2nd Training of Cross Sectoral Stakeholder Group

Transnational Decision Support Toolbox

Interreg CENTRAL EUROPE
European Union European Regional Development Fund
DEEPWATER-CE

TUM
Chair of Hydrogeology
TUM Department of Civil, Geo and Environmental Engineering
Technical University of Munich

Managed Aquifer Recharge Webinar 23.09.2020

Held in the framework of the DEEPWATER-CE Interreg Project about developing an integrated implementation framework for Managed Aquifer Recharge solutions to facilitate the protection of Central European water resources endangered by climate change and user conflict

Time (UTC+2)	Agenda
13:30-14:30	Good Practice and Benchmark Analysis of MAR
14:30-15:00	Virtual Coffee Break
15:00-16:00	Transnational Decision Support Toolbox for designating potential MAR locations in Central Europe

Location:
ZOOM Conference Room
https://tum-conf.zoom.us/j/97349866167
Meeting ID:
973 4986 6167
Password: 346397

Contact:
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Structure of the decision-support toolbox

Climatological selection criteria

Hydrogeological/ geological selection criteria

Analysing sensitivity of MAR to climatic extremes

Decision-support toolbox

including checklists (sets of selection criteria) specific to MAR types

Maps of suitable areas for MAR

Selected MAR types for Toolbox

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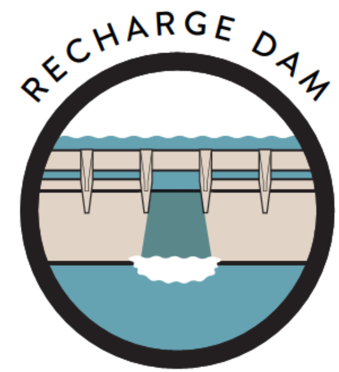

4-step procedure for MAR suitability

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	SELECTION CRITERIA	SCALE	MAR-SPECIFIC	AIMS
1ST STEP	Exposure to climate extremes	Central Europe	NO	Identify the need for MAR systems due to climate change and exposure to climate extremes.
2ND STEP	Geology and hydrogeology: general screening	Country or region	YES	Identify suitable areas for the implementation of the six selected MAR schemes.
3RD STEP	Geology and hydrogeology: specific screening (dependent on aquifer type)	Pilot area (sub-regional scale)	YES	Further evaluate the suitable areas by applying a three-level scale (low, moderate, and high suitability) and identify suitable pilot sites for MAR implementation.
4TH STEP	Sensitivity of MAR schemes to climate extremes *Costs and-benefits, regulatory framework* *Feasibility of technical solutions and acceptability of associated risks: field measurements and monitoring* *Water demand and supply*	Pilot site(s)	YES	Investigate and characterize the feasibility of the selected pilot site(s) for a specific MAR-scheme.

not subject of this handbook (refers to: Costs and-benefits, regulatory framework; Feasibility of technical solutions and acceptability of associated risks: field measurements and monitoring; Water demand and supply)

First step: Exposure to climate extremes (1)

Investigation of the expected water demand due to climate change, based on climatological data and modelling for Central Europe.

Key climatological parameters:

- temperature
- precipitation
- potential evapotranspiration (PET)

Based on these three parameters, the climatic water balance is determined, providing information about the water supply of the area. This is considered as the **climate exposure indicator** in the frame of this project.

Based on the climatic water balance, four climate exposure categories – which are not MAR-specific – are defined to characterize the need for MAR systems.

First step: Exposure to climate extremes (2)

Using **climate modelling data,** a set of **maps** **for the periods of 2021-2050 and 2071-2100** (compared to the reference period of 1971-2000) is created.

Maps present the expected:

- ✓ change of mean temperature
- ✓ change of mean precipitation
- ✓ change of mean potential evapotranspiration
- ✓ resulting climate exposure

From these maps, areas with a higher MAR potential, in terms of climate exposure, can be identified

Maps for Central Europe; resolution: each grid point 12.5 km x 12.5 km (15128 grid points in total)

Applied climate simulations

GLOBAL MODEL	REGIONAL MODEL	SCENARIO	
CNRM-CM5	RCA4	RCP4.5	"relatively optimistic scenario"
CNRM-CM5	RCA4	RCP8.5	"pessimistic scenario"
EC-EARTH	RCA4	RCP4.5	"relatively optimistic scenario"
EC-EARTH	RCA4	RCP8.5	"pessimistic scenario"

Scoring scheme for climate exposure categorisation

CLIMATIC WATER BALANCE 30-YEAR AVERAGE FOR CLIMATE WINDOW	30-YEAR AVERAGE SCORE	DIFFERENCE OF 30-YEAR AVERAGE BETWEEN CLIMATE WINDOW AND REFERENCE PERIOD	DIFFERENCE SCORE
> 75^{th} p	1	> 75^{th} p	1
50^{th} p - 75^{th} p	2	50^{th} p - 75^{th} p	2
25^{th} p - 50^{th} p	3	25^{th} p - 50^{th} p	3
< 25^{th} p	4	< 25^{th} p	4

Example:

if at a grid point (12.5 km x 12.5 km) the 30-years average is **< 25^{th} percentile**,
4 points are assigned: this value is **rather "exceptional"** (relatively low probability)

if at this grid point the difference value, indicating climatic change, is **> 75^{th} percentile**,
1 point is assigned: this value is **rather "common"** (relatively high probability)

