The DSS DESYCO:

a decision support system for the regional risk assessment of climate change impacts in coastal zones

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- **Complex** environmental **problems**;
- Need to provide **solutions**.

Growing desire to develop **effective** and **efficient computational methods** and **tools** that facilitate **environmental analysis**, **evaluation** and **problem solving**.

↓

Decision Support Systems (DSS)

DSSs Definitions

DSS is an interactive computer-based information provider (Loucks, 1995)

DSS is an integrated, interactive computer system, consisting of analytical tools and information management capabilities, designed to aid decision makers in solving relatively large, unstructured problems.
(Watkins & McKinney, 2001)

DSS can be defined as a computer-based tool used to support complex decision-making and problem solving
(Shim et al., 2002)

What is a decision support system?

Decision Support Systems couple the intellectual resources of individuals with the capabilities of computers to improve the quality of decisions. It is a computer-based support for management decision makers who deal with semi-structured problems.

Keen and Scott-Morton, 1978

What is a decision support system?

Decision Support Systems are computer-based systems used to assist and aid decision makers in their decision making processes

They AID and ASSIST decision makers, but they DO NOT REPLACE them

Decision Support Systems (DSS)

A Decision Support System (DSS) can be defined as a computer-based tool used to support complex decision-making and problem solving (Shim et al., 2002)

Computerized system that help decision-makers in:

- Structuring and evaluating decisions.
- Gathering and integrating information.
- Selecting and applying analytical procedures.
- Defining management options.
  (Watkins and McKinney, 1995)

DSS users

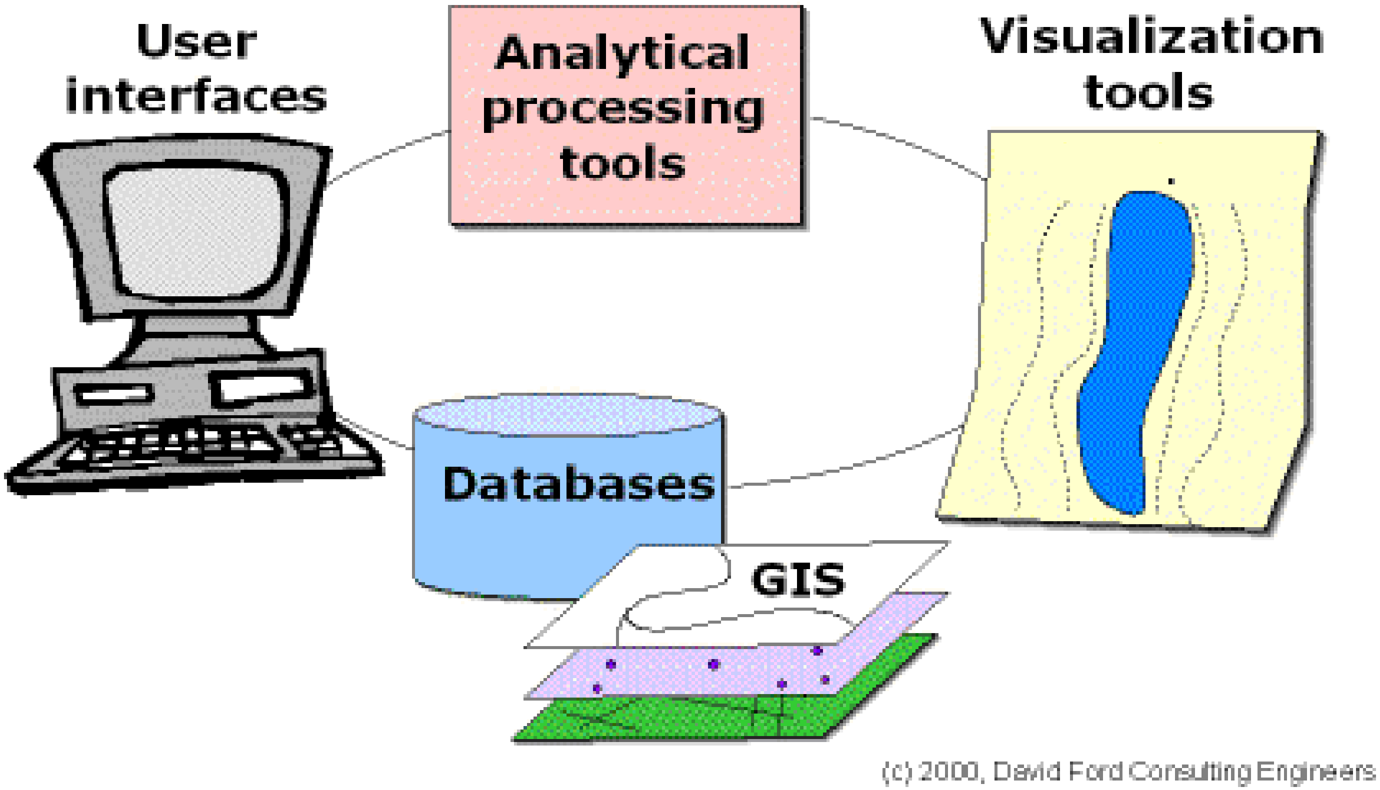
Decision-makers: a person or group **responsible for making the decision**; they "own the problem".
(French and Geldermann, 2005)

Stakeholders: those **with a legitimate stake** in the outcome of the decision.
(Bardos et al., 2001)

Experts: provide **economic, engineering, scientific, environmental and other professional advice** used to model and assess the likelihood of the impacts.
(French and Geldermann, 2005)

DSS structure/components

Conventional DSSs consist of components for database management, powerful modeling functions and powerful (but simple) user interface designs.
(Shim et al, 2002; Ascough et al., 2002)



DSS components

Database management system, which allows organization of basic spatial and thematic data and facilitate their efficient use.

Model management system, which includes quantitative and qualitative models to support the resource analysis.

Knowledge base, which provides information on data and models to identify problem, to generate solutions, evaluate their performances, and to communicate the results.

User-friendly interface, which allows communication with the system and visualization of results.

Spatial DSSs

Spatial Decision Support Systems (SDSS) are decision support systems where **the spatial properties of the data** to be analyzed play a major role in the decision making. Usually, these properties refer to the data's location on the Earth's surface – the so-called **georeferenced data**
(Woods et al, 1999)

SDSS were created to support the analysis of complex spatial problems

SDSS are explicitly designed to provide the user with a decision-making environment that enables the **analysis of geographical information** to be carried out in a flexible manner
(Densham, 1991)

Spatial DSSs

Spatial decision support relies heavily on maps: the backbone upon which plans and policies are defined

Problems can roughly be classified into:

- **Siting**, i.e. **WHERE** to place some given object (e.g. a dam, a house, a park)
- **Spatial allocation**, i.e. for a predefined location, **WHAT** is the best object among a class of objects to place there (e.g. a crop or a building type)

In the first case, the main issue is **determining** the **location**, whereas in the spatial allocation the unknown is the object itself.

Some problems may require combination of both characteristics (e.g. urban planning)

(Woods et al, 1999)

Spatial DSSs

Environmental decision making through a **Geographic Information System** (GIS) corresponds to **defining** and **calibrating** a model by using the **GIS' functions** to construct a set of **maps**.

Map generation is a partially ordered sequence of activities, which are related by data and control links.

(Woods et al, 1999)

DSS properties and characteristics

To be effective in user involvement, the DSS should be:

- Flexible;
- Adaptable to changes in the decision making process and user requirements;
- User friendly;
- Interactive;
- Providing quantitative and qualitative analyses.

Advantages/benefits for use - 1

- **Structured approach** to problem solving;
- **Summary** of **information**;
- **Integration** of many **information** sources;
- **Enhancement** of effectiveness of **decision process**;
- **Improvement** of interpersonal **communication**, active **participation** and **consensus** building;
- Inclusion of **uncertainty analysis**.

Advantages/benefits for use - 2

- **Identifying** preferred **options** for further discussion;
- **Dealing** with **trade-offs**: social, economic, biophysical, legislation;
- **Flexibility** and **adaptability** to accommodate changes in the environment and in the decision making approach;
- Promoting **learning**.

Disadvantages/limits of use - 1

- DSS **complexity**;
- Information **overload**;
- Users find the system **too detailed**, **time consuming** and **costly to use**;
- No end **user input before** and **during** the DSS development;
- **Unclear** definition of the **beneficiaries**.

Disadvantages/limits of use - 2

- **Difficulty** in gaining **acceptability** and trust for the **outputs**;
- “**Transfer of power**” perception;
- Need to be **continuously updated**;
- **Uncertainty** of the **model output** and of the **appropriateness** for **solving** the decision question;
- **Limited** computer **ownership** among users;
- **Userfriendliness** is **low**;
- **Lack** of **fields testing**.

Regional Risk Assessment approach (Landis 2005)

Regional Risk Assessment (RRA):
prioritization of impacts, targets and affected areas at the regional scale

RRA is a methodology that enables to evaluate **all the components contributing to** the computation of **risk** in different **sub-areas** of the same region, to **prioritise** the importance of these zones and finally combine the information for estimating the **relative risk** in the individual sub-areas of the region and rank the individual risk factors.

- Useful in situations where **multiple stressors** are of concern and for assessments covering **broad geographic areas**;
- Allow the **identification** and **ranking** of the **sources**, **habitats** and **impacts** in the region;
- Based on a **Relative Risk Model**: a system of numerical **ranks** and **weights** factors developed in order to combine and assess different kinds of risks.

Maps of the prioritized **risk regions** and of the spatial distribution of the analyzed **stressors** and **targets**.

