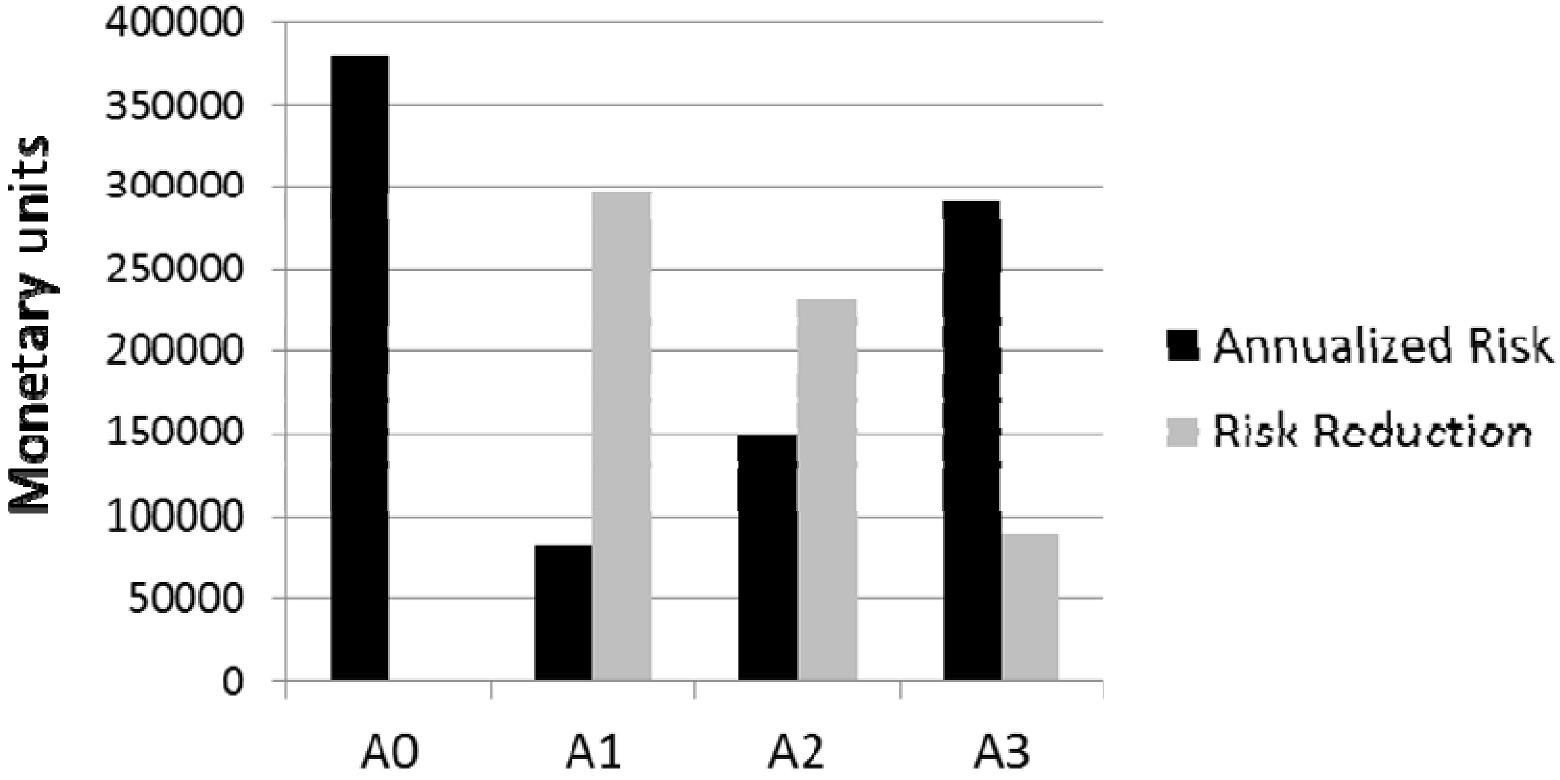


Re-analyse the risk for each alternative

After re-analyzing the hazard, elements-at-risk and vulnerability for the situation after the implementation of the planning alternative, the next step is to analyze the resulting level of risk, and compare this with the current risk level. The difference between the average annual losses before and after the implementation of the planning alternative, provides information on the risk reduction. This should be done for all the possible planning alternatives. The risk reduction should be done preferable both in terms of economic risk reduction (reduction in the average annual losses in monetary values) as well as in population risk reduction (reduction in the expected casualties or exposed people).



