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CENTRO DE HIDROGEOLOGÍA DE LA UNIVERSIDAD DE MÁLAGA

Groundwater recharge assessment in karst aquifers by APLIS method and potential at European scale

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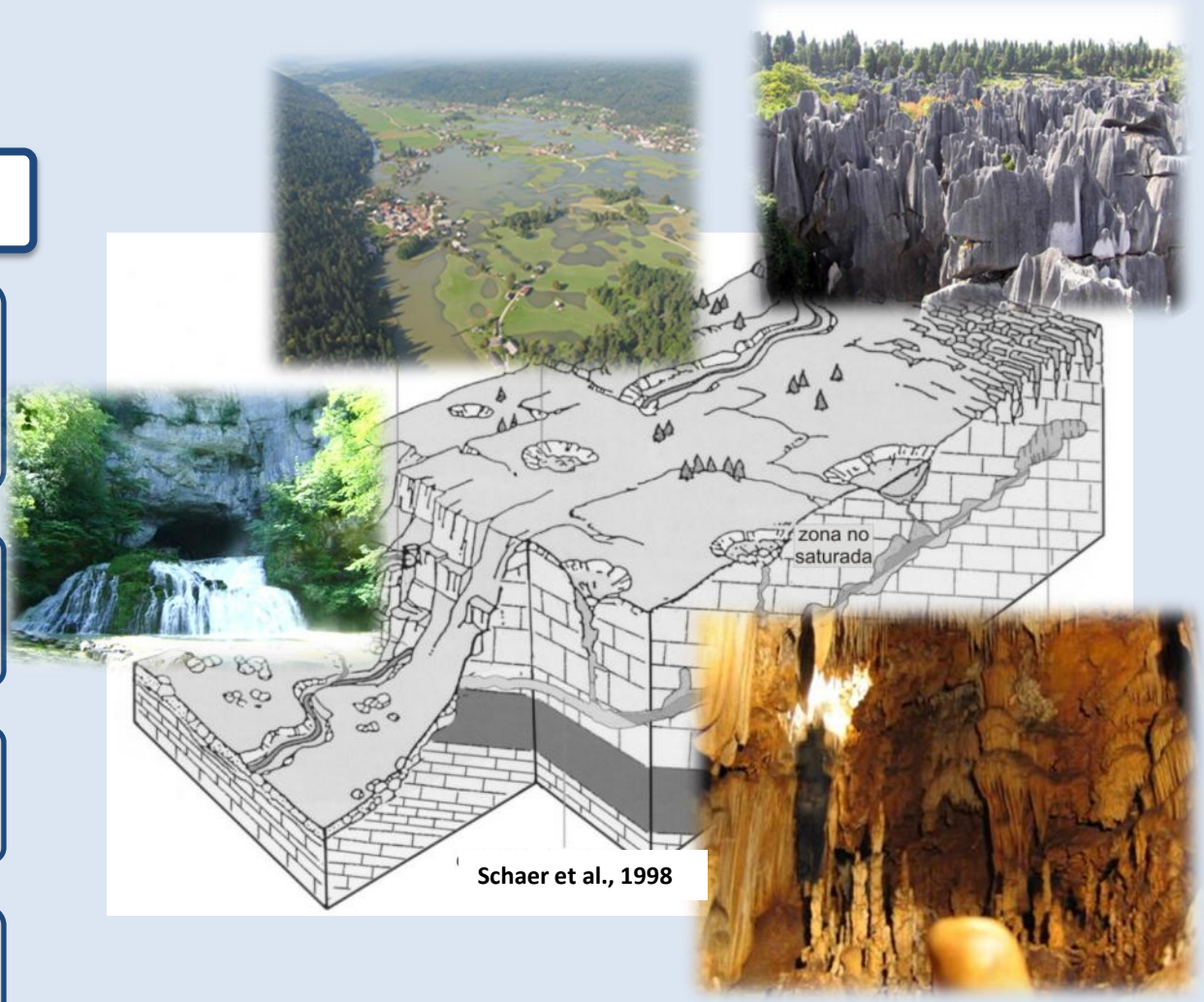
- Contents -

- Brief introduction on karst aquifers and recharge
- APLIS method (developed by Spanish Geological Survey –IGME- and CEHIUMA partnership)
- Application in Spanish and some worldwide sites
- Potential application in Europe (cooperation with ETC-SIA)
- Final remarks