The regional risk assessment methodologies allow to evaluate:

- a wide range of **different** types of **sources** releasing a **variety** of **stressors** which can impact a **multiplicity** of **assessment endpoints**.
- many **environmental hazards** which impact large geographical areas (increased global CO_2, ozone depletion, global climate change, biodiversity loss,…).

Regional risk assessment becomes important when:

- **policymakers** are called to face problems caused by a multiplicity of sources of hazards, widely spread over a large area, which impact a multiplicity of endpoint of regional interest;
- the limited **economical resources** don't allow to plan remediation strategies to reduce all the identified risk to health, safety and environment;
- it is necessary to **classify risks** in terms of their magnitude and to select those to be investigated more thoroughly or to prioritize the remediation actions.

RRA characteristics

- Large area of interest (region).
- The presence of multiple sources, stressors, impact and receptors.
- The huge amount input data.
- The need of regional fate and transport models for stressors.
- The need of setting spatial relations between sources and receptors.
- The use of relative risk assessment models (to prioritize the risk).

RRA spatial information

- Landscape **morphology**.
- Spatial distribution of the **sources**.
- Spatial distribution of the **receptors**.
- Identification of the **spatial relations** between sources and receptors.
- Spatial distribution of the **variables** influencing **exposure**.

The development of the RRA depends on the availability of **regional data** and **spatial data**.

Methods to manage and analyse the data (i.e. GIS).

RRA approach (Landis and Wiegers, 1997):

- Identification of the different **sources**, **habitats** and possible **impacts** and their **locations** in the region.
- **Ranking** the importance of the different components of the risk assessment (sources, habitats and impacts).
- **Spatial visualisation** of the different components of the risk assessment to verify if they overlap.
- Division of the region in **sub-regions**.
- Relative **risk estimation**.

Based on a **Relative Risk Model**: a system of numerical ranks and weights factors developed in order to combine and assess different kinds of risks.

Each **combination** among the three components of regional risk assessment establishes a possible pathway to a hazard.

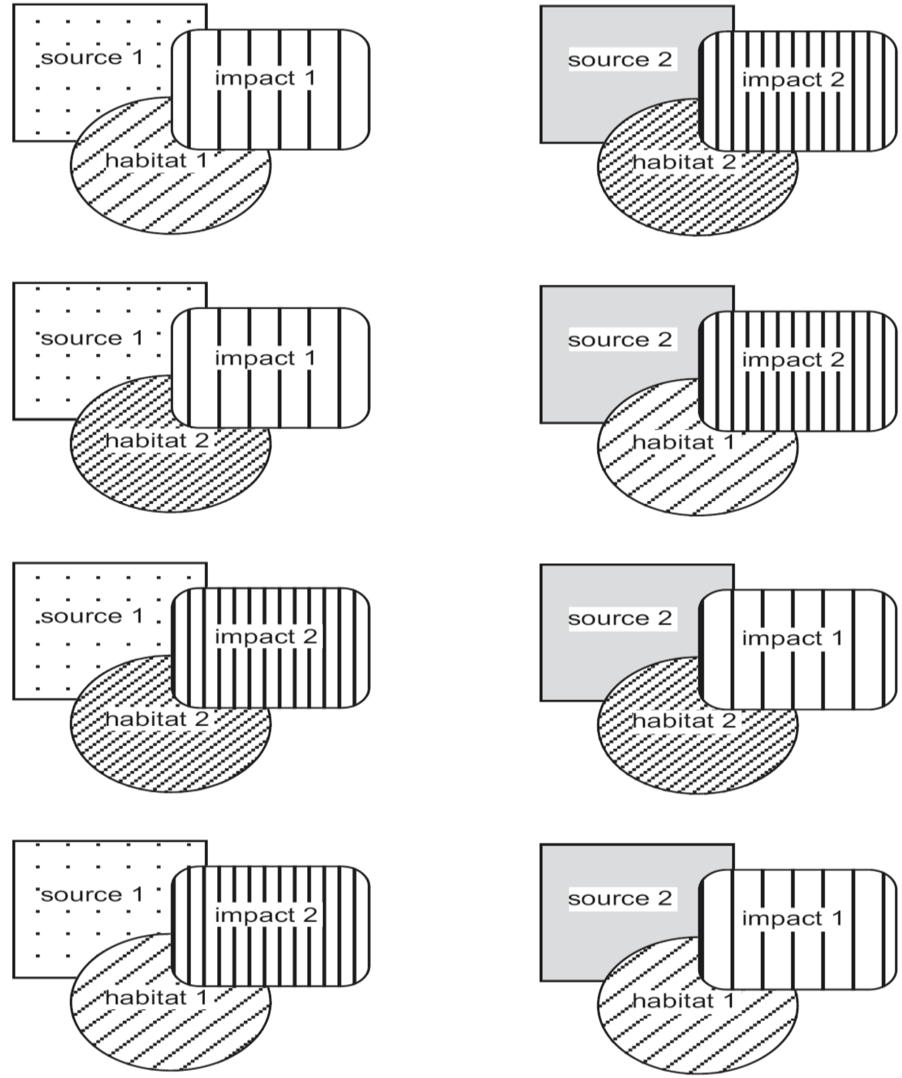
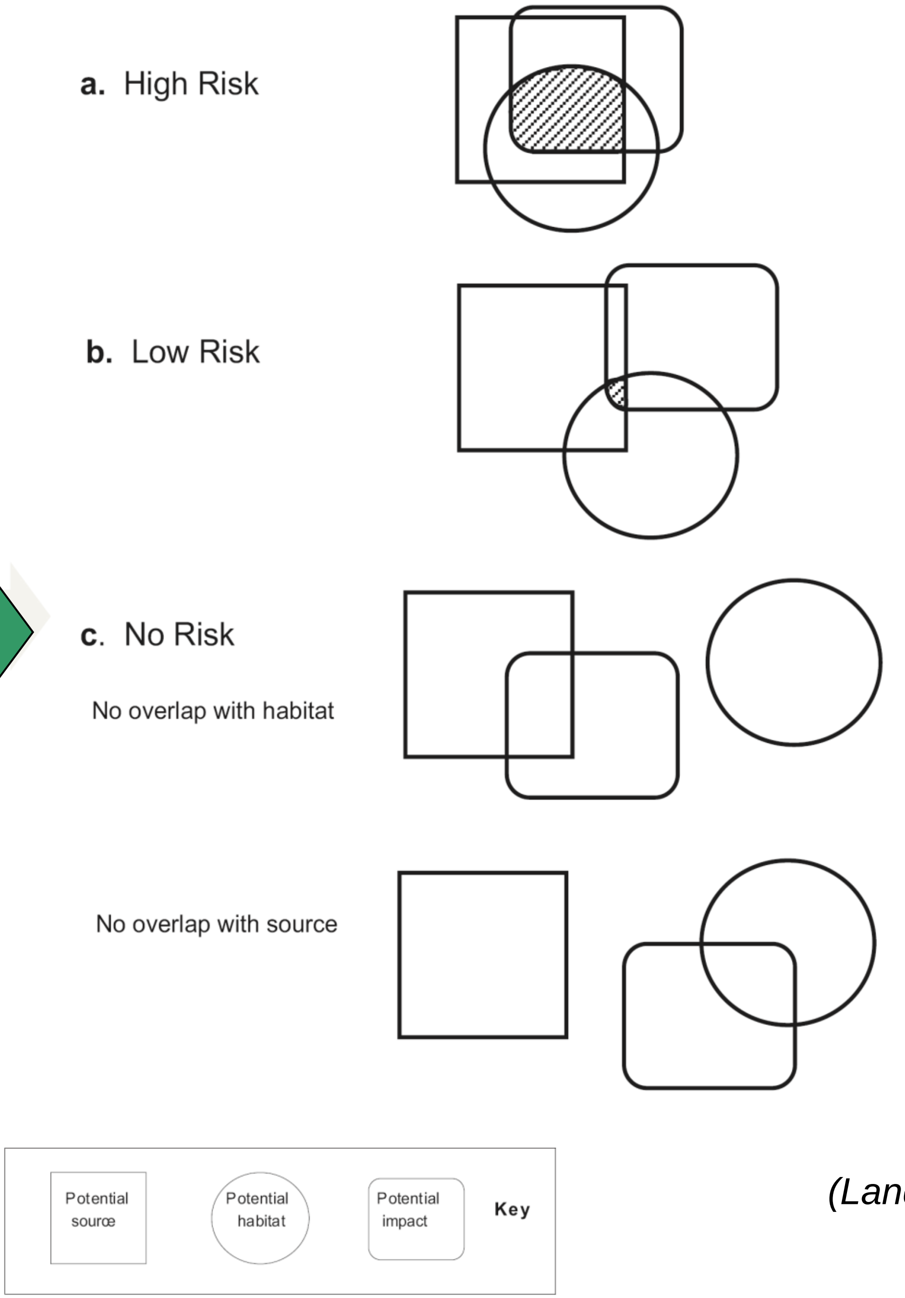


Fig. *Possible combinations characterizing risk from two sources, two habitats and two potential impacts to assessment endpoints. (Landis, 1997)*

- Impacts can be due to a variety of **combinations** of stressors and habitats.
- To result in an environmental impact the risk components must **overlap.**
- Risk is **proportional** to the overlap of source, habitat and impact.