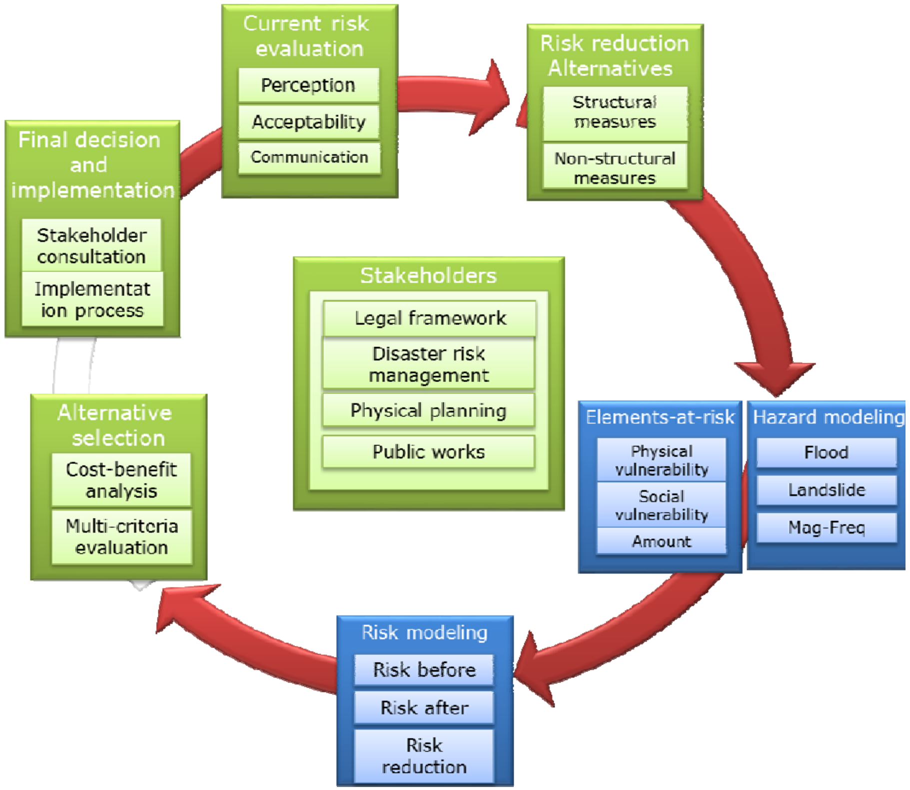
Comparing risk



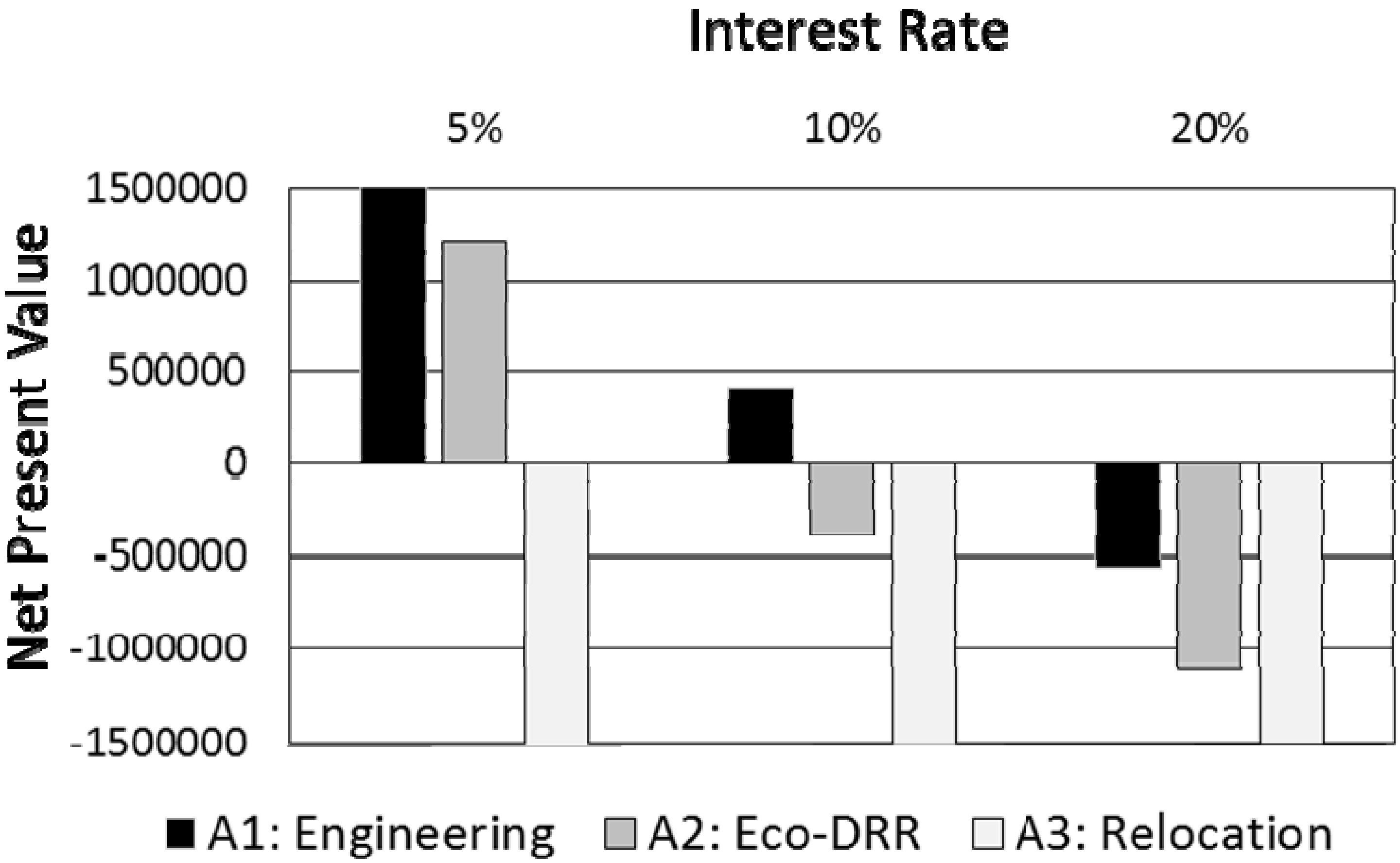
Alternative evaluation

Which alternative is the best?
This could be done through different methods:

- **Cost-benefit analysis**. Here both the benefits and the costs can be quantified. The benefit of a risk reduction alternative is represented by its annual risk reduction in monetary values, which was calculated in the previous step (risk after implementation minus current risk).
- **Cost-effectiveness analysis**. This is carried out when the costs can be quantified and compared, but the benefits in terms of risk reduction cannot be quantified in monetary values
- **Multi-Criteria Evaluation**. When both the costs and benefits cannot be quantified in monetary values, or when additional to cost-benefit or cost-effectiveness also other non-quantifiable indicators are used

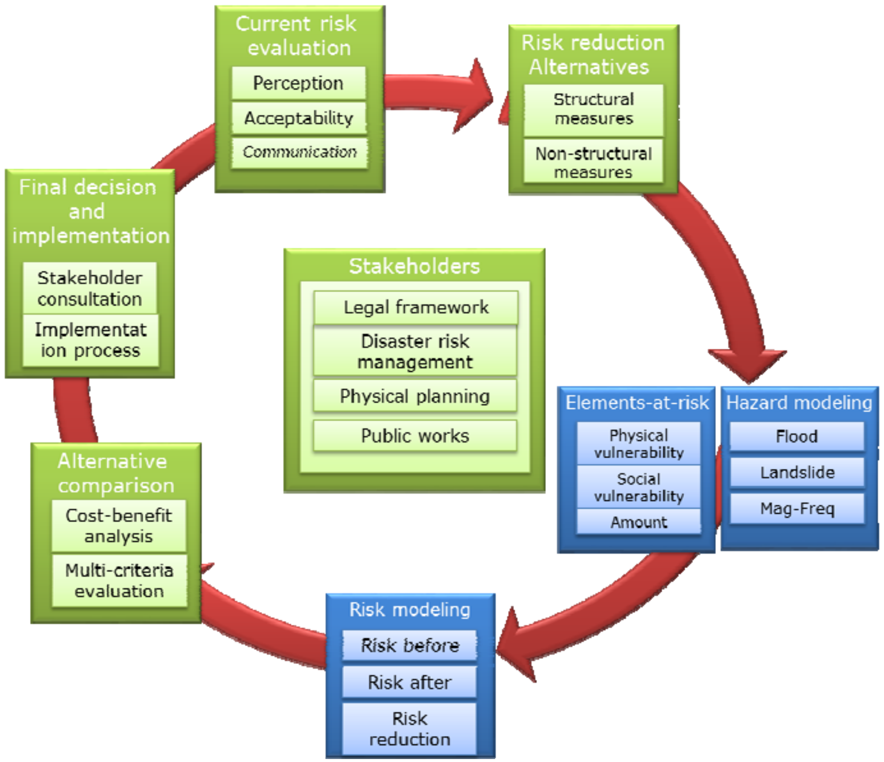


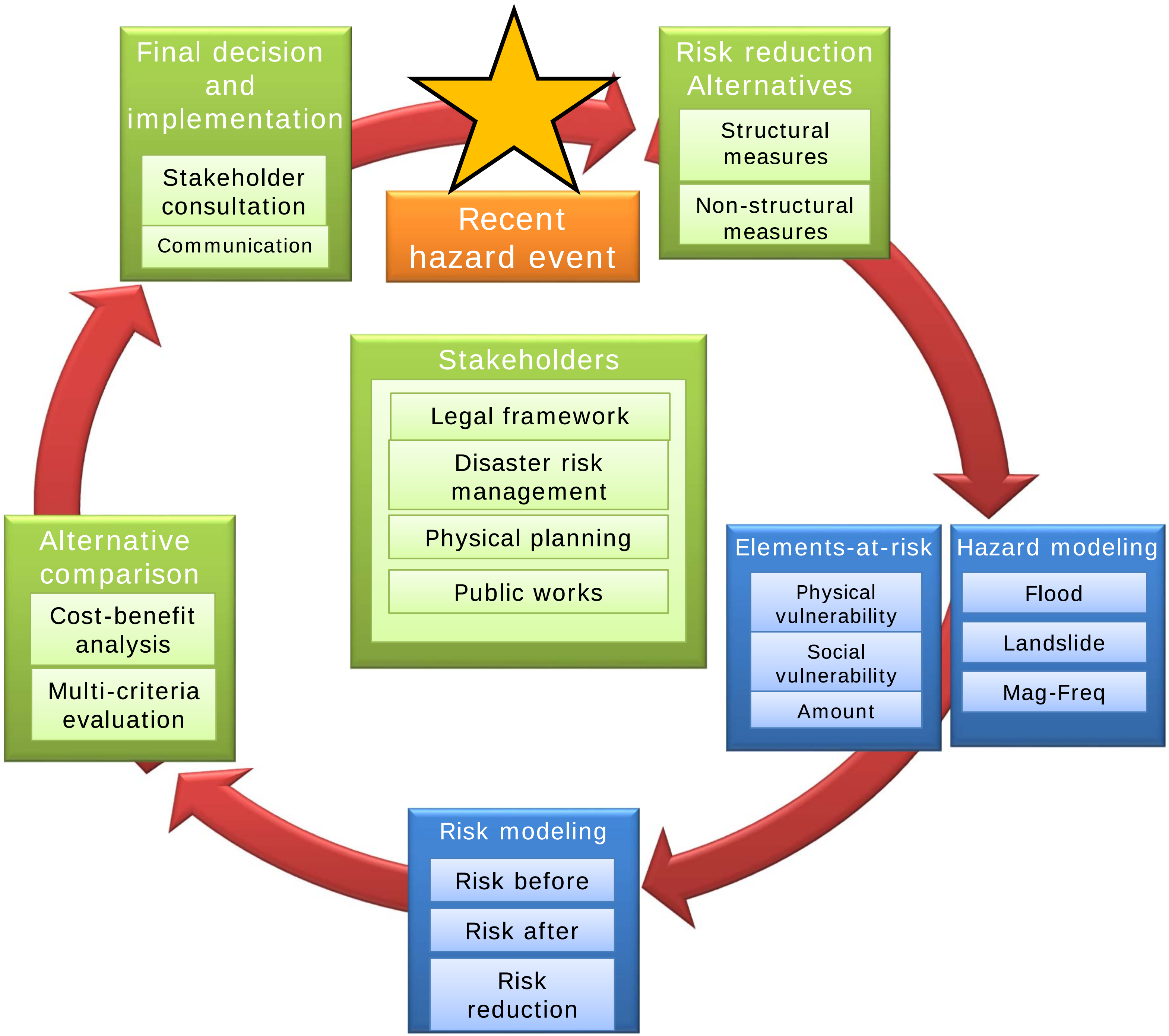
Results cost-benefit analysis



Risk reduction alternative selection

The last step of this workflow related to the selection of the optimal planning alternative in relation to the reduction of risk to hydro-meteorological hazards is the consultation with the various stakeholders involved. This includes public hearings with the population, private sector, non-governmental organizations, and various social network groups (e.g. communities, churches). The stakeholders have the opportunity to request adjustment to the proposed plan of action, and if these adjustments are considered valid, and substantial, a new round of evaluation might be needed if the change of expected hazard and risk impact is substantial. Once the plan is approval the procedures will start for the implementation of the plan.