Carbonate (karst) aquifers

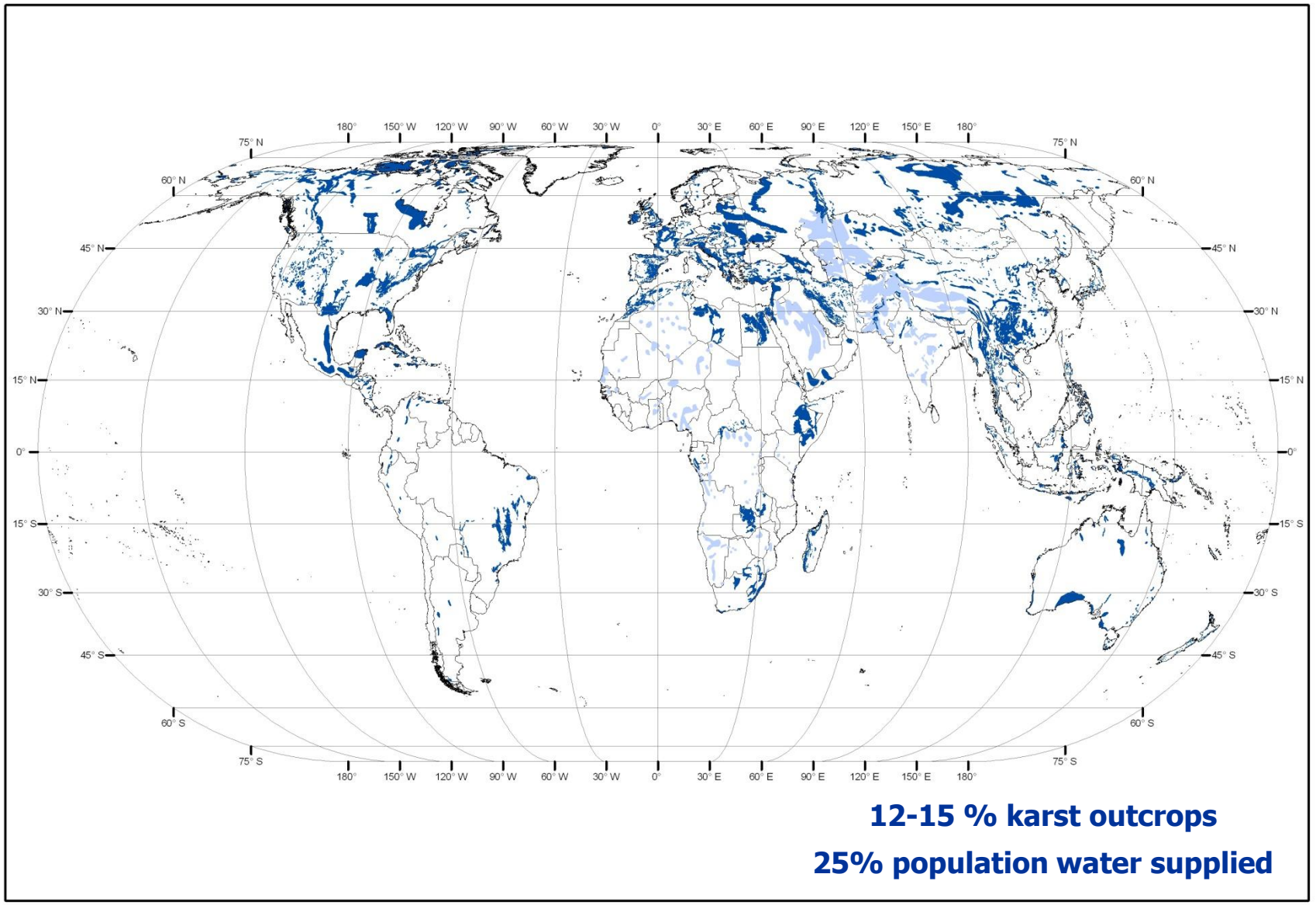
Hydrogeological characteristics:

- Diffuse or concentrated infiltration, from the permeable outcrops (autogenic recharge) or from adjacent low permeability materials (allogenic recharge)
- Spatial heterogeneity and marked anisotropy in the distribution of their characteristics hydraulic parameters
- Water flow may be slow (through fissures) or quickly (by conduits)
- Good hydrogeological connection between the exokarst features and the groundwater drainage toward the discharge points