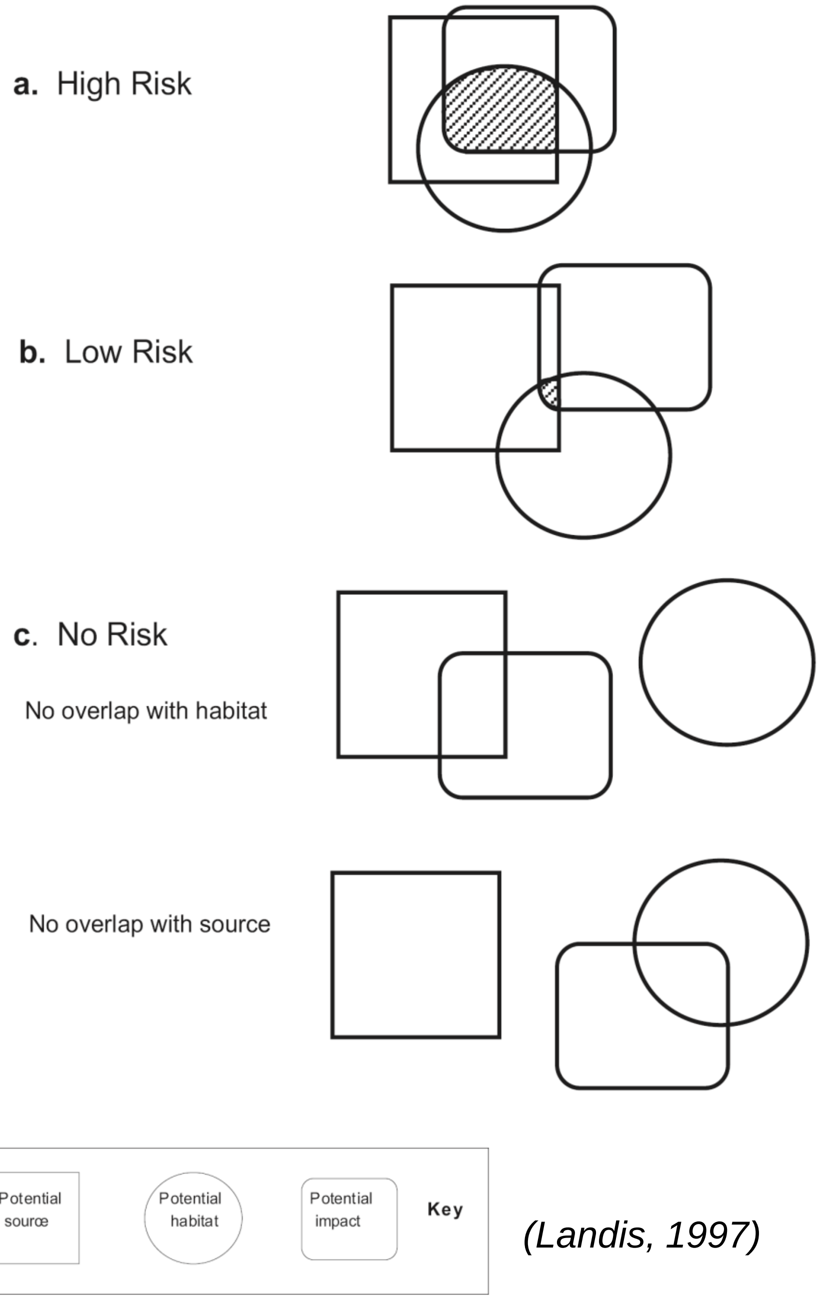


(Landis, 1997)

If a source generates stressors that affect habitats important to the investigated target, the risk is HIGH.

A minimal interaction between the components results in LOW risk.

If one component does not interact with one of the other two components, there is NO risk.



(Landis, 1997)

Outputs:

- **Maps of the risk** regions with the associated sources, land-uses, habitats and the spatial distribution of the assessment endpoints.
- Regional **comparison** of the **relative risk**, their causes, the patterns of impacts to assessment endpoints and the associated uncertainty.
- A model of source-habitat-impact that can be used to ask what-if questions about different scenarios that are potential options in environmental management.

DESYCO

DEcision support SYstem for COastal climate change impact assessment

MAIN OBJECTIVE:
Identify, prioritize and visualize areas and targets at risk from climate change impacts on coastal areas and related ecosystems.

DESYCO can be used to:

- Adopt a **Source-Pathway-Receptor-Consequence** risk assessment approach.
- Analyse long-term **climate change hazard scenarios**.
- **Rank** coastal **receptors** and **areas** vulnerable to or at risk from different climate change impacts.
- Produce **interactive GIS-based maps** (i.e. vulnerability, exposure, risk and damage maps).
- **Transfer information** about potential climate change impacts for **adaptation actions.**

Specific technical features of DESYCO

- **Two-dimensional visualization** of vulnerability and risk based on raster maps;

- **Multi-target** vulnerability and risk assessment;

- Analysis of **different** climate change **impacts** (e.g. sea level rise inundation, storm surge flooding, water quality variations);

- Integrates **GIS spatial analysis** to calculate indicators: distance and surface calculation, vector analysis (e.g. intersection, union, merge);

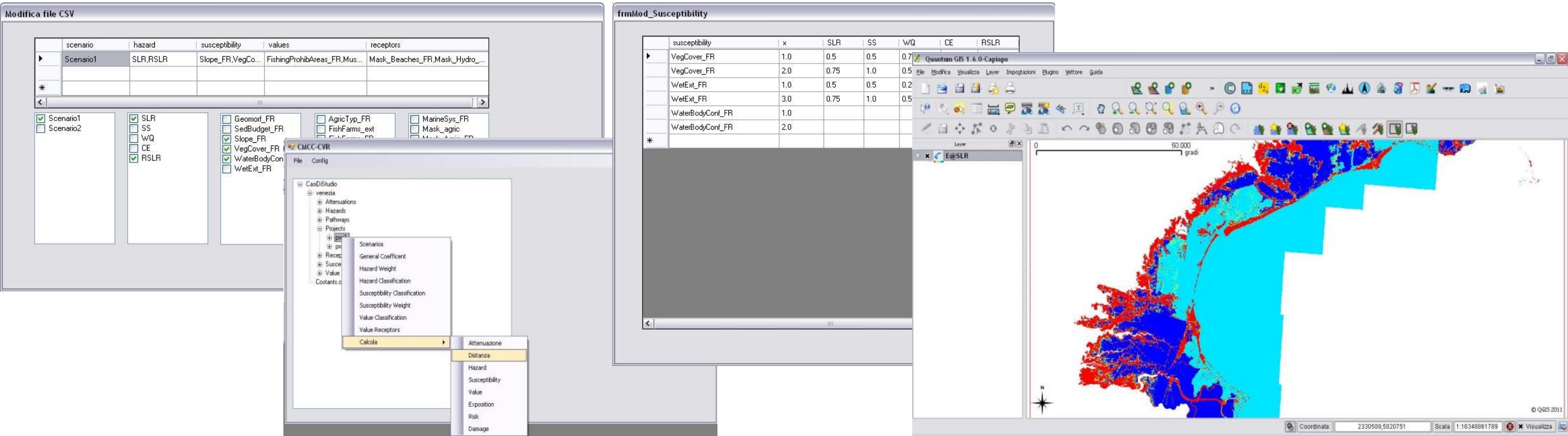
- **MCDA module** integrating multiple vulnerability indicators with **expert** and **stakeholder judgment**;

- Flexibility to manage **different input** data (i.e. raster or shape files) provided by different **scenarios models** and **vulnerability datasets**.