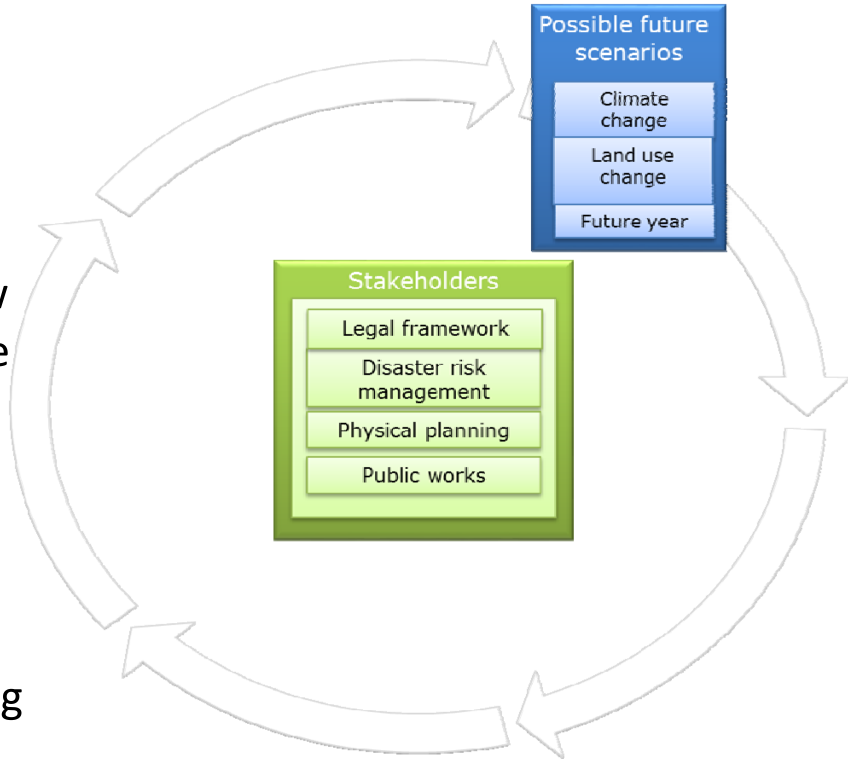



Final decision and implementation
Stakeholder consultation
Communication
Recent hazard event
Risk reduction Alternatives
Structural measures
Non-structural measures
Stakeholders
Legal framework
Disaster risk management
Physical planning
Public works
Elements-at-risk
Physical vulnerability
Social vulnerability
Amount
Hazard modeling
Flood
Landslide
Mag-Freq
Risk modeling
Risk before
Risk after
Risk reduction
Alternative comparison
Cost-benefit analysis
Multi-criteria evaluation

Identification of possible future scenarios

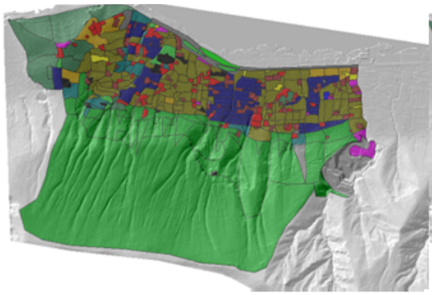
The scenarios are related to possible changes related to climate, land use change or population change due to global and regional changes, and which are only partially under the control of the local planning organizations. The stakeholders might like to evaluate how these trends have an effect on the hazard and elements-at-risk and how these would translate into different risk levels. The possible future could be of the following types:

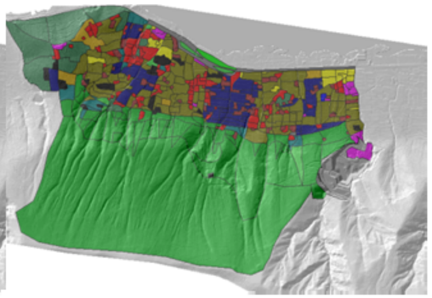
- Climate change scenarios (with effect on the frequency and intensity of the hazards)
- Land use change scenarios (based on macro-economic and political developments)
- Future planning scenarios (for instance resulting from the national physical development plan)
- A combination of the above.

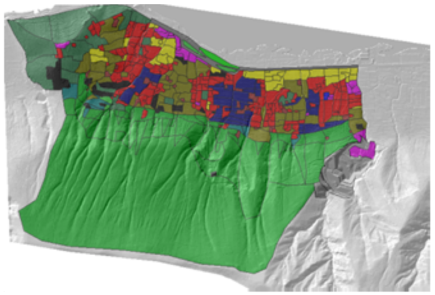


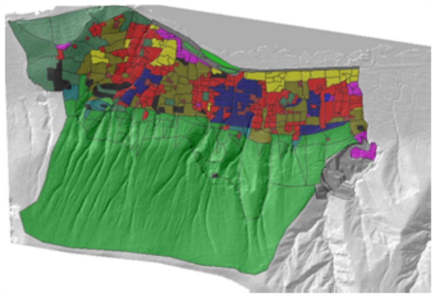
Possible future scenarios

	Name	Land use change	Climate change
Scenario 1	**Business as usual**	Rapid growth without taking into account the risk information	No major change in climate expected
Scenario 2	**Risk informed planning**	Rapid growth that takes into account the risk information and extends the alternatives in the planning	No major change in climate expected
Scenario 3	**Worst case**	Rapid growth without taking into account the risk information	Climate change expected, leading to more frequent extreme events
Scenario 4	**Most realistic**	Rapid growth that takes into account the risk information and extends the alternatives in the planning	Climate change expected, leading to more frequent extreme events


2014


2020

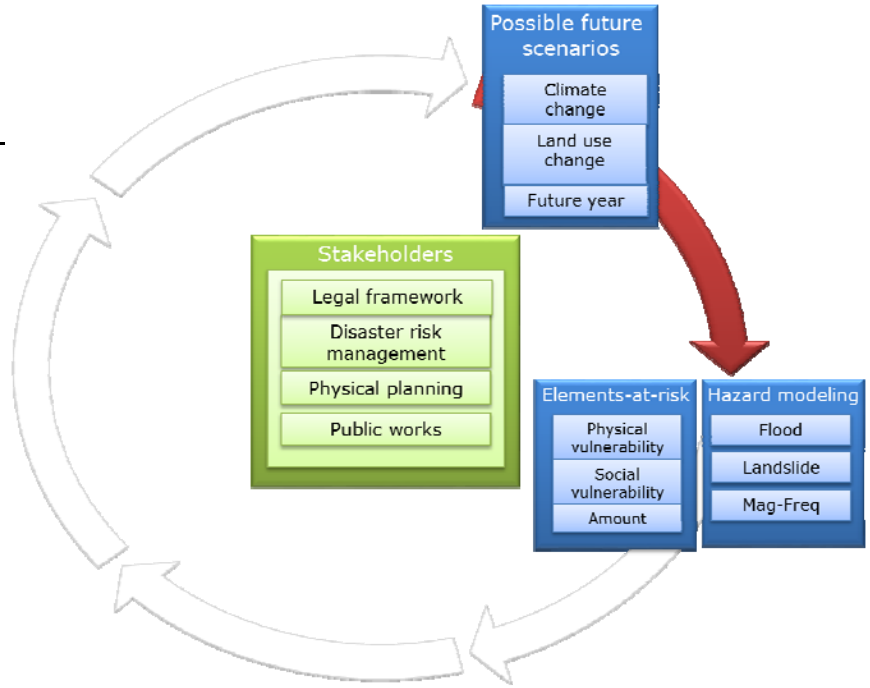

2030


2040

New hazard & elements at risk maps for future years

The possible future scenarios might lead to a modification of the hazard, exposure and vulnerability in certain future years from now. Therefore it is required to re-analyse:

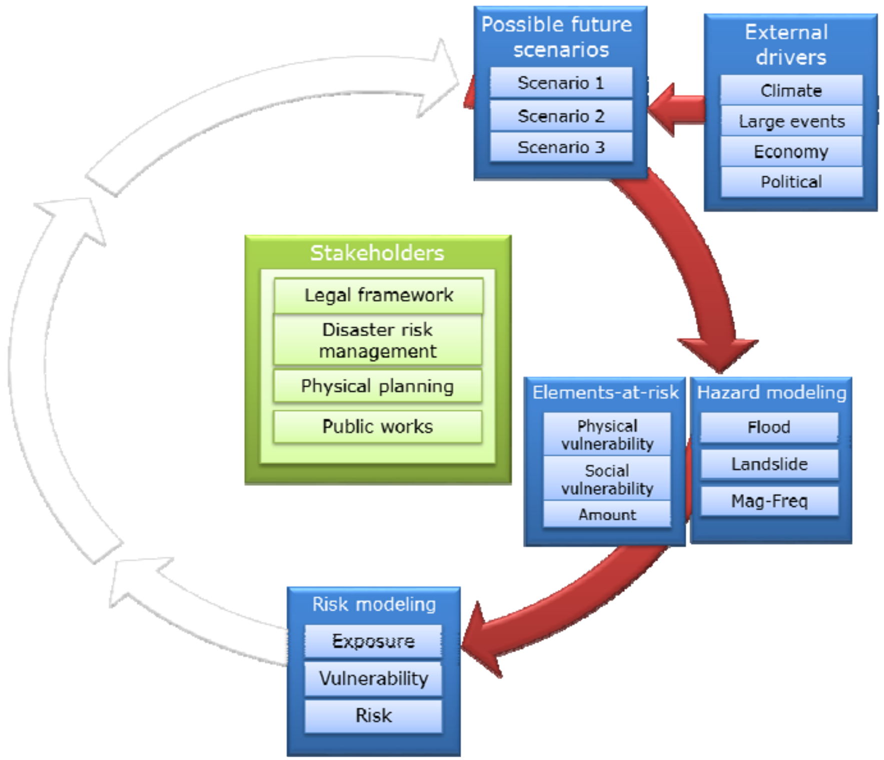
- The hazard. change in the frequency and magnitude of triggering events. New magnitude-frequency analysis might be required, that take into account changing trends in frequencies of extreme events.
- The exposure of elements-at-risk. The possible land use scenarios might lead to substantial changes in land use/land cover, which also has an important effect on the number of elements-at-risk within the various land use classes.



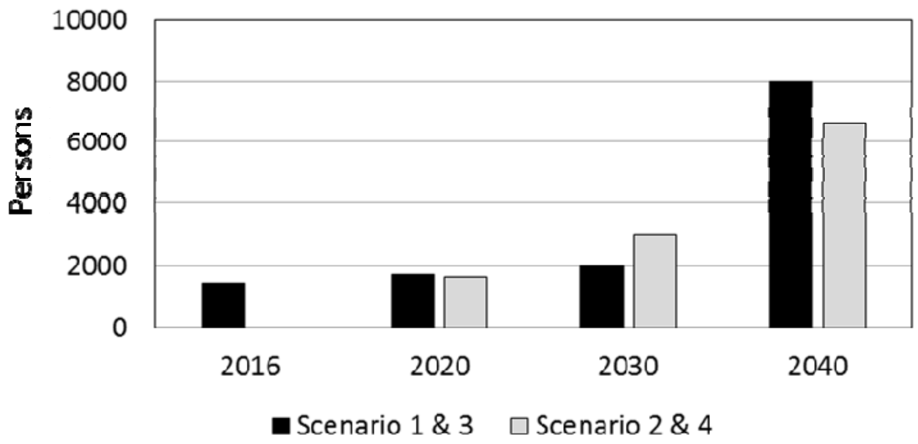
What would be the effect of the possible future scenarios on the hazard, elements-at-risk location and characteristics and the vulnerability?
If needed new modelling and maps should be made.

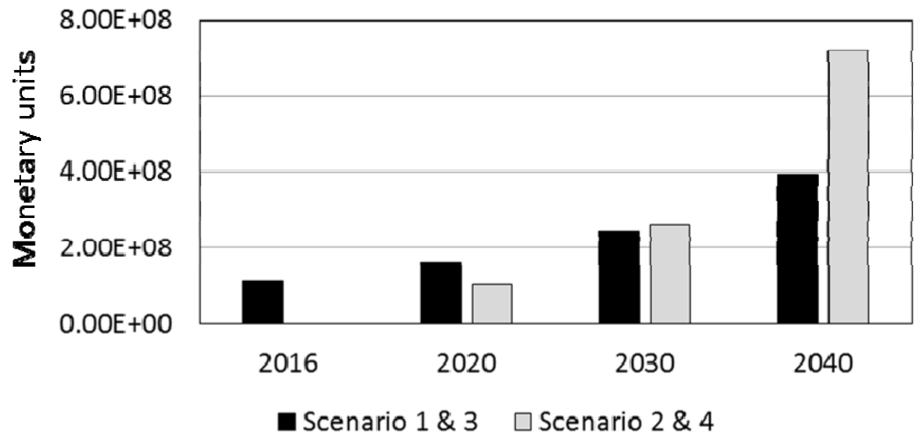
Re-analysing the risk for scenarios and future years

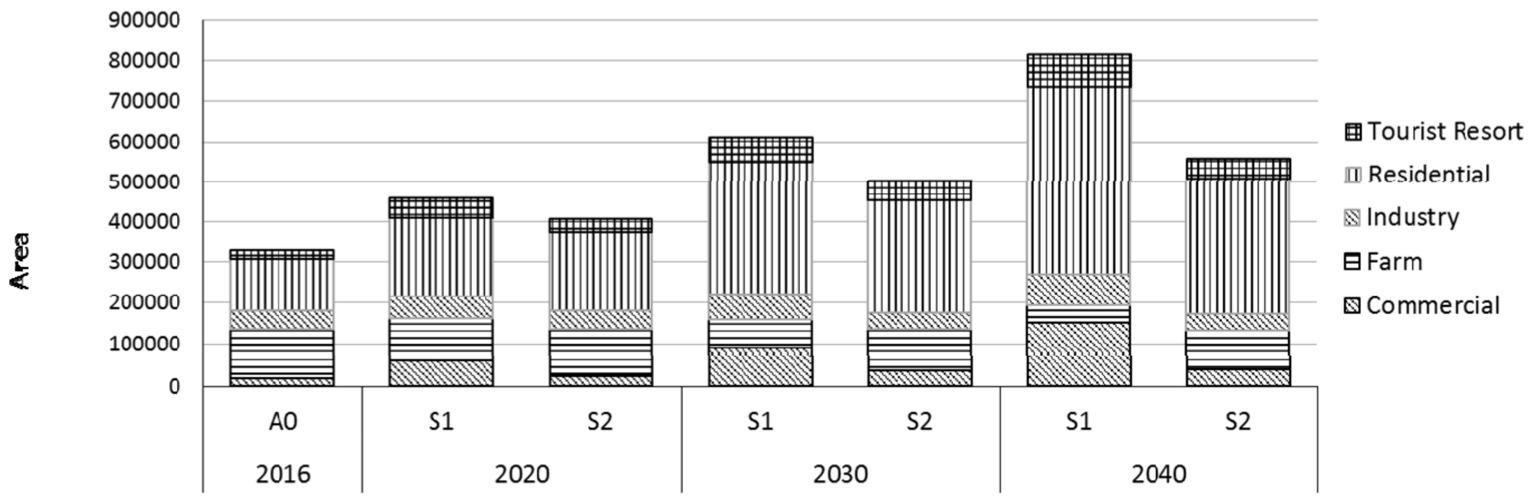
Re-analyze the resulting change in risk, and compare this with the current risk level.
The difference between the current average annual losses and those in a future year under a given change scenario provides information for decision makers on the possible negative consequences of climate change and land use change scenarios.
They can be used as a basis for designing appropriate strategies for adaptation. The risk reduction should be done preferable both in terms of changes in economic risk (average annual losses in monetary values) as well as in population risk reduction (expected casualties or exposed people). It is also important to incorporate the uncertainty levels in this type of analysis, thus providing a range of change rather than concrete values.