Climate exposure categories with final score values

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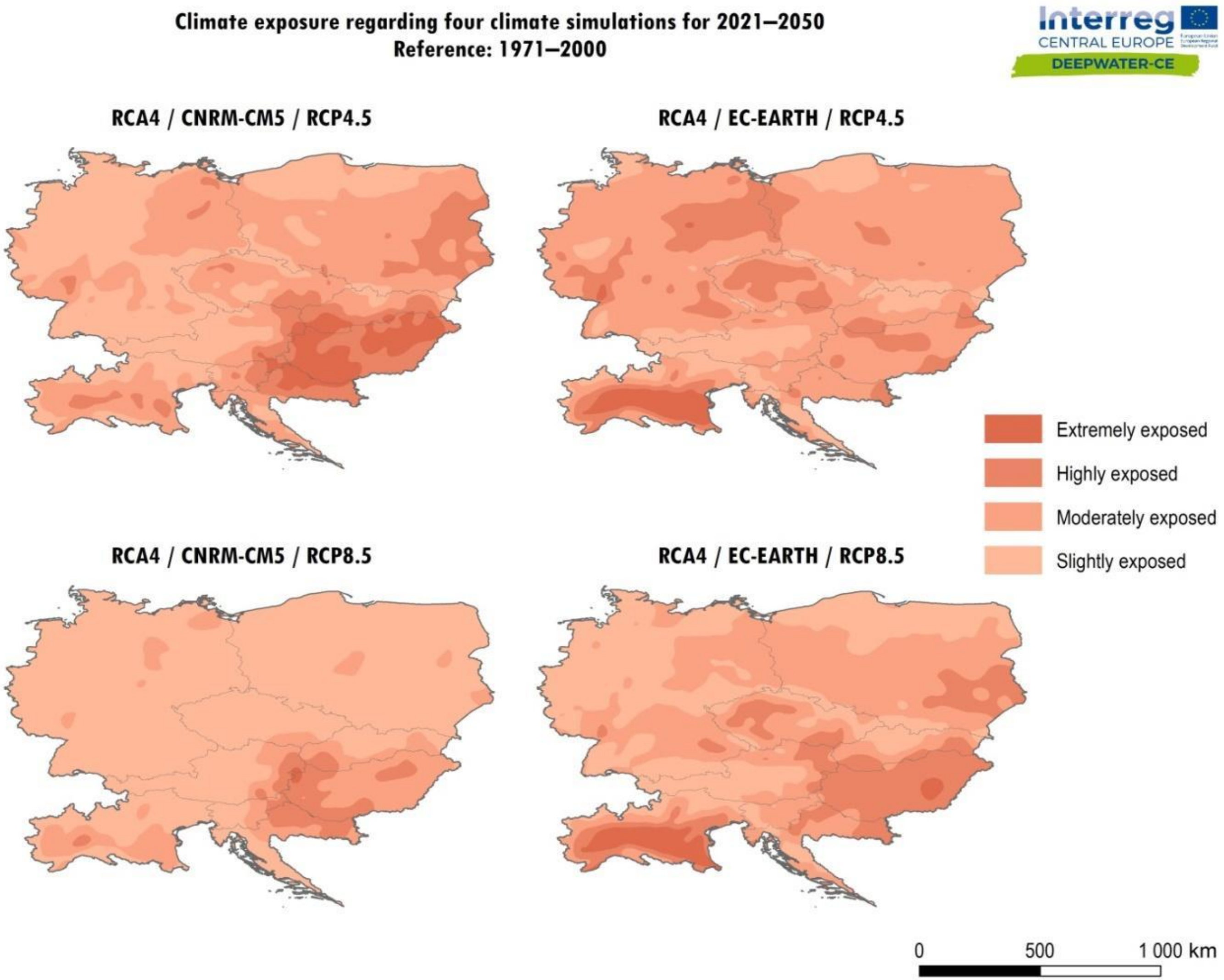
obtained by multiplying "30-years average score" by "difference score"

FINAL SCORE	EXPOSURE CATEGORY
1-4	Slightly exposed
5-8	Moderately exposed
9-12	Highly exposed
13-16	Extremely exposed

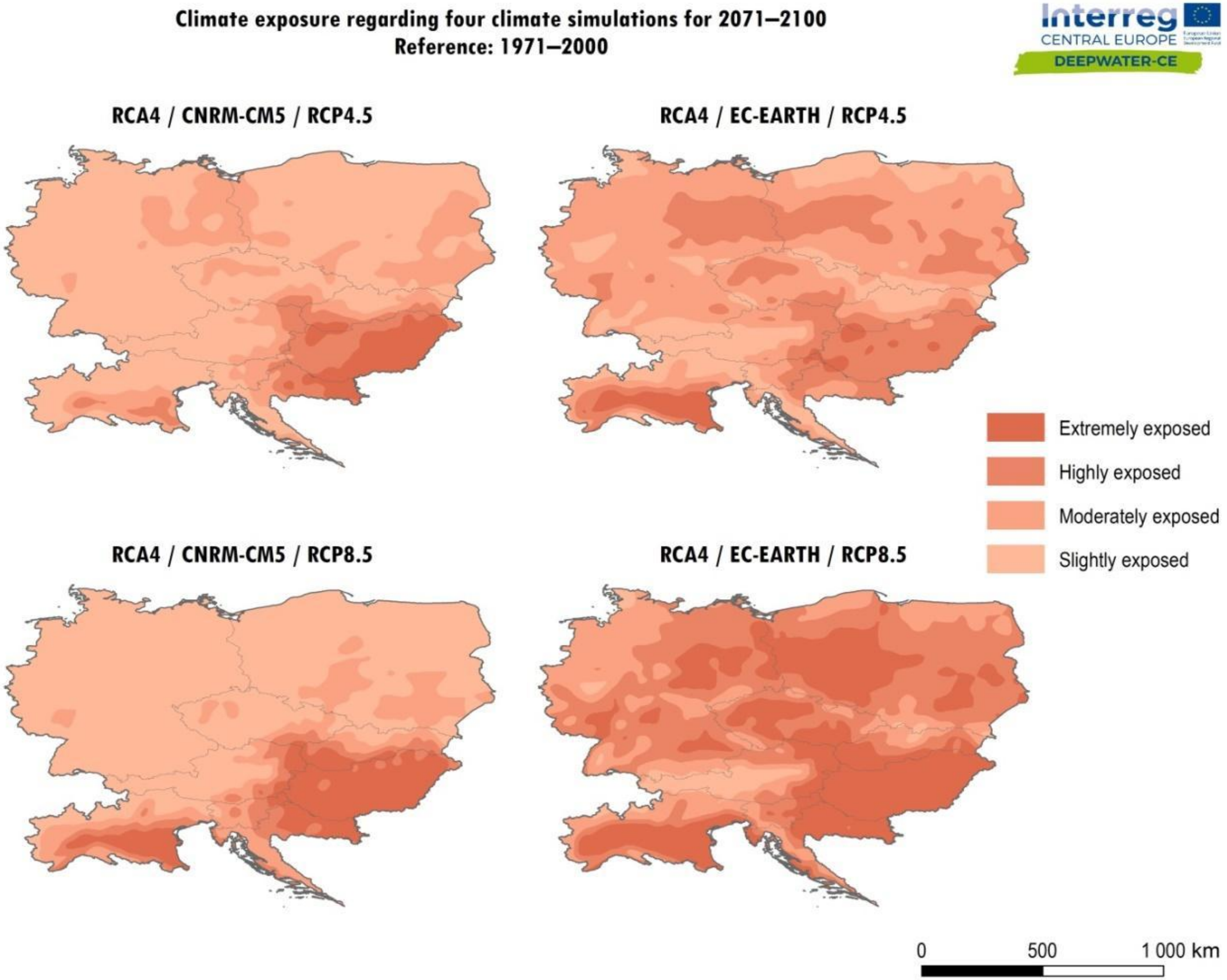
In our example:

we multiply the two scores from the previous slide: 4 x 1 = 4,
so the final score is 4: this grid point is within the "slightly exposed" category

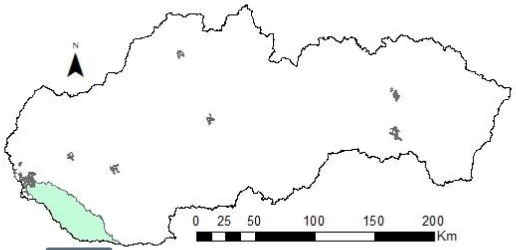
Climate exposure 2021-2050

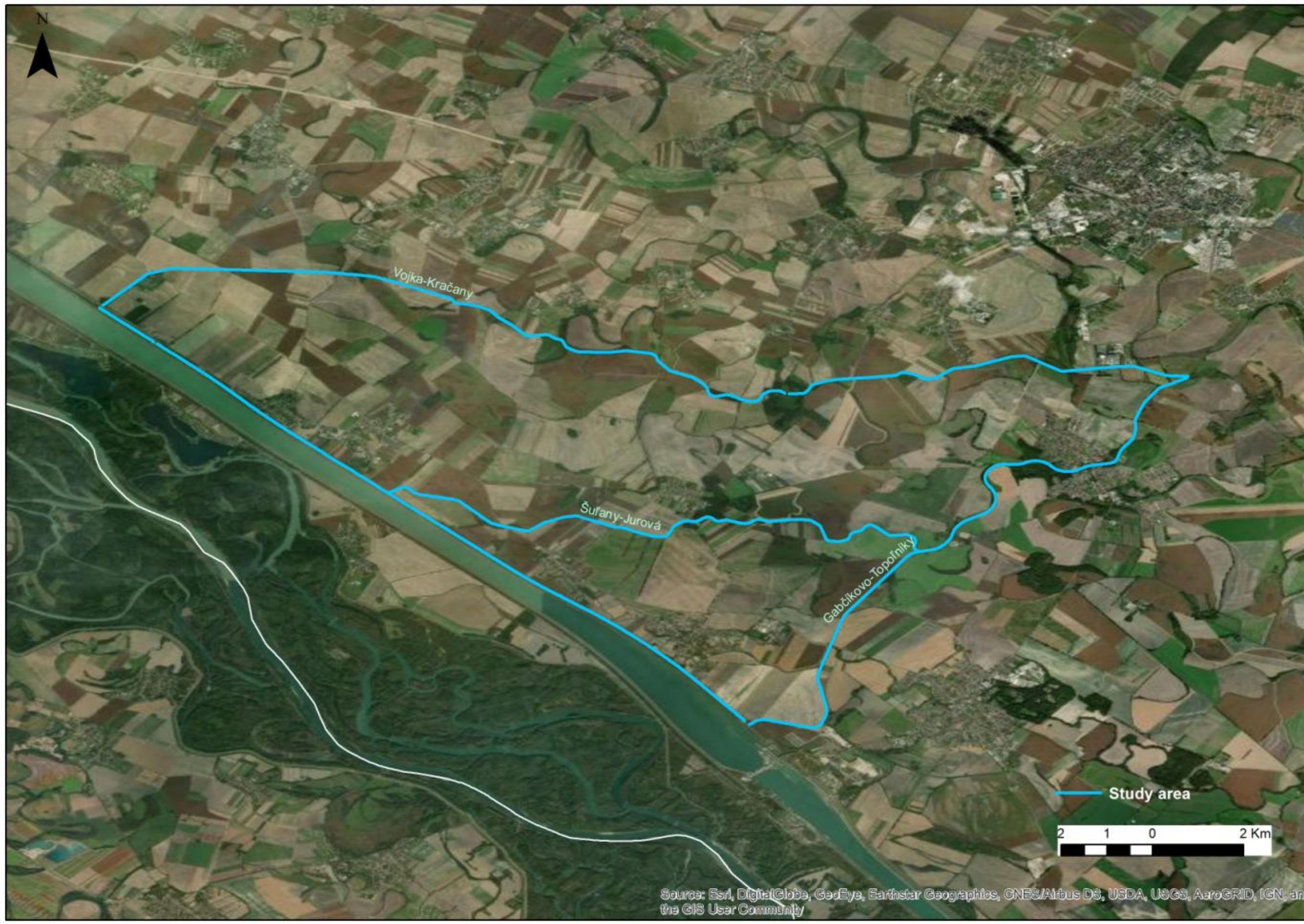


Climate exposure 2071-2100



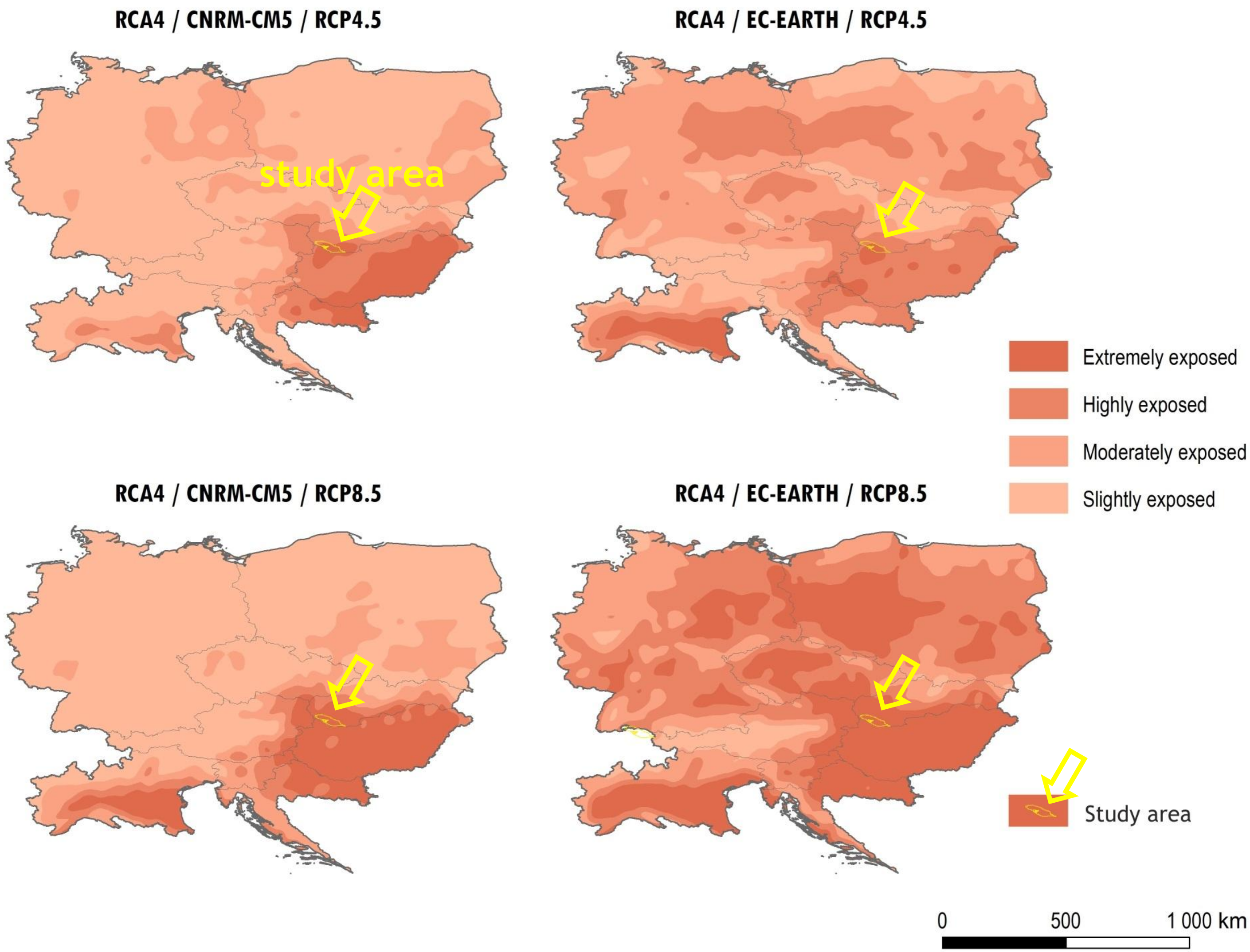
Map of Podunajska lowland, Slovakia





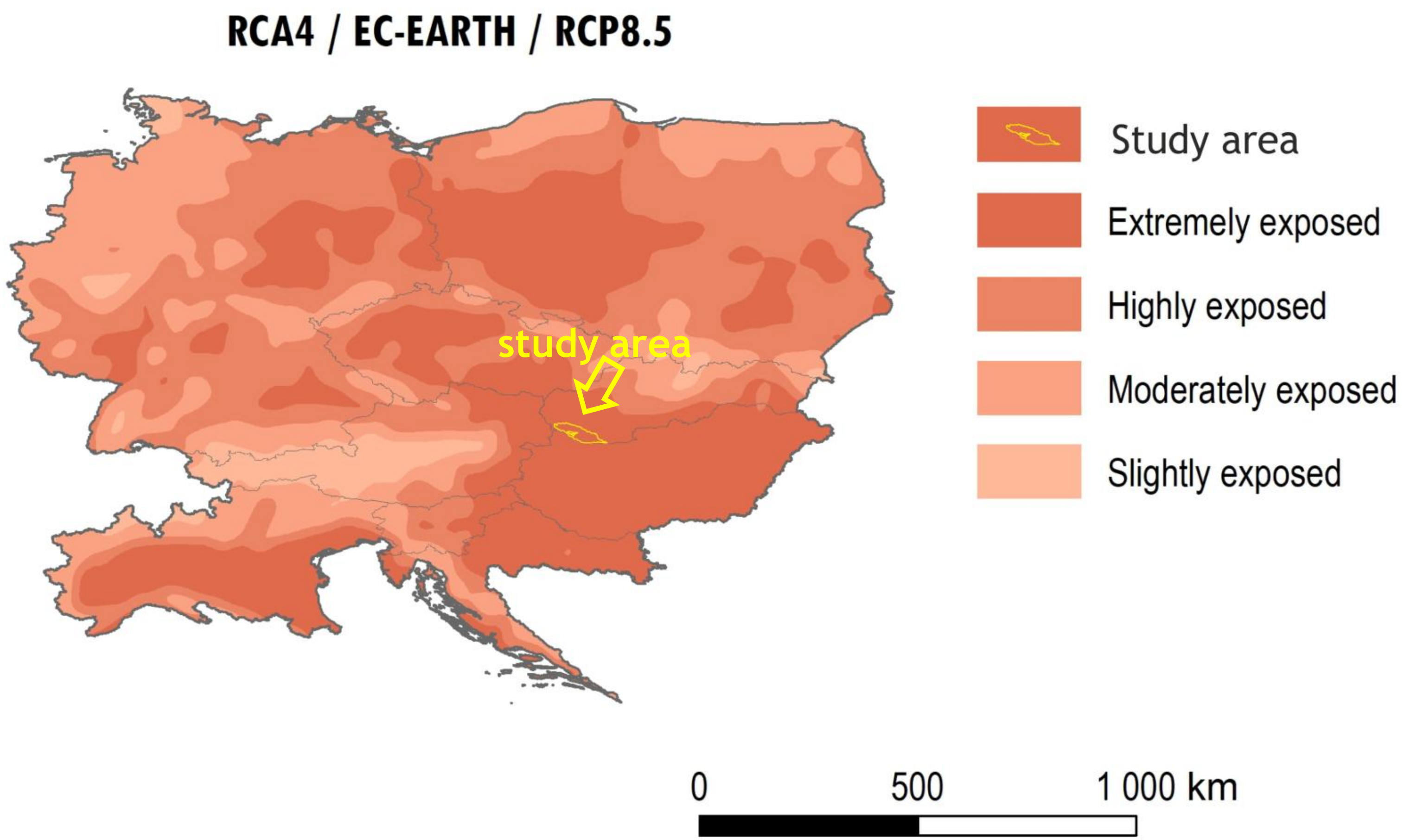
General selection criteria - Climate exposure