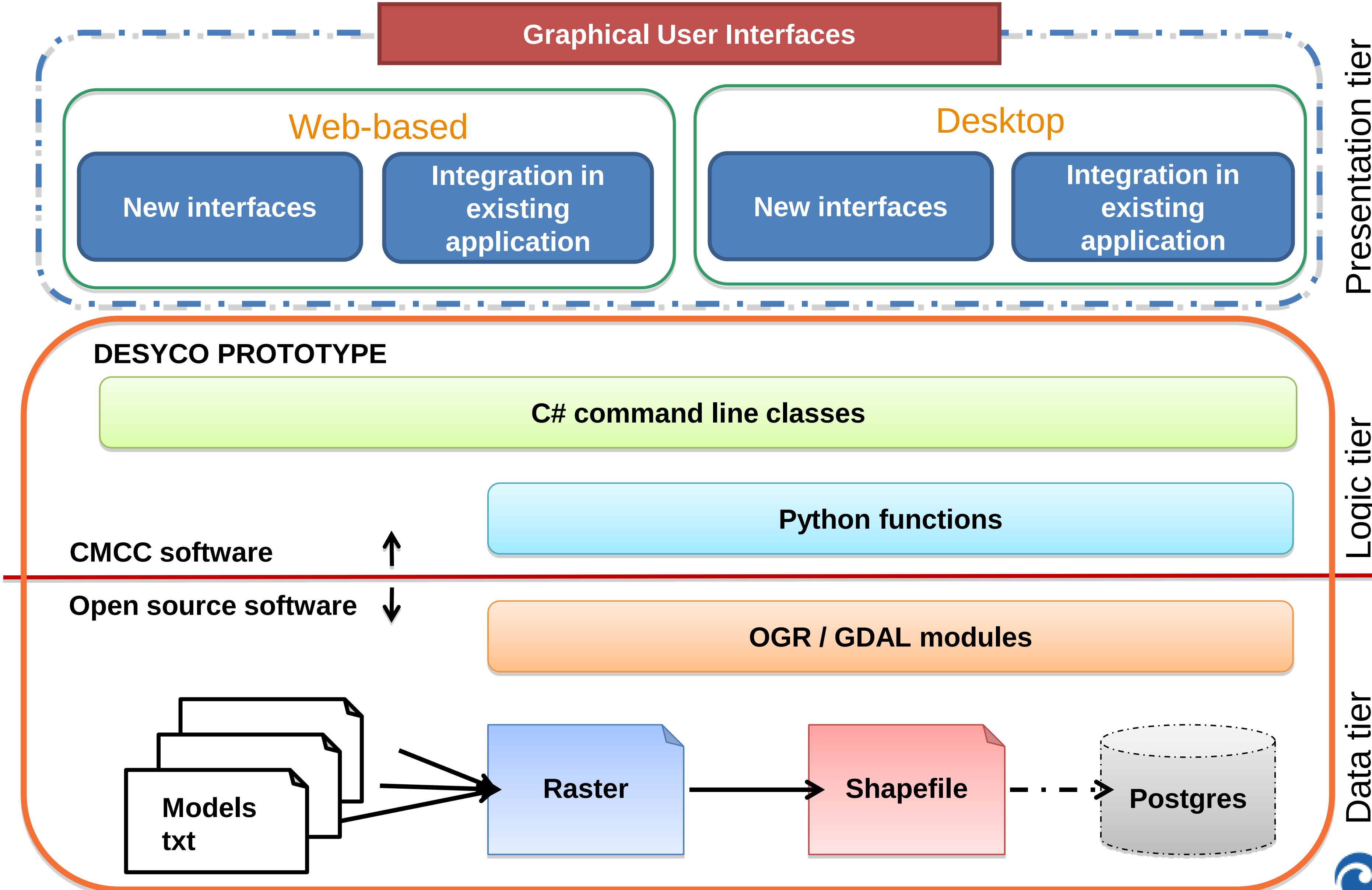
DESYCO: structure

The structure of DESYCO consists of 3 main components:

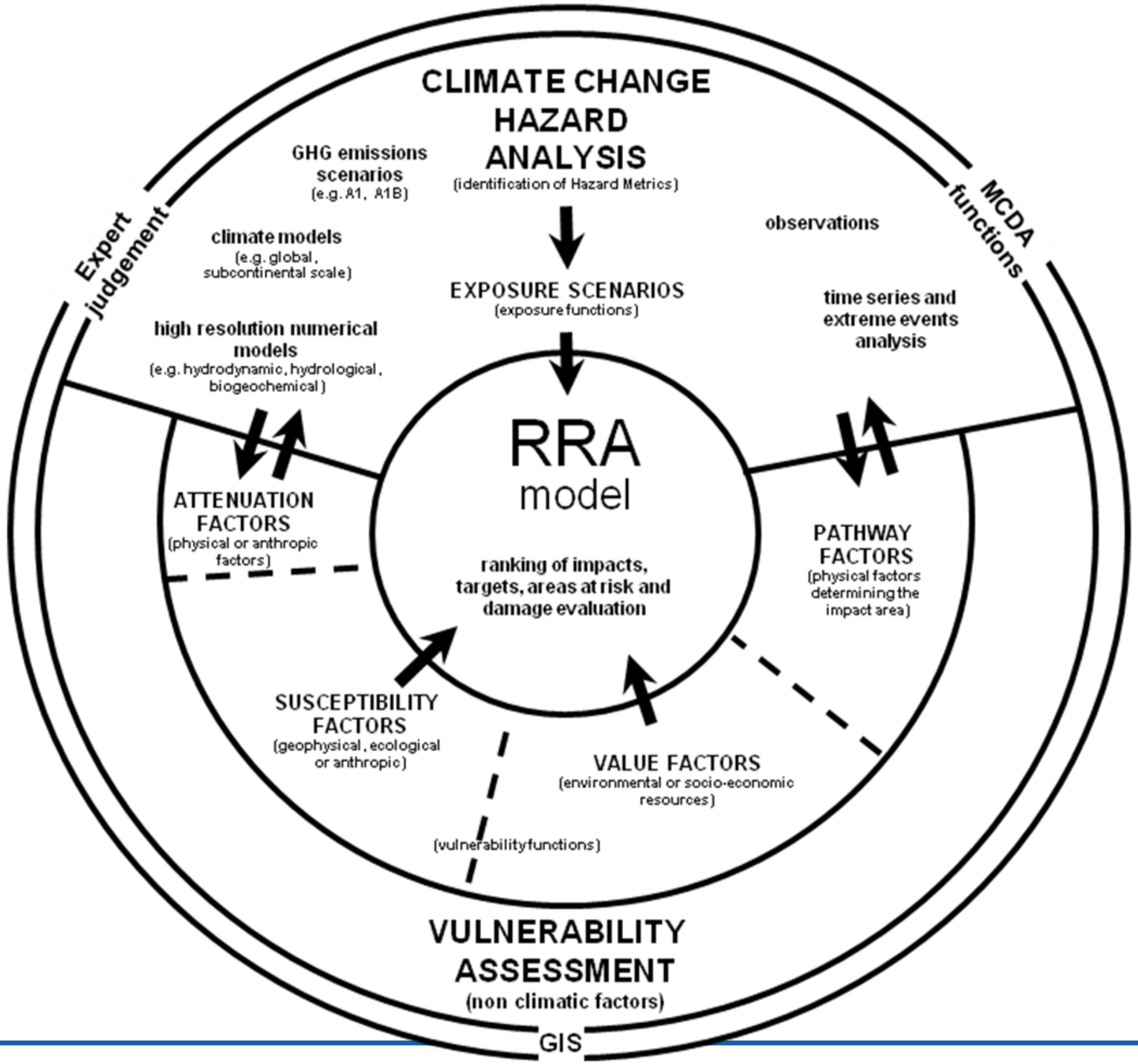
- **A GEODATABASE with bio-physical and socio-economic data for the investigated coastal area.**
- **Multi-scale SCENARIOS Module, provided by numerical models simulations or time series analysis.**
- **A Relative Risk Model (RRM) for the application of the Regional Risk Assessment (RRA) methodology.**