Changes per scenario



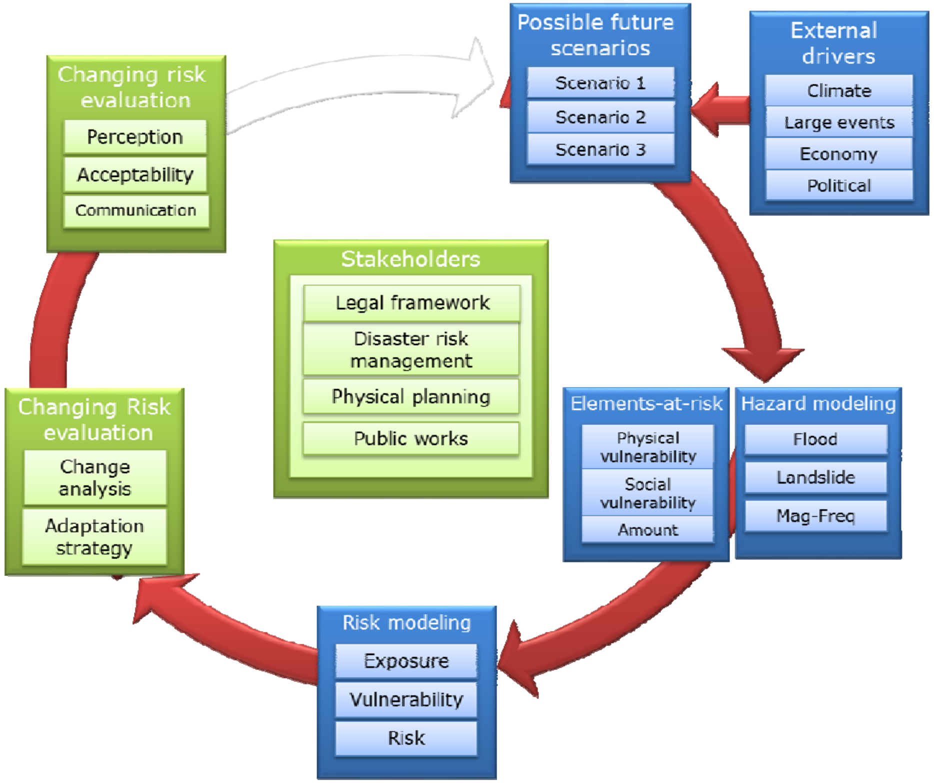




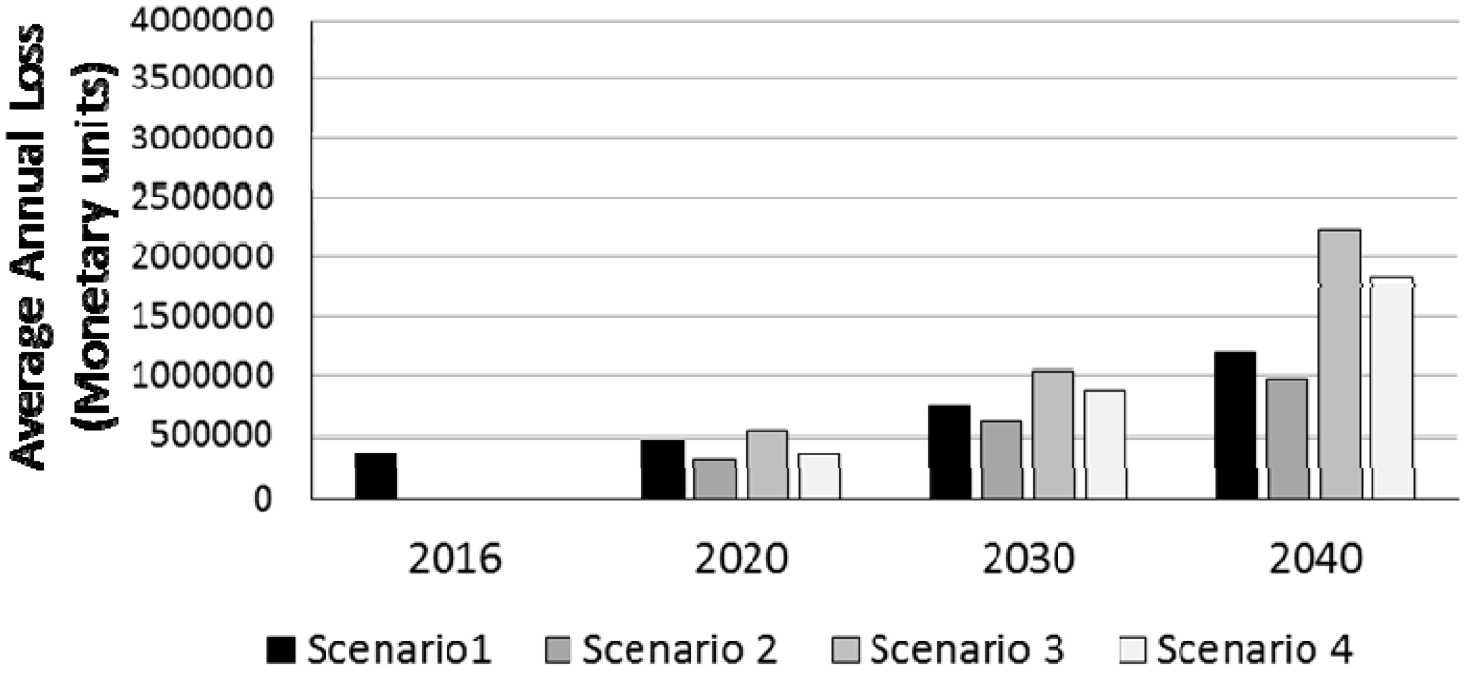
Evaluate changing risk under different scenarios

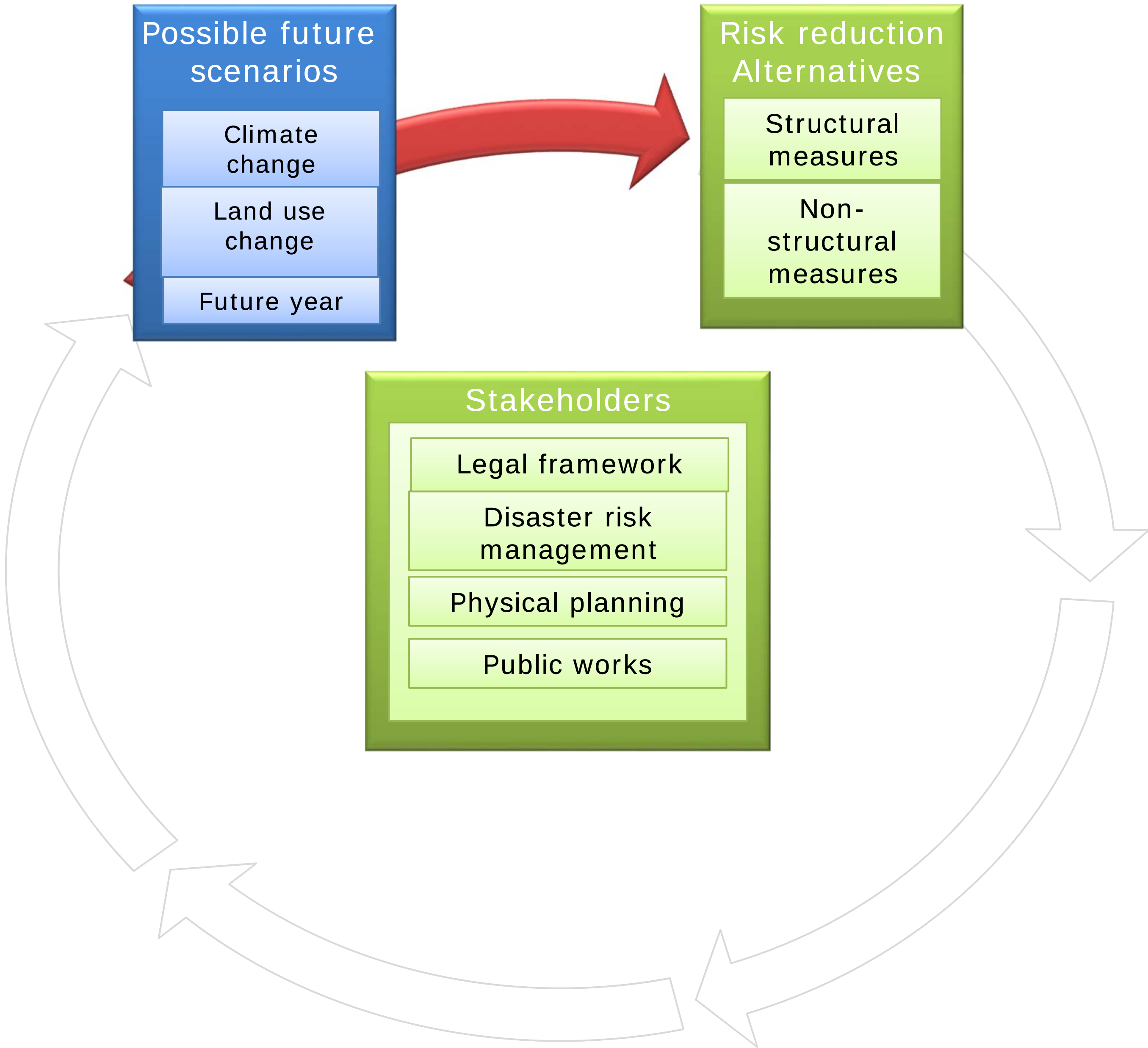
After assessing the possible changes in risk that might result from a number of possible future scenarios related to climate change and land use change, stakeholders should analyze these changes carefully in terms of :

- **Spatial location of changes in risk**. Some areas might be much more impacted by these possible future changes than others. Based on the outcomes of the analysis stakeholders could then prioritize certain areas for critical interventions.
- **Critical sectors**. Changes in risk could be analysed for different sectors of society, such as economy, agriculture, tourism, education, transportation etc.
- **Development of adaptation strategies**. formulation of adaptation strategies that aim to reduce these possible impacts through planning alternatives that could be implemented now.