2071-2100



General selection criteria - Climate exposure

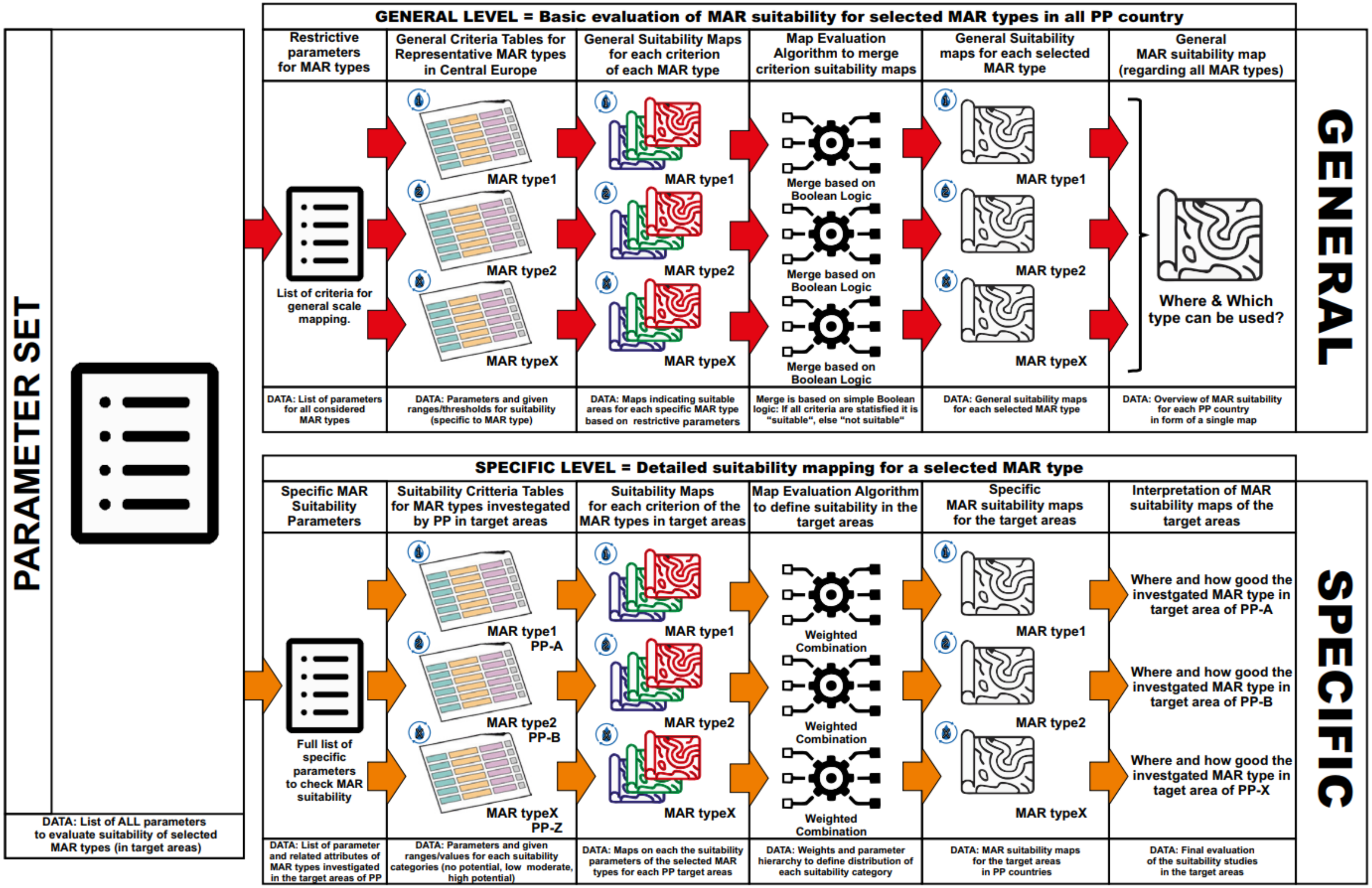
2071-2100



Second step: General screening with geological and hydrogeological selection criteria

- Screening for a suitable geological and hydrogeological environment starts with an investigation area of country-wide or regional extent.
- At this level, general geological and hydrogeological selection criteria for MAR suitability are defined and arranged in checklists.
- Evaluation using these checklists results in maps identifying MAR-suitable areas.
- The maps help divide each MAR type into two categories:
  a) suitable
  b) unsuitable

Scheme for general and specific screening



General parameters

The general parameters are MAR restriction parameters.