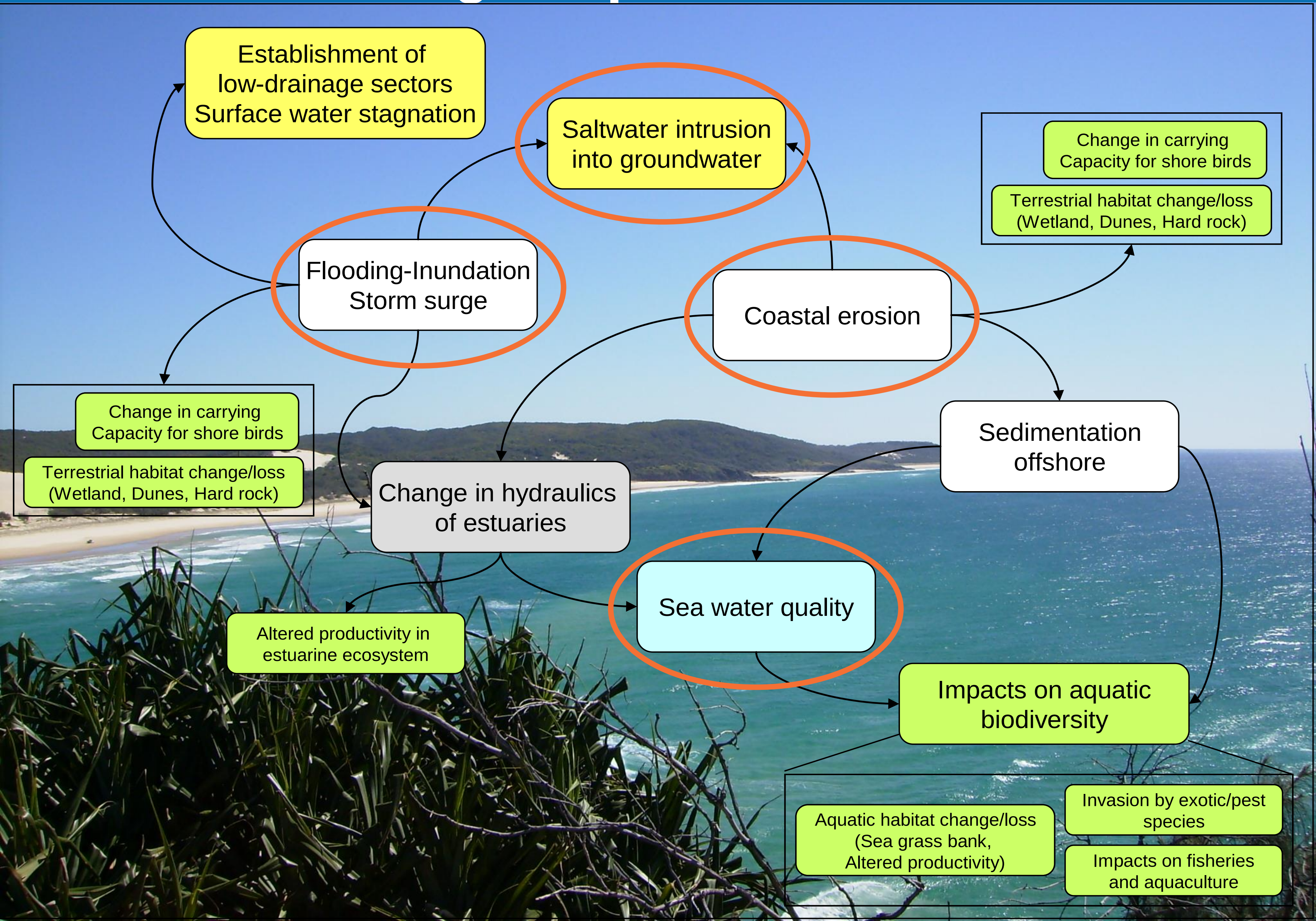
DESYCO Software architecture



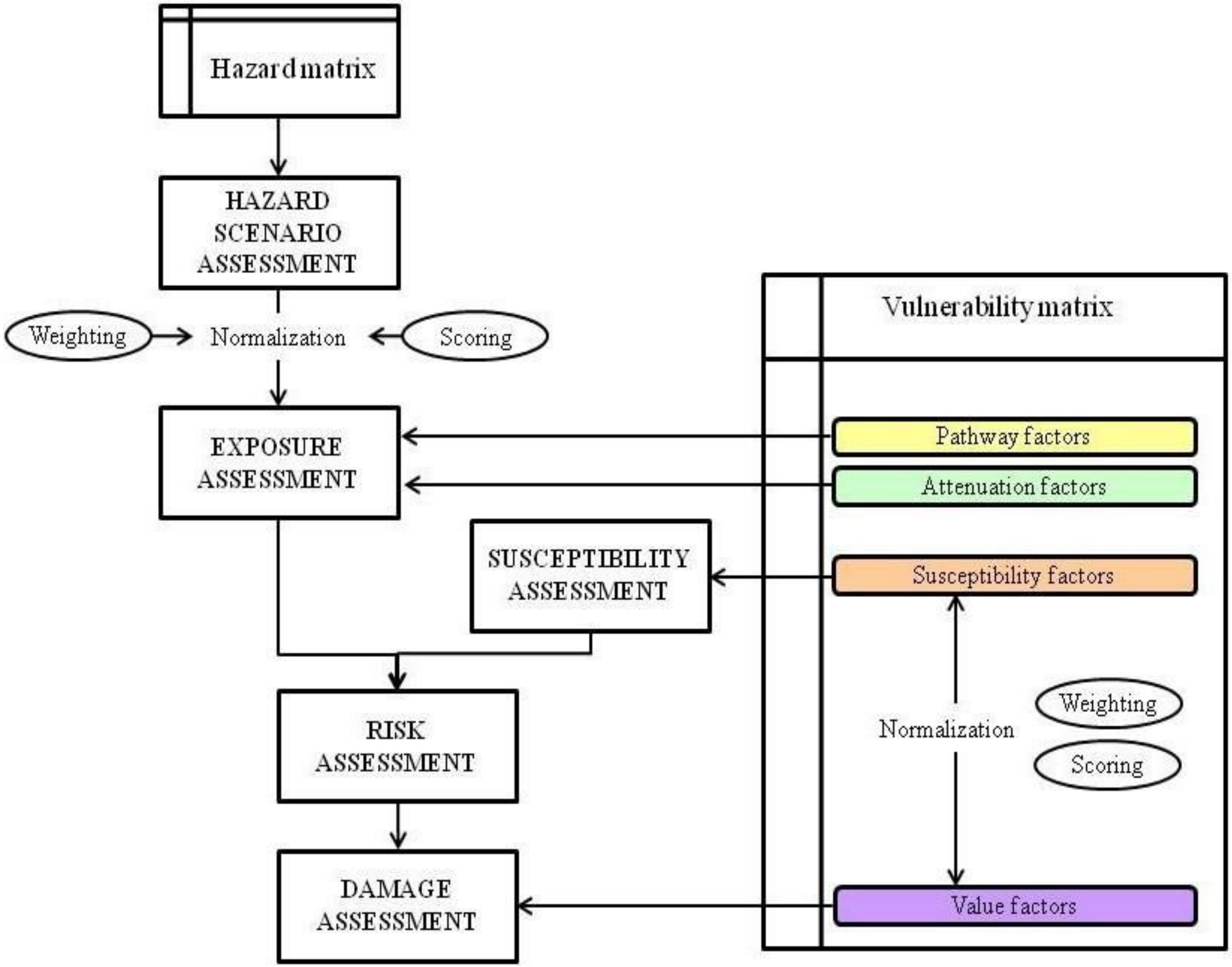
Regional Risk Assessment (RRA) conceptual framework



Climate change impacts in coastal zones



RRA methodology: steps



Input data

HAZARD MATRIX

BOTTOM STRESS	EXTREME STORMS SURGE	SEA LEVEL RISE	TIDE	WAVE	CLIMATE CHANGE IMPACTS
					HYDRODYNAMIC IMPACTS
		Projected water level			SLR Inundation
		Projected water level			
	Water levels associated to extreme events with different return periods	Projected water level			Storm surge flooding
Bottom stress		Projected water levels		Height	Coastal erosion

HAZARD METRICS

VULNERABILITY MATRIX

		RIVER MOUTHS	WETLANDS	HYDROLOGICAL SYSTEMS
		- Elevation	- Elevation	- Elevation
SLR Inundation	- Protection level	- Protection level	- Protection level	- Water body configuration
			- Extension of	evel
Storm surge flooding	- Ele			
	- Di coas			om
	- Ar protections	protections	protections	configuration
	- Vegetation cover	- Vegetation cover	- Vegetation cover	- Protection level
	- Coastal slope	- Coastal slope	- Extension of	

VULNERABILITY FACTORS:

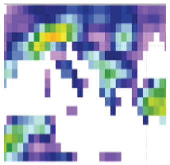
- **Susceptibility factors;**
- **Pathway factors;**
- **Value factors;**
- **Attenuation factors.**

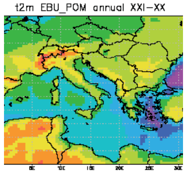
1) Hazard scenario assessment

Characterization of **climate change hazards** that impact on a system.

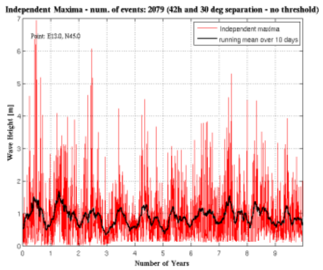
Information useful to construct climate change hazard scenarios can be provided by:

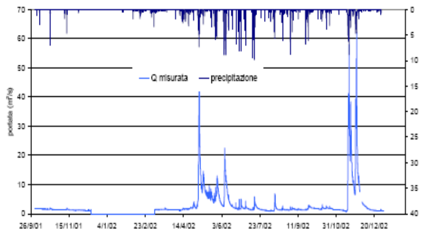
- **Global** and **regional climate models** forced by **emission scenarios** (e.g. IPCC SRES A1B);
- **Downscaling** of climate results in order to force **high resolution "impact" models** at the regional scale (e.g. hydrodynamic, hydrological, biogeochemical).





- Analysis of **historical records** by means statistical techniques, trend analysis, model-derived output based on observed data.





Select representative statistics to summarize the huge amount of information into the **hazard metrics** *($h_{k,s}$).*

Information for hazard scenarios construction

Examples of **statistics** associated with **metrics** for climate change risk assessment are (UKCIP, 2003):

- **mean** or average, **mode** or **median** of values determined over a particular period;
- **cumulative** (time-integrated) **value**;
- the **frequency** or **probability** of particular values or events including **percentiles**,
- the frequency or probability that values of variables will fall **between particular bounds**, or **exceed** a particular (often extreme) value;
- absolute **maximum** or **minimum values** that may be recorded, usually over a particular interval of time;
- measures of **variance**, **standard deviation** or standard error, or more complete descriptions in terms of probability distributions or functions.

choosing and **using** suitable statistics to represent hazard metrics in hazard scenario assessments is not always a simple task

2) Exposure assessment

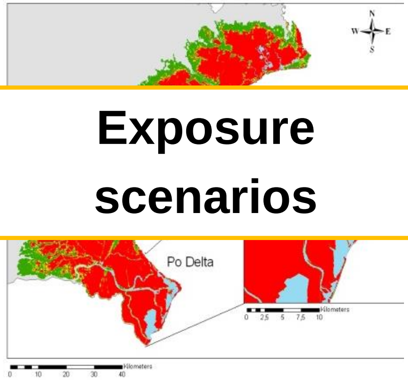
Identify and **classify** areas where the **hazard** can be in **contact** with the **target**.

$$E_{k,s} = F(h_{k,s}, P_k, At_k)$$

Hazard metrics ($h_{k,s}$)

Pathway factors (P_k)
(e.g. distance from coastline, elevation).