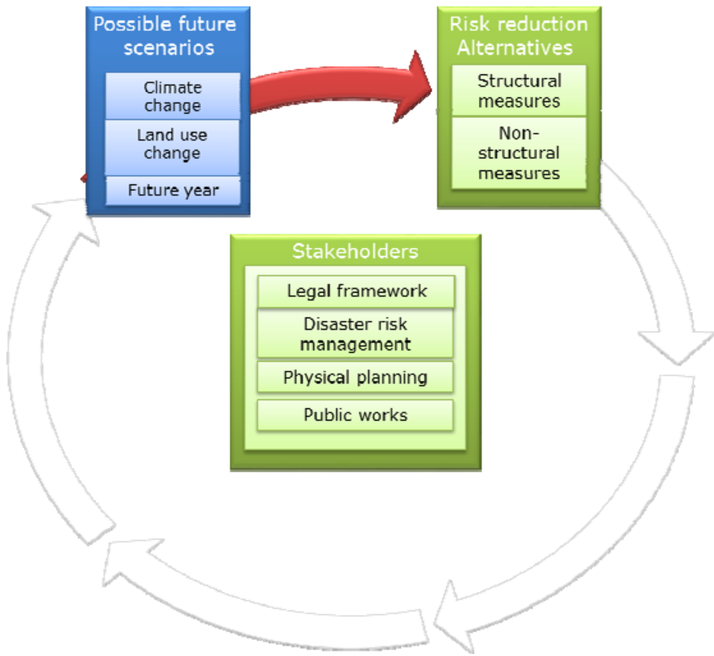
Changing risk per scenario




Possible future scenarios
Climate change
Land use change
Future year
Risk reduction Alternatives
Structural measures
Non-structural measures
Stakeholders
Legal framework
Disaster risk management
Physical planning
Public works

Which risk reduction alternative will work best under different scenarios

The evaluation how different risk reduction alternatives will lead to risk reduction under different future scenarios (trends of climate change, land use change and population change) is the most complicated workflow, as it requires to calculate the present risk level, the effect of different risk reduction alternatives, and the overprinting of these on the scenarios. For each of these combinations of alternatives & scenarios new hazard, assets and risk maps need to be made. However, this type of analysis allows Stakeholders to make the most optimal "change proof" selection of planning alternatives. This type of analysis is entirely based on experts and consultants which should evaluate both the effects of the planning alternatives as well as the associated effects of possible future scenarios on hazard, vulnerability and risk. Such type of analysis could be applied to specific critical areas, such as the capitals or important critical infrastructure.



Alternatives, scenarios and future years

Scenario: Possible Future trends	Alternative: risk reduction options	Now 2014	Future years		
			2020	2030	2040
S0 (Without including any future trends)	A0 (no risk reduction)	2014_A0_S0	No future trends are taking into account, and all hazards, elements at risk and vulnerabilities are considered constant in future.		
	A1 Engineering	2014_A0_S1			
	A2 Ecological	2014_A0_S2			
	A3 Relocation	2014_A0_S3			
S1 Business as usual	A0 (no risk reduction)	Does not exist: use existing situation	2020_A0_S1	2030_A0_S1	2040_A0_S1
	A1 Engineering		2020_A1_S1	2030_A1_S1	2040_A1_S1
	A2 Ecological		2020_A2_S1	2030_A2_S1	2040_A2_S1
	A3 Relocation		2020_A3_S1	2030_A3_S1	2040_A3_S1
S2 Risk informed planning	A0 (no risk reduction)	Does not exist: use existing situation	2020_A0_S2	2030_A0_S2	2040_A0_S2
	A1 Engineering		2020_A1_S2	2030_A1_S2	2040_A1_S2
	A2 Ecological		2020_A2_S2	2030_A2_S2	2040_A2_S2
	A3 Relocation		2020_A3_S2	2030_A3_S2	2040_A3_S2
S3 Worst case (Rapid growth + climate change)	A0 (no risk reduction)	Does not exist: use existing situation	2020_A0_S3	2030_A0_S2	2040_A0_S3
	A1 Engineering		2020_A1_S3	2030_A1_S3	2040_A1_S3
	A2 Ecological		2020_A2_S3	2030_A2_S3	2040_A2_S3
	A3 Relocation		2020_A3_S3	2030_A3_S3	2040_A3_S3
S4 Climate resilience (informed planning under climate change)	A0 (no risk reduction)	Does not exist: use existing situation	2020_A0_S4	2030_A0_S3	2040_A0_S4
	A1 Engineering		2020_A1_S4	2030_A1_S3	2040_A1_S4
	A2 Ecological		2020_A2_S4	2030_A2_S3	2040_A2_S4
	A3 Relocation		2020_A3_S4	2030_A3_S3	2040_A3_S4