By the mapping and spatial analysis of these parameters, the areas which are unsuitable for establishing the selected six MAR types (one by one) can be excluded on a country level.

The resulting maps show unsuitable areas at a general level.

Parameters for selection criteria - General parameter set (1)

GENERAL PARAMETER SET / MAR RESTRICTION PARAMETERS

MAIN PARAMETER CATEGORY	NAME OF THE PARAMETER(S)	TYPE OF THE PARAMETER(S)	DIMENSION	EXPLANATION
CHARACTER-ISTICS OF THE WATER SOURCE	distance from surface water source	numeric value	number/ category	The distance of the surface water source can define its suitability. A long distance entails higher costs, due to the need for hydraulic infrastructure to transport the water.
SURFACE CHARACTER-ISTICS	lithology of the surface formations	category	category	The lithology of the surface formations is an important geological and hydrogeological parameter that influences hydraulic and biogeochemical processes, such as infiltration and aquifer recharge.
	slope	numeric value	number/ category	Many processes related to the land surface depend on the slope. Some MAR types require specific slope categories. Areas with a high relief are not optimal for various MAR types, due to the resulting surface water runoff characteristics (high runoff rates). In contrast, in areas with a very low relief, recharge might be lower compared to hilly landscapes, such that these areas might not be well suited as a water source. Sites with low slopes show comparatively low surface water runoff and still enable comparatively high infiltration. However, on steep slopes it is possible to slow/prevent parts of the runoff by constructing recharge dams, which can facilitate infiltration.

Parameters for selection criteria - General parameter set (2)

GENERAL PARAMETER SET / MAR RESTRICTION PARAMETERS

MAIN PARAMETER CATEGORY	NAME OF THE PARAMETER(S)	TYPE OF THE PARAMETER(S)	DIMENSION	EXPLANATION
AQUIFER CHARACTER-ISTICS	depth of the top of the aquifer (location)	numeric value	number/ category	The top of the aquifer has to be located within an acceptable range in view of related MAR operational costs. It specifies suited technological solutions for some MAR types (e.g. well injection). Deeper aquifers require different MAR systems than shallow aquifers.
	lithology of the aquifer	category	major rock types	The lithology of the aquifer is an important geological and hydrogeological parameter that influences hydraulic and biogeochemical processes in the subsurface, such as groundwater flow, storage properties, as well as fate and transport of groundwater pollutants.
	depth of the groundwater table	numeric value	number/ category	Provides information on water storage capacity and availability. Deeper aquifers need different MAR systems than shallow aquifers. A very shallow groundwater table usually leads to unsuitable conditions for MAR systems. For each MAR scheme there are optimal ranges for the groundwater table in order ensure an efficient use of MAR.

Selection of potential MAR locations in karst areas

Methodologies for MAR suitability mapping in karst areas are based on:

- geological and
- hydrogeological selection criteria

Significant discrepancies exist in the consideration of processing the geological and hydrogeological data, namely, their resolution and scale of mapping. It was found that pre-existing methods which are applicable in other geological environments are not suitable for karst environments.

Due to the extreme complexity and heterogeneity of karst systems, extensive research is required to provide geological and hydrogeological parameters that can be considered adequate for suitability mapping.

Third step: Specific screening with geological and hydrogeological selection criteria

- Suitable areas are further investigated with more specific selection criteria to characterize their actual **suitability** on a three-level scale (**low**, **moderate**, **high**), and to specify potential pilot areas for feasibility studies.

- These pilot areas include potential MAR pilot sites.

- In this step, relative weight of the selection criteria is also defined in the checklists to handle their uneven contribution to the final suitability.

Specific sets of geological and hydrogeological parameters for MAR suitability

Specific parameters define MAR suitability

- Based on these parameters we are able to examine to what extent the previously screened areas are suitable (high/moderate/low) for installing the six selected MAR types.

- This screening for the suitable areas needs to be done separately for each MAR type.

- The territories which are considered to be suitable on a general level (2nd step) are further sub-divided into smaller areas of high, moderate, and low suitability, using the specific selection criteria (3rd step).

- This procedure aims at identifying areas that are most promising for the given MAR technology.

- These specific-level studies can provide information to regional water management authorities and experts.

- Since parameters have a different effect on suitability, a weight has to be assigned to each of them.

Multi Influencing Factor (MIF)

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MIF methodology is used for weighting:

- It investigates the influence of each criterion to the others; based on the degree of correlation, a factor is assigned to each relationship.
- A factor of 1 is assigned if the criterion has a major influence on the other one, factor of 0.5 if it has only a minor impact, factor 0 if it has no significant impact.
- In general, determining the influences between parameter pairs is done based on professional experience *(in the current project, by the respective experts within the project consortium)*.
- Parameter ranges are defined and min and max values assigned to each of them.
- The higher the suitability, the higher the value.
- The final weight of a criterion is given by the sum of its multiplied suitability values divided by the sum of the multiplied suitability values for all criteria, expressed in percentage.

Set of specific geological and hydrogeological MAR suitability parameters

MAIN PARAMETER CATEGORY	NAME OF THE PARAMETER(S)	TYPE OF THE PARAMETER(S)	DIMENSION	EXPLANATION
CHARACTERISTIC OF THE WATER SOURCE	distance from surface water source	numeric value	number/category	The distance of the surface water source can define its suitability. A long distance implies higher costs for the realization due to the need for hydraulic infrastructure to transport the water. Exceeding a threshold value for the distance of the surface water source can be a constraint parameter for certain MAR types.
SURFACE CHARACTERISTICS	lithology of the surface formations	category	category	As described in Table 9.
	(hydrologic) soil type	category	texture class (sand, silty clay loam, loam, clay, etc.) and/or hydrologic soil group	Soils can be classified into four hydrologic soil groups based on the soil's runoff potential (USDA, 2009): Group A: sand, loamy sand, or sandy loam Group B: silt loam or loam Group C: sandy clay loam Group D: clay loam, silty clay loam, sandy clay, silty clay, or clay
	land use	category	e.g. pasture, agricultural terrain (arable land), forest, surface water, urban areas, industry	The land use affects important parameters such as infiltration, depth, and gradient of the groundwater table, or the suitability of an area for MAR (e.g. urban areas or nature reserves are usually not optimal areas for MAR systems).
	slope	numeric value	number/category	As described in Table 9.