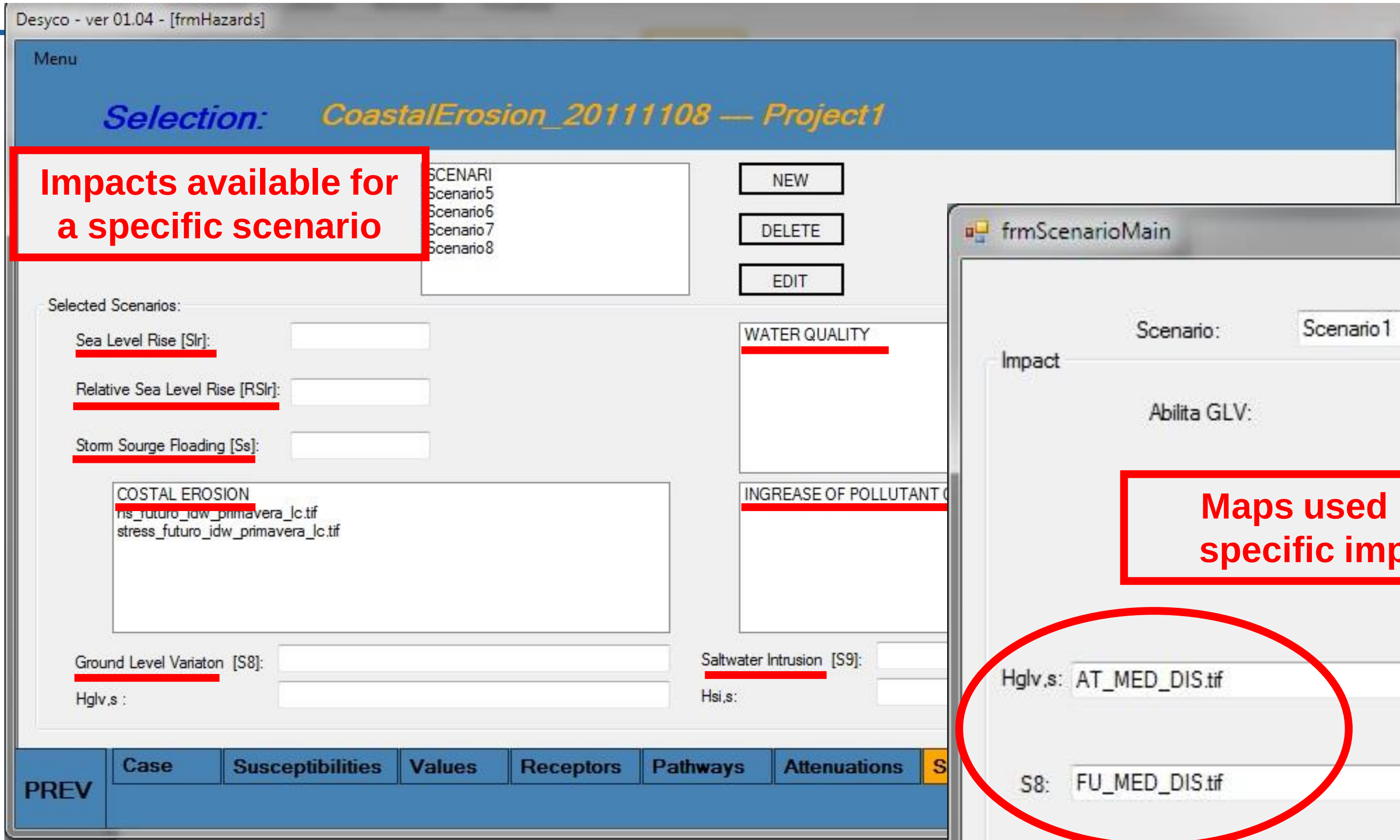
Attenuation factors (At_k)
(i.e. current or planned adaptation options, e.g. seawalls, natural dunes).

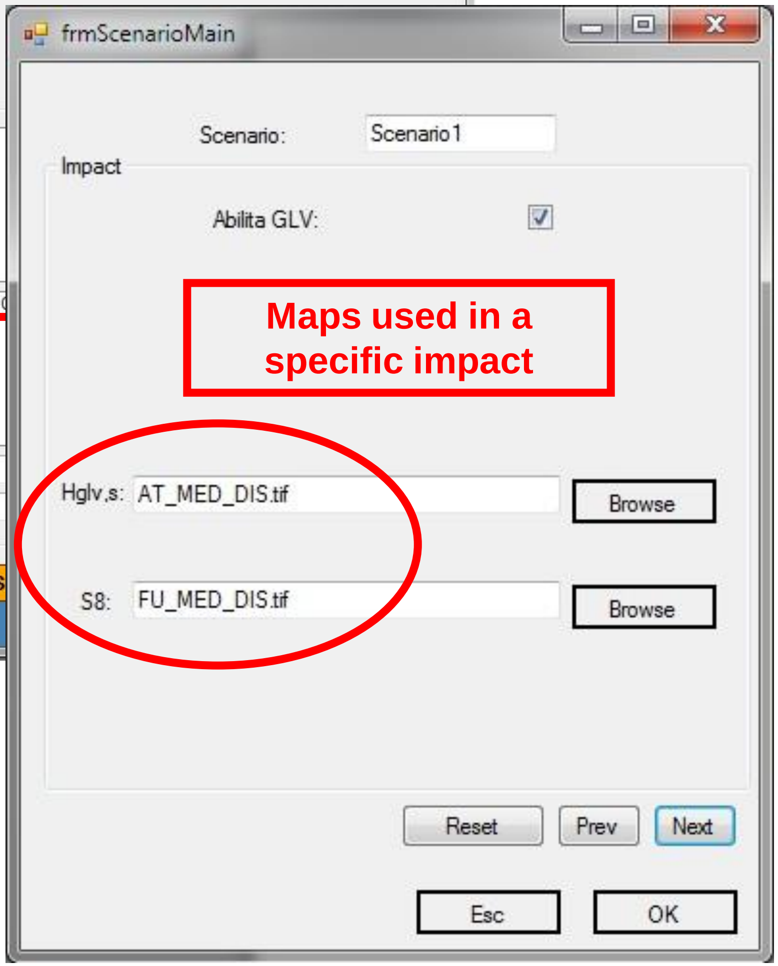


Exposure scenarios

- Exposure functions are defined according to the specific impact;
- The hazard metrics can be normalized with the assignation of scores and weights, if it is specifically required in the Exposure function.

Scenarios Definition in DESYCO





The user can define several scenarios within each application and can import the maps to be used for each specific impact.

Exposure function for the Sea Level Rise inundation impact

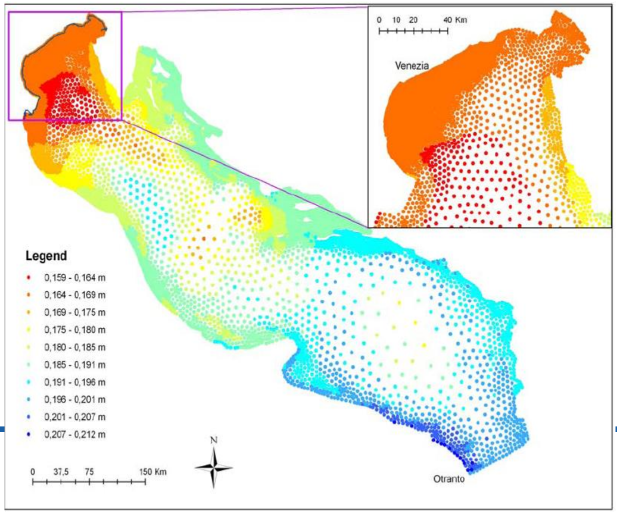
The **risk function** for the sea level rise inundation impact aggregates **data** provided by regional **hydrodynamic models** forced with climate change scenarios and **topographical data** coming from Digital Elevation Models in order to calculate coastal areas and targets at risk from inundation.

$$E_{slr,s} = min\left(max\left(\frac{h_{slr,s} - pf_1}{s_1}, 0\right), 1\right)$$

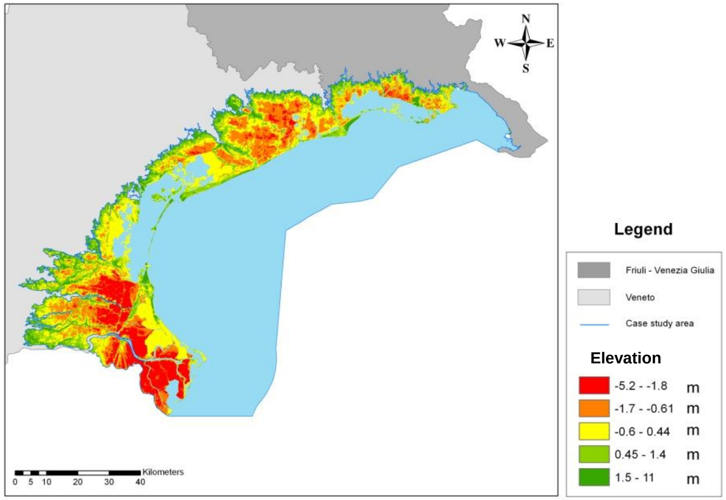
$E_{slr,s}$ = exposure score in a scenario *s;*
$h_{slr,s}$ = height of sea level rise according to scenario *s;*
pf_1 = height of a cell;
s_1 = threshold representing the amount of water above a cell which generate the maximum impact.

North Adriatic data sources:

SHYFEM hydrodynamic model.



Digital Elevation Model (DEM) 25 m.



Exposure function for the storm surge impact

The **exposure function** for the storm surge impact is composed of 3 main components:

- **Hazard** (H) → based on **water level return period**, **projected water level**, **tidal range**, **waves height** and **direction**;
- **Attenuation** (A)→ **artificial/natural protections**;
- **Pathway** (P) → **distance from the coastline**.

$$E_{ssf,s}\begin{cases} 0 & if\ pf_3 \geq b \\ min\left[max\left(\frac{\left(\left(h_{ssf,s}(1- \quad Af_2)\right)-pf_1\right)d_1}{s_1},0\right),1\right] & otherwise \end{cases}$$

$E_{ssf,\,s}$= exposure score;
$h_{ssf,s}$= projection of the height of a storm surge water level (cm);
Af_2= attenuation factor related to protections from storm surge;
pf_3= distance of the center of the cell from the sea (always >= 1 m);.
pf_1= elevation of the cell (cm);
d_1= distance factor related to distance of the cell from the sea (cm). It is calculated through an hyperbolic distance function;
s_1= threshold given by the decision-maker. It represents the amount of water above a cell which generates the maximum impact (cm).
b= it represents the distance from the sea over which the probability that a cell may be inundated by storm surge flooding is minimum (i.e. 0).