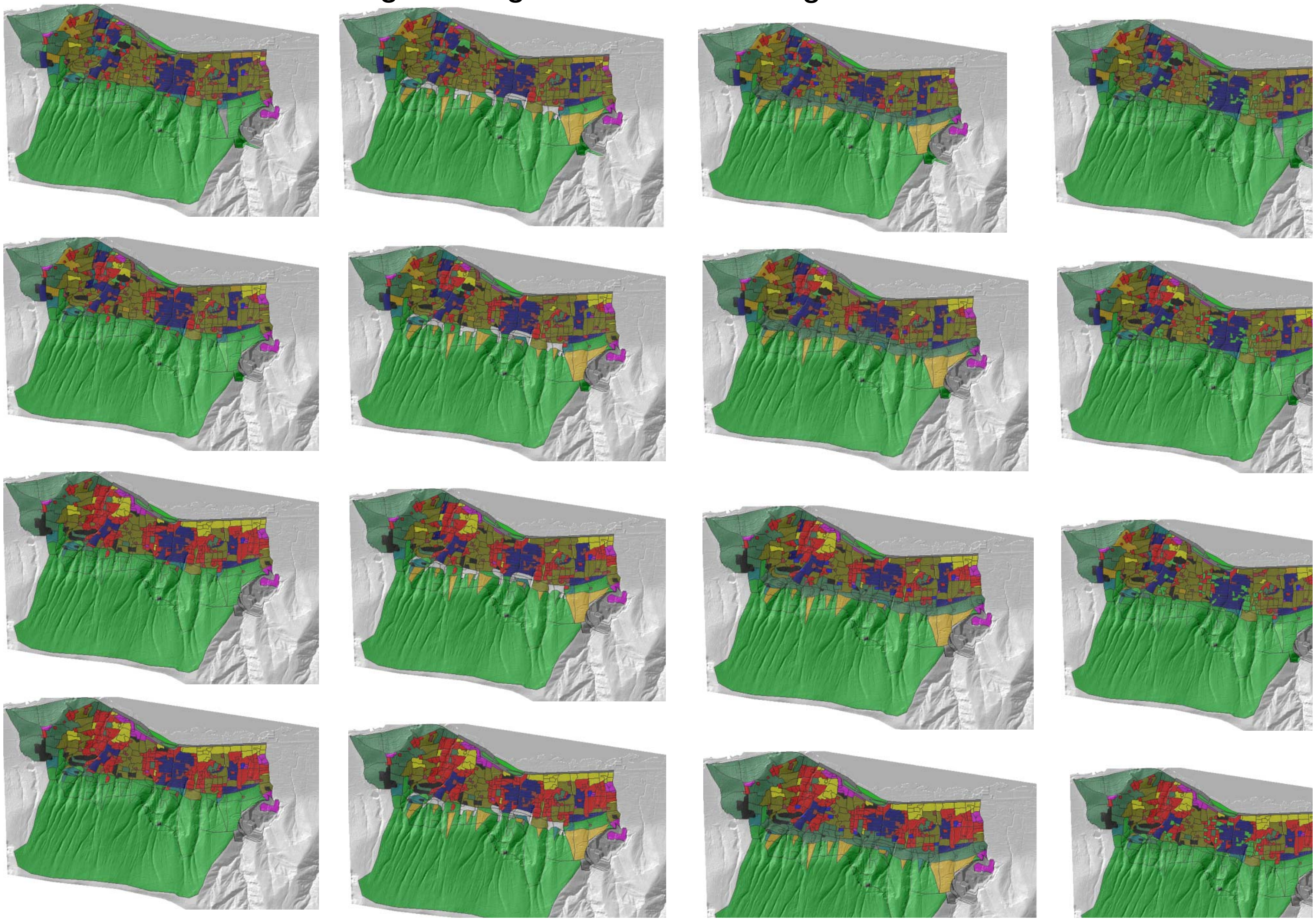
Scenario 1: Business as usual

No risk reduction

Alternative 1: Engineering solutions

Alternative 2: Ecological solutions

Alternative 3: Relocation



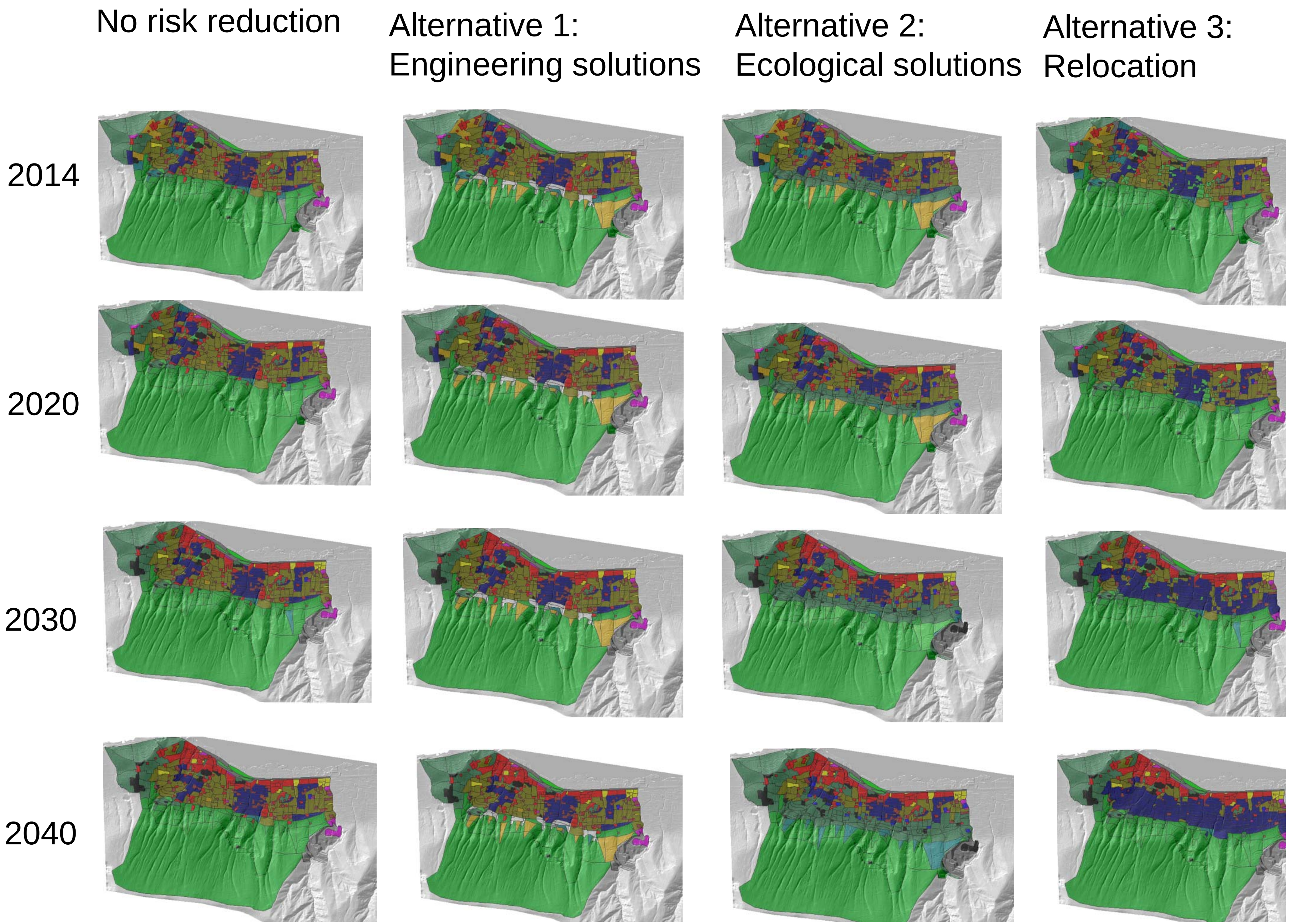
2014

2020

2030

2040

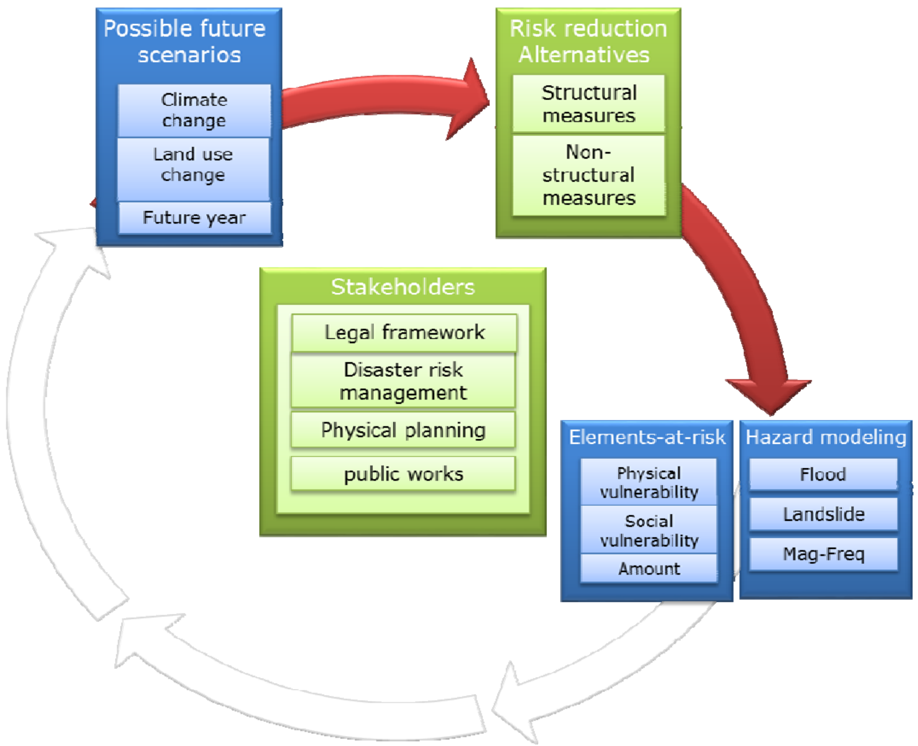
Scenario 2: Risk-Informed Planning



Update hazard & vulnerability & elements-at-risk ?

The combination of the implementation of certain planning alternatives (structural or non-structural risk mitigation measures) in combination with certain possible future scenarios will certainly lead to a modification of the hazard, exposure and vulnerability.
This is why both the hazard maps and the elements-at-risk maps should be updated for each combination.

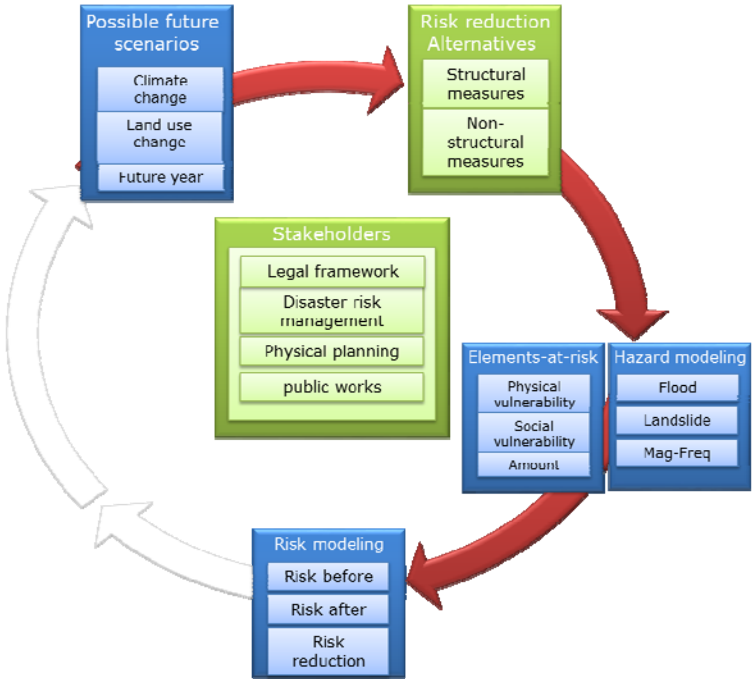
- **The hazard**. probability (or return period) of specific hazard events, the spatial distribution of the hazard and the intensity of the hazards.
- The **exposure** of elements-at-risk. The number of elements-at-risk might change as a result of the risk mitigation measure, or planning alternative, and also as a result of the possible future scenario.
- The **vulnerability** of the elements-at-risk. The type of elements-at-risk might change as a result of the planning alternative and scenario combination.