Specific geological and hydrogeological parameter set for MAR suitability

MAIN PARAMETER CATEGORY	NAME OF THE PARAMETER(S)	TYPE OF THE PARAMETER(S)	DIMENSION	EXPLANATION
AQUIFER CHARACTERISTICS	confinement of the aquifer	category	confined/semi-confined/unconfined	It defines e.g. hydraulic pressure conditions of the aquifer and recharge mechanisms/pathways. Confined aquifers may be recharged (replenished) by precipitation or stream water infiltrating at considerable lateral distance.
	thickness of the aquifer	numeric value	number/category	Some parameters depend on the thickness of the aquifer, such as transmissivity or aquifer storage.
	depth of the top of the aquifer (location)	numeric value	number/category	The top of the aquifer has to be located within an acceptable range in view of related MAR operational costs. It specifies suited technological solutions for some MAR types (e.g. well injection). Deeper aquifers require different MAR systems than shallow aquifers.
	depth of the aquifer base (location)	numeric value	number/category	The aquifer base (impermeable layer below the aquifer) has to be in an acceptable range regarding MAR operational costs. It specifies technological solutions e.g. for underground dams.
	lithology of the aquifer	category	major rock types	As described in Table 9.
	depth of the groundwater table	numeric value	number/category	As described in Table 9.
	regime type of the groundwater flow system	category	recharge/transition/discharge area	Recharge and transition areas can be used for different MAR types. That said, regional recharge and discharge areas are not optimal due to dominant vertical groundwater flow components.
	Presence of subsurface structures providing storage or acting as barriers or channels	Boolean	yes/no	Subsurface structures (heterogeneities) can act as channels or barriers that guide or restrict groundwater flow locally. They can also form geological traps providing prosperous water storage potentials (such as buried riverbeds, alluvial fans in piedmont zones, buried anticlines and synclines, tectonic traps).
	Storage coefficient	numeric value	number/category	It is used to characterize the aquifer storage and is also important for determining MAR potentials and expected performance and limitations (among others).

Fourth step: Feasibility study for selected pilot site(s)

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<u>The feasibility of selected pilot site(s) for MAR-scheme implementation is investigated.</u>

Feasibility studies comprise:

- Analysing the sensitivity of MAR-schemes to climate extremes
- Setting up guidelines for assessing water demand and supply, before and after MAR implementation
- Setting up guidelines for selecting suitable technical solutions and risk management techniques for MAR-schemes, including field measurements and monitoring
- Setting up guidelines for performing cost-benefit analyses and defining the Central European regulatory framework for MAR-schemes

Sensitivity of MAR systems to climate-induced extreme situations

- For analysing the sensitivity of MAR systems to extreme climate events, it is necessary to characterise the inputs, outputs, and interconnection among parameters.
- Methodological approach using impact chains
- next slide

Proposed methodology of analysing the sensitivity of MAR systems to climate-induced extreme events

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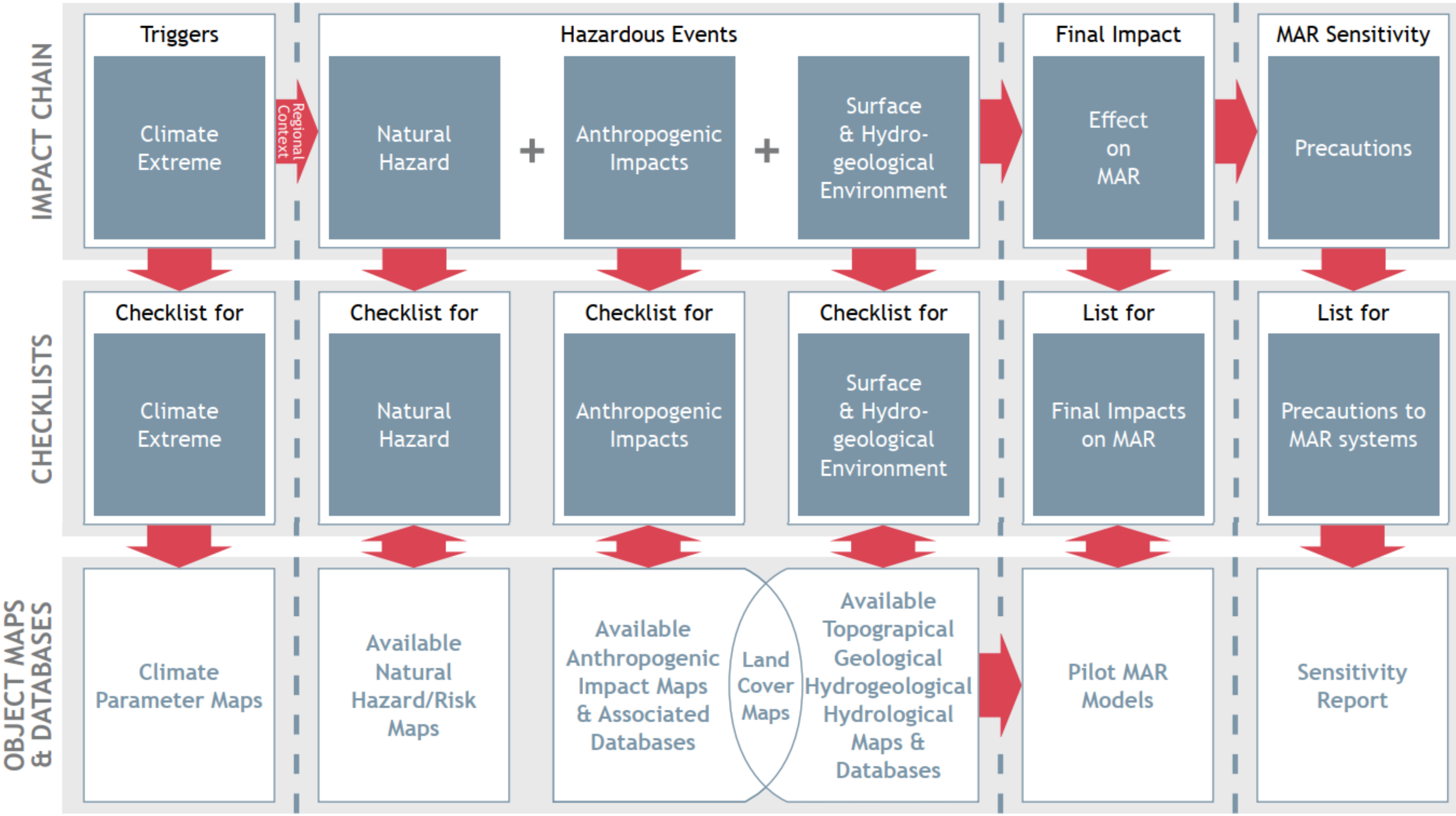