Exposure function for the coastal erosion impact

The **exposure function** for the coastal erosion impact is composed by 3 main components:

- **Hazard** component → to aggregate the hazard metrics with the "probabilistic or" function;
- **Attenuation** component → to define the role of the attenuation factors (i.e. artificial protections) in decreasing the magnitude of the coastal erosion impact;
- **Pathway** component → to consider the distance from the coastline in the definition of the exposure.

$$E_{ce,s}\begin{cases} 0 & if\ pf_3 \geq s_2 \\ \left(\bigotimes_{i=1}^{n}\left[h'_{ce,i,s}\right]\right)(1 - At_{ce}) \cdot d_2 & otherwise \end{cases}$$

$E_{ce,s}$= exposure score related to coastal erosion impact;
pf_3= distance of the center of the cell from the sea;
s_2= 1 km (i.e. the radius of influence of coastal erosion);
$h'_{ce,I,s}$= hazard metrics classified and weighted in (0,1);

$\otimes$ = "probabilistic or" function;
At_{ce}= attenuation factor related to protections from erosion;
d_2= distance factor related to distance from the shoreline.

“Probabilistic or” function

$$\otimes_{i=1}^{4}[f_i] = f_1 \otimes f_2 \otimes f_3 \otimes f_4$$

where:

f_i= i-th generic factor f

The “probabilistic or” operator can be evaluated as follow, due to the associative and commutative proprieties:

$$f_1 \otimes f_2 = f_1 + f_2 - f_1 \ f_2 = F_1$$

$$F_1 \otimes f_3 = F_1 + f_3 - F_1 \ f_3 = F_2$$

$$F_2 \otimes f_4 = F_2 + f_4 - F_2 \ f_4 = \otimes_{i=1}^{4}[f_i]$$

The process can be repeated until evaluating all operands.
If just a factor (f) assumes the maximum value (i.e. 1) then the result of the “probabilistic or” will be 1. On the other side, factor with low scores contribute in increasing the final “probabilistic or” score: the more is the number of low factor scores, the greater is the final score.

Kalbfleisch J. G, 1985. Probability and Statistical Inference: Volume 1: Probability. Springer Texts in Statistics-Sep 9, 1985.

Susceptibility assessment

Evaluate the degree to which a receptor could be affected by a given climate change impact based on **site-specific territorial information**.

$$S_k = \otimes_i^n \left[sf'_{i,k} \right]$$

S_k = susceptibility score of the cell to the impact *k*;

$\otimes$ = “probabilistic or” function;

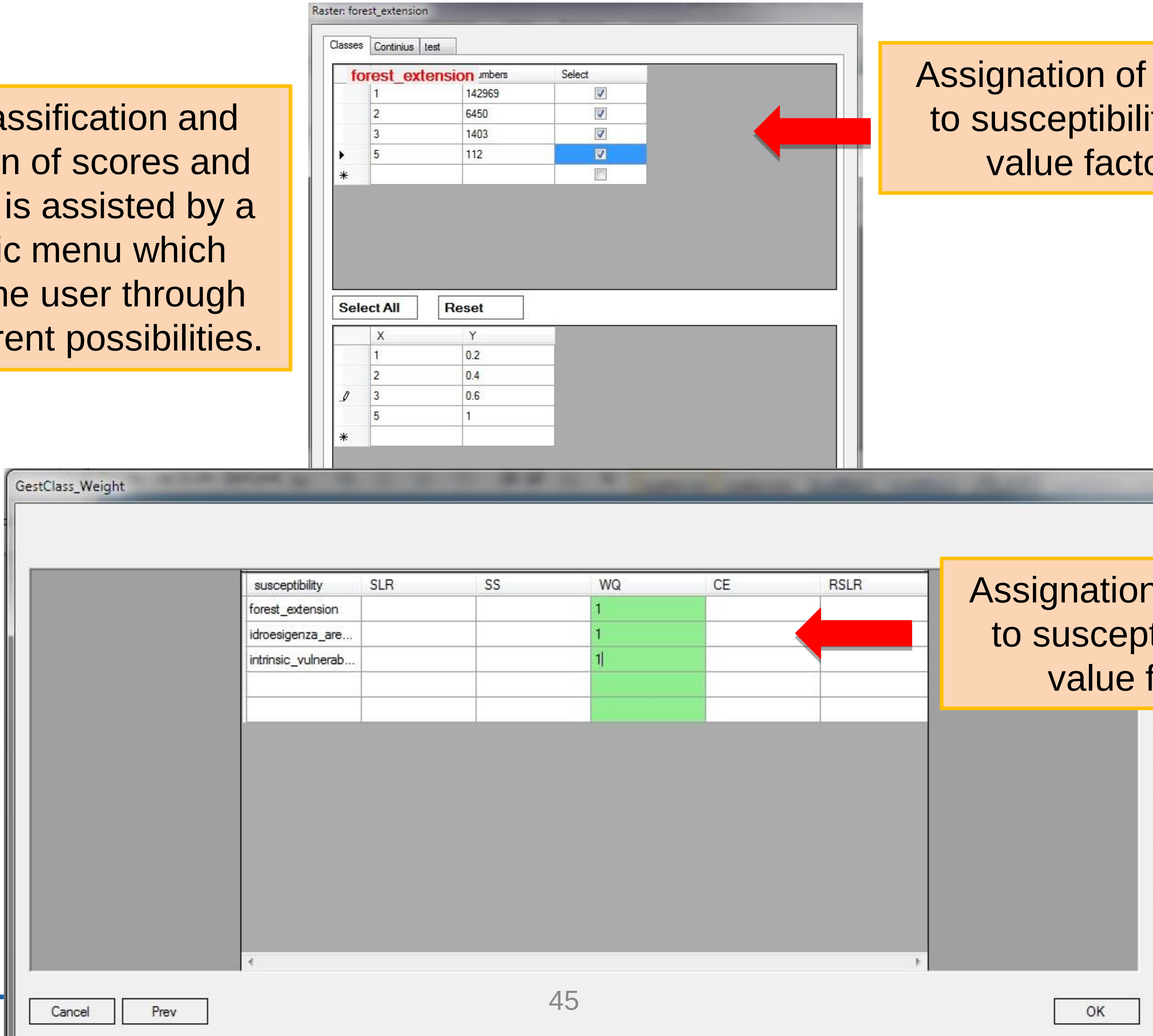
$sf'_{i,k}$ = i^{th} susceptibility factor related to the impact *k* (normalized in [0,1]).

- Normalization is provided by expert judgment ;
- If just a susceptibility factor assumes the maximum value (i.e. 1) then the susceptibility score will be 1;
- $sf'_{i,k}$ with low scores contribute in increasing the final susceptibility score: the more is the number of low susceptibility scores, the greater is the final susceptibility.

Classification and definition of scores and weights

The classification and definition of scores and weights is assisted by a specific menu which guide the user through the different possibilities.

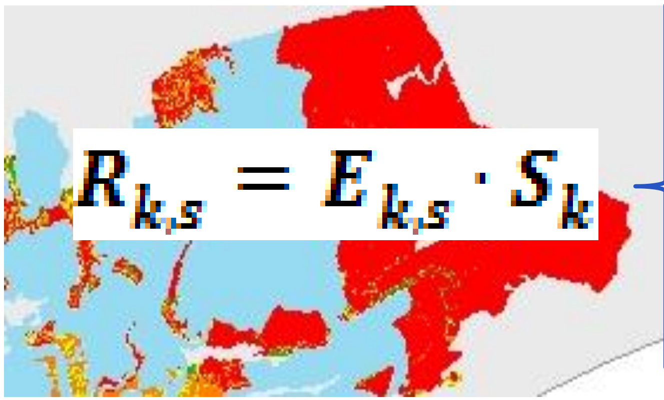
Assignation of scores to susceptibility and value factors



Assignation of weights to susceptibility and value factors

Risk assessment

Integrate information about the **exposure** to a given climate change scenario and the territorial **susceptibility** in order to **identify** and **prioritize** coastal **receptors** and **areas** at risk from different impacts in the case study area.



$$R_{k,s} = E_{k,s} \cdot S_k$$

$R_{k,s}$= risk score related to an impact (k), an exposure ($E_{k,s}$ and therefore a scenario s);

$E_{k,s}$= exposure score related with the impact k in scenario s;

S_k= susceptibility score to the impact k.

- Risk score varies from 0 (i.e. no risk) to 1 (i.e. higher risk for the considered area);
- It provides relative classifications about areas and targets that are likely to be affected by climate change impacts more severely than others in the same region;
- It allows to evaluate statistics (e.g. percentage of the territory associated to each risk class, percentage and surface of receptors at risk to a specific impact for each municipality) useful to support the DM in the definition of adaptation measures.