Many risk analysis runs

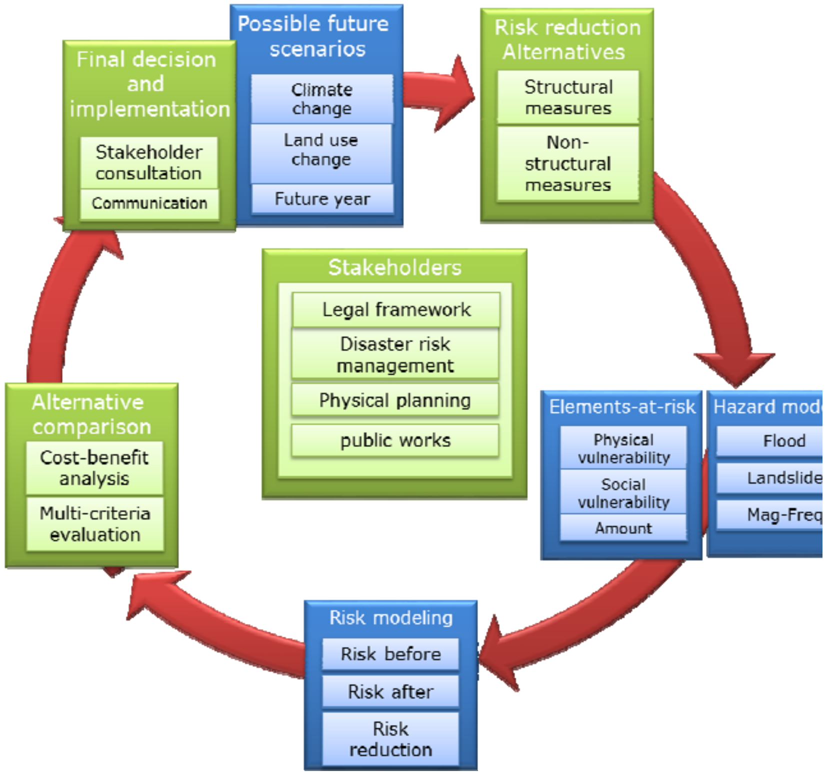
The combination of the implementation of certain planning alternatives (structural or non-structural risk mitigation measures) in combination with certain possible future scenarios will certainly lead to a modification of the hazard, exposure and vulnerability.
Therefore also risk maps should be re-analysed and the the difference between risk values analysed for:

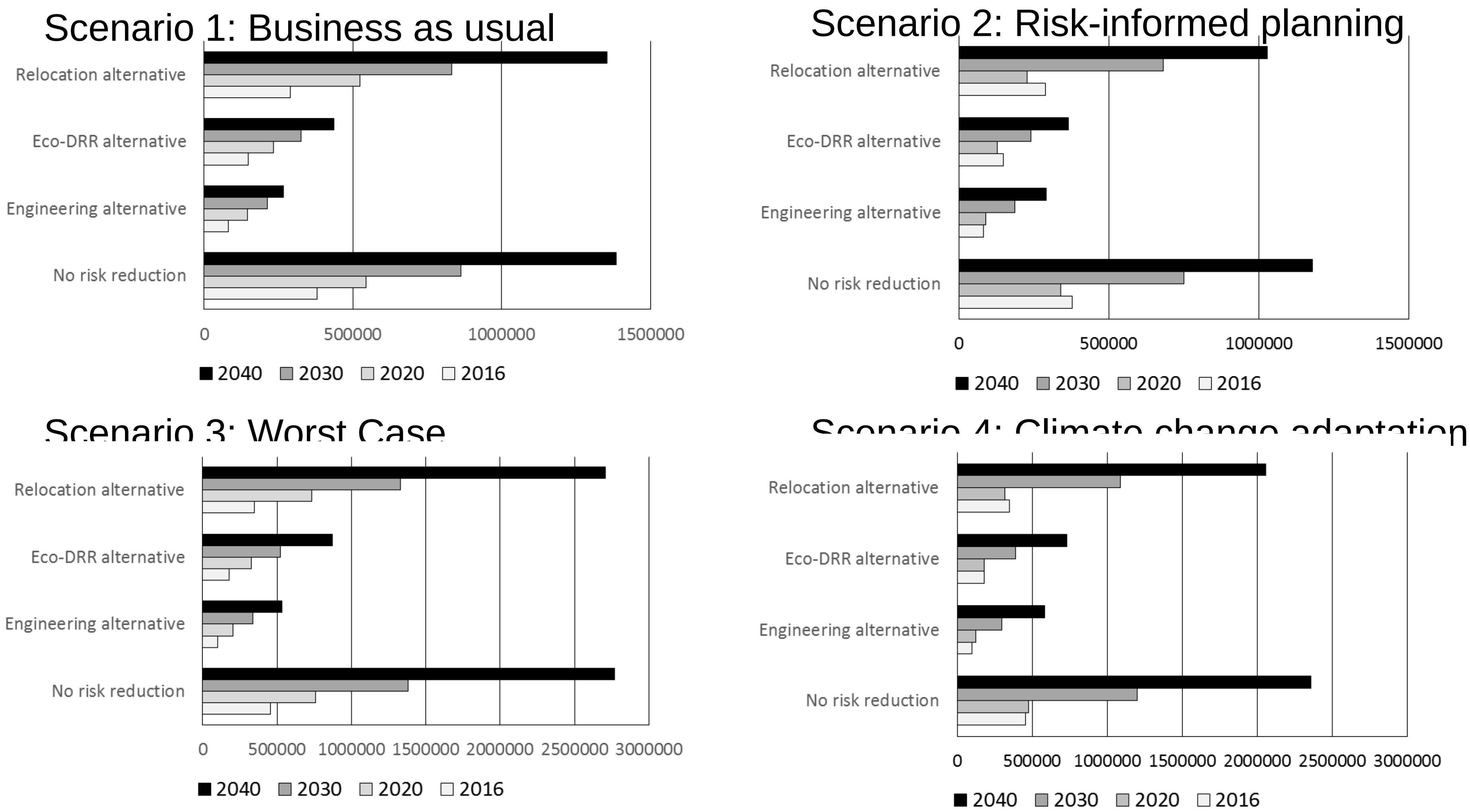
- Different alternatives
- Different future scenarios
- Different future years
- Compare for scenario&future year the risk without alternative and with alternative



Which alternative is best change proof

Compare them using a cost-benefit analysis. The benefit of a risk reduction alternative is represented by its annual risk reduction in monetary values. However, whereas the benefit would remain constant in the analysis which was presented earlier under ”Analyzing planning alternative”, when we analyze the risk reduction of planning alternatives for different future years under possible change scenarios, the risk reduction might also change considerably over time. The costs for the planning alternative can be quantified as well in terms of their investment costs, maintenance costs, project life time etc. Cost-benefit analysis can be carried out by calculating relevant indicators, such as the Net Present Value, Internal Rate of Return or Cost-Benefit ratio. When we take into account possible future changes the cost-benefit ratios of the various alternatives might be quite different than if we consider no future changes, which might lead to the selection of another planning alternative that may be the most “change proof”.





Scenario 1: Business as usual
Relocation alternative
Eco-DRR alternative
Engineering alternative
No risk reduction
0
500000
1000000
1500000
2040
2030
2020
2016
Scenario 2: Risk-informed planning
Relocation alternative
Eco-DRR alternative
Engineering alternative
No risk reduction
0
500000
1000000
1500000
2040
2030
2020
2016
Scenario 3: Worst Case
Relocation alternative
Eco-DRR alternative
Engineering alternative
No risk reduction
0
500000
1000000
1500000
2000000
2500000
3000000
2040
2030
2020
2016
Scenario 4: Climate change adaptation
Relocation alternative
Eco-DRR alternative
Engineering alternative
No risk reduction
0
500000
1000000
1500000
2000000
2500000
3000000
2040
2030
2020
2016

UNIVERSITY OF TWENTE.

THANK YOU

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