Checklists

- For each impact chain category, checklists are created for the six selected MAR types

- The checklists comprise **triggers of climate extremes** that result in **hazardous events** (natural hazards and anthropogenic impacts, influenced by the surface and hydrogeological environment) and also aim at describing the **final impacts** on selected MAR schemes specifying precautions for MAR systems

- The information provided in the checklists can be used by potential MAR users as a basis for developing thematic maps, databases, or models for MAR sites at the site-specific level

- The checklists can contribute to draft recommendations for the planning and implementation of future MAR systems

Overall checklist for analysing sensitivity of MAR to extreme events

P: precipitation, GW: groundwater, SW: surface water; ET: Evapotranspiration

<table>
<tr><th colspan="2">TRIGGER/STIMULUS</th><th colspan="4">HAZARDOUS EVENTS</th><th>FINAL IMPACT</th><th>SENSITIVITY TO MAR</th></tr>
<tr><th colspan="2">CLIMATE EXTREMES</th><th colspan="2">NATURAL HAZARDS</th><th>ANTHROPOGENIC IMPACTS</th><th>SURFACE & HYDROGEO-LOGICAL ENVIRONMENT</th><th>EFFECT ON MAR</th><th>PRECAUTION TARGETS</th></tr>
<tr><td rowspan="2">WET PERIOD</td><td rowspan="2">Short period of extremely high P amount
Extremely long period of P
Extremely high frequency of P events
Extremely high amount of snow accumulation</td><td>FLASH FLOOD</td><td>Flash flood
Extreme run-off</td><td rowspan="5">Overexploitation of GW
(changes in GW dynamics)

Land use impacts
(urban, industrial, agricultural) leading to water overexploitation

Diffuse pollution
(e.g. agriculture-related soil pollution by plant protection products, fertilisers; atmospheric input of contaminants)

Point pollution
(e.g. waste landfills, fuel spills, wastewater treatment plants, untreated urban water)

Mining activity
(intensive drainage of SW and GW; leaching of pollutants)</td><td rowspan="5">Land cover
(e.g. grass, trees/forest (or deforestation), asphalt, agricultural crops)

Slope
(e.g. influence of infiltration)

SW source
(e.g. surface water level dynamics)

Soil hydraulic properties

Aquifer type
(unconfined, confined, porous, fractured, karst, etc.)

Aquifer characteristics
(e.g. porosity, transmissivity, properties related to pollutant transport & fate)

Connection between aquifers

GW quality
(e.g. dissolved mineral content, changes in GW chemistry)

Position in the GW flow system
(recharge, transitional or discharge area; order of aquifers in vertical position; aquifer depth & thickness)

Geological structure
(fractures, faults, other in-homogeneities)
Coastal area</td><td rowspan="5">Slope instabilities
(e.g. landslides)

Erosion

Flooding of infrastructure
(e.g. of treatment/desalinization plant, rainwater collecting system)

Decrease of water storage in SW bodies
due to sedimentation

Increased residence time in SW bodies
Eutrophication

Overflowing GW Clogging
(by fine particles or biogeochemical processes)

Contamination of (shallow) aquifers
(infiltration, influx from surface water; salt water intrusion from ocean)

Mobilization or dissolution of contaminants
(biological, chemical, physical)

SW sources or GW production wells drying out

Reduction in GW well yield
(due to GW table depression, decrease of GW level, decrease of GW recharge)</td><td rowspan="5">Temporary interruption in MAR operation

Structural damage in MAR infrastructure & related effects
(specific to MAR type & technology)

Water quantity problems & related effects
(specific to MAR type & technology)

Water quality problems & related effects
(specific to MAR type & technology)</td></tr>
<tr><td>FLOOD</td><td>Flood (high P)
Rapid snow melting
Extremely high GW table ("GW flooding")
Inland excess water</td></tr>
<tr><td rowspan="3">DRY PERIOD</td><td rowspan="3">Extremely low P amount
Extremely high temperature/ ET
Extremely low amount of snow accumulation
Extremely low temperature/ ET</td><td>HYD. DROUGHT</td><td>Low surface water level for extremely long time durations
Drought (lack of physical P)</td></tr>
<tr><td>GW DROUGHT</td><td>GW table depression</td></tr>
<tr><td>SOIL DROUGHT</td><td>Decrease of soil moisture and GW recharge</td></tr>
</table>

Could you please fill in the webinar questionnaire?

https://forms.gle/DWNwGyUHy8wT4q7t6

(link also provided in the webinar chat)

Thank you !

Thank you for your kind attention

https://www.interreg-central.eu/Content.Node/DEEPWATER-CE.html

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