Damage assessment

Provide a **relative estimation** of the potential **social, economic** and **environmental losses** associated to **targets** and **areas** at risk in the case study area.

$$D_{j,k,s} = R_{k,s} \cdot V_j$$

$D_{j,k,s}$= damage score related to an impact (*k*) and a receptor (*j*) in the scenario (*s*);

$R_{k,s}$= risk score related to impact *k* in scenario *s*;

V_j= value score of receptor *j* .

$$V_j = \frac{\sum_{i=1}^{n}\left[fv'_{i,j}\right]}{n}$$

V_j= value score of receptor *j;*

$fv'_{i,j}$ = i^{th} value factor related to the receptor *j* (normalized in [0,1]);

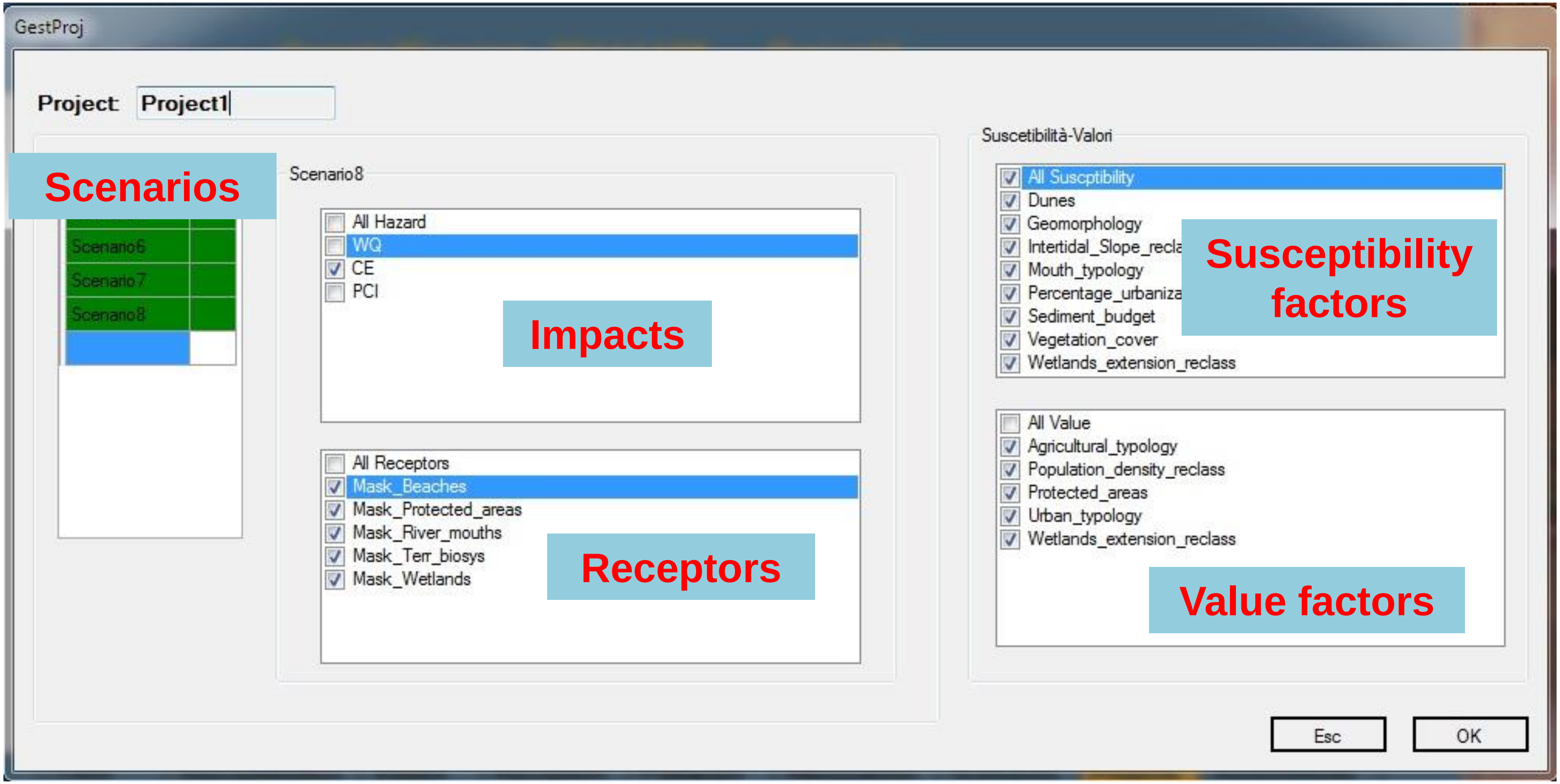
n= number of value factors.





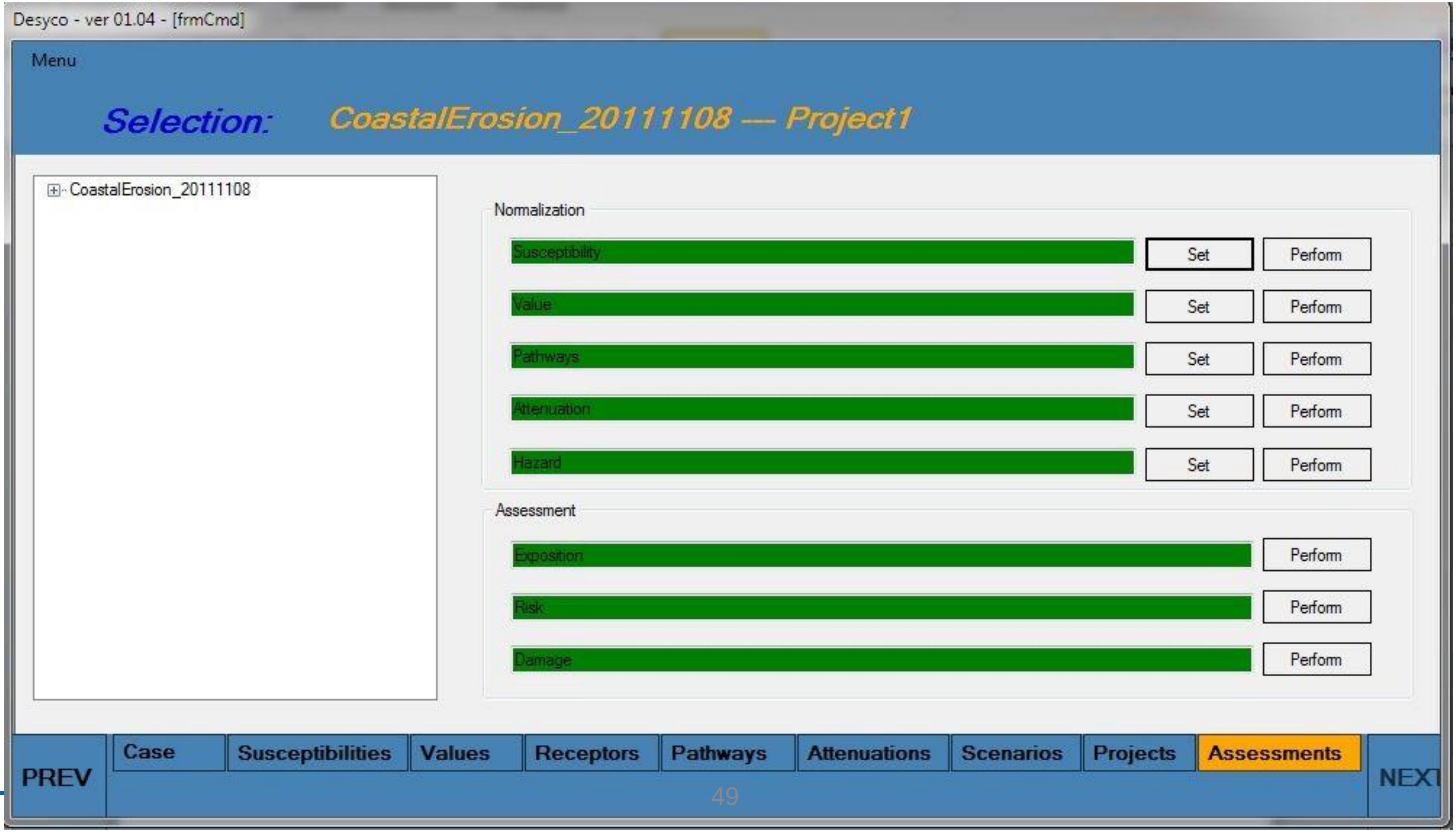
Creation of project

A project allows to connect the different elements involved in the implementation of the RRA procedure.



Creation of project

Final interface that allows to perform each single step of the RRA methodology in order to produce the output maps.



RRA output

HAZARD METRICS
PATHWAY FACTORS
ATTENUATION FACTORS
→ Exposure maps

SUSCEPTIBILITY FACTORS → Susceptibility maps

Exposure maps + Susceptibility maps → Risk maps

VALUE FACTORS → Value maps

Risk maps + Value maps → Damage maps

Exposure map

Susceptibility map

Risk map

decision support tools useful to guide the impact/risk management phase.

Adapted from: http://www.adrc.or.jp/publications/Venten/HP/herath4.jpg

Conclusions

- **DESYCO** can be a useful tool to **investigate** the **impacts** associated to **different climate change scenarios in sensitive targets** (e.g. river deltas, beaches and wetlands) and to support the **development** of **sustainable adaptation strategies**.

- Regional risk/damage classifications should not attempt to provide **absolute predictions** about the impacts of climate change. Rather, they should be **relative indices** which provide information about the areas/targets within a region likely to be affected more severely than others.

- DESYCO is an **open configuration** (users can add their receptors and factors) and it can be used in different contexts and case studies.

- DESYCO and its RRA methodology is adapted and applied in several European projects: **PEGASO** (FP7, 2010-2013); **CLIM-RUN** (FP7, 2011-2013); **CANTICO** (ERANET, 2008-2011); **TRUST** (Life+, 2009-2011); **SALT** (Life+, 2009-2011); **KULTURisk** (FP7, 2011-2013); **ORIENTGATE** (2013-2015).

Thanks for your attention!

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