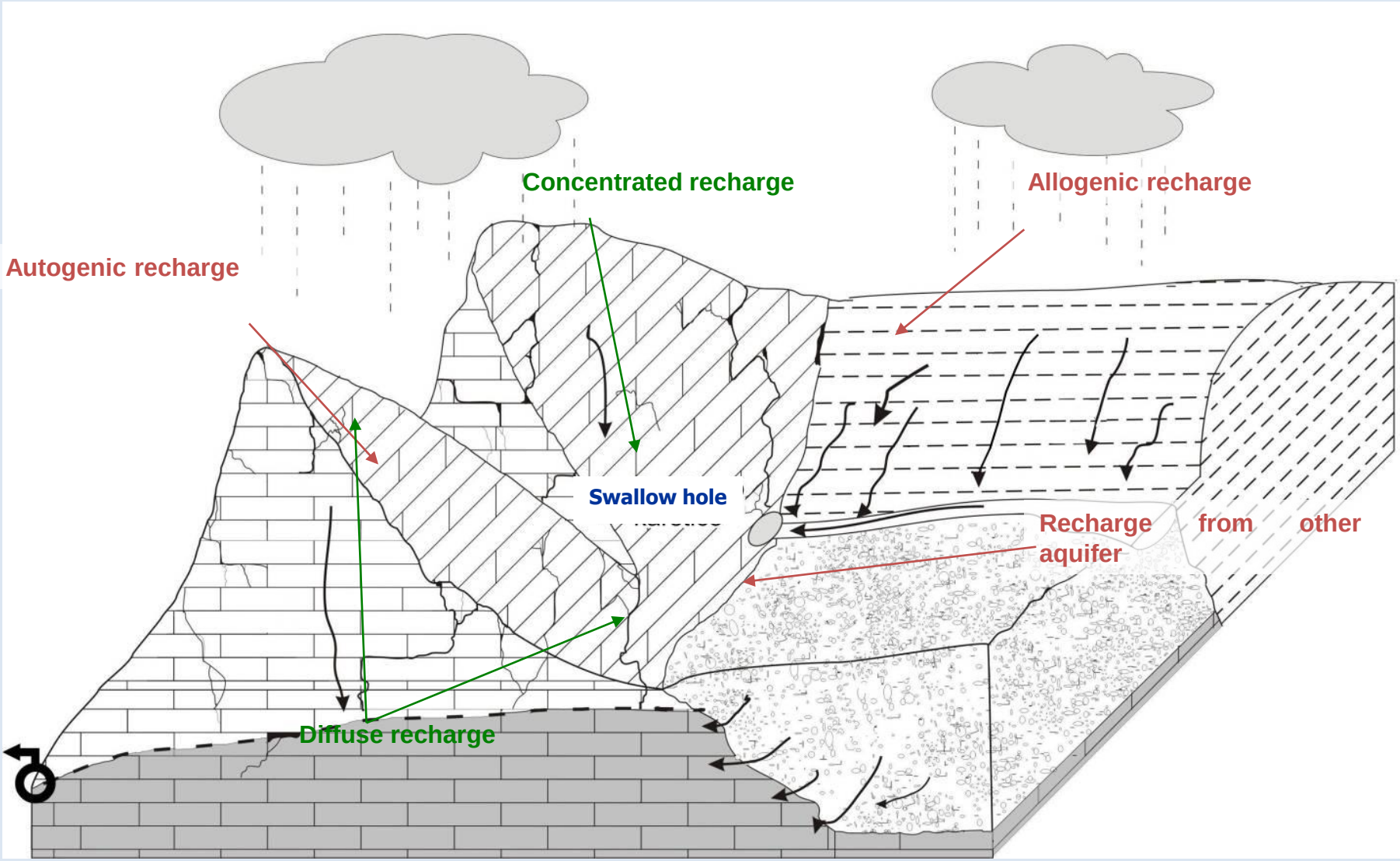
Schaer et al., 1998

Carbonate (karst) aquifers



12-15 % karst outcrops

25% population water supplied


Concentrated recharge
Allogenic recharge
Autogenic recharge
Swallow hole
Recharge from other aquifer
Diffuse recharge

The RECHARGE of an aquifer is the amount of water entering it during a given period of time.
The recharge coming from rainfall can be expressed as a percentage of precipitation, this being termed the **recharge rate.**

AQUIFER RECHARGE

Recharge rate, is addressed in most text books on Hydrogeology and in a more specific way

Spatial distribution, has been somewhat not always considered (interpolation of recharge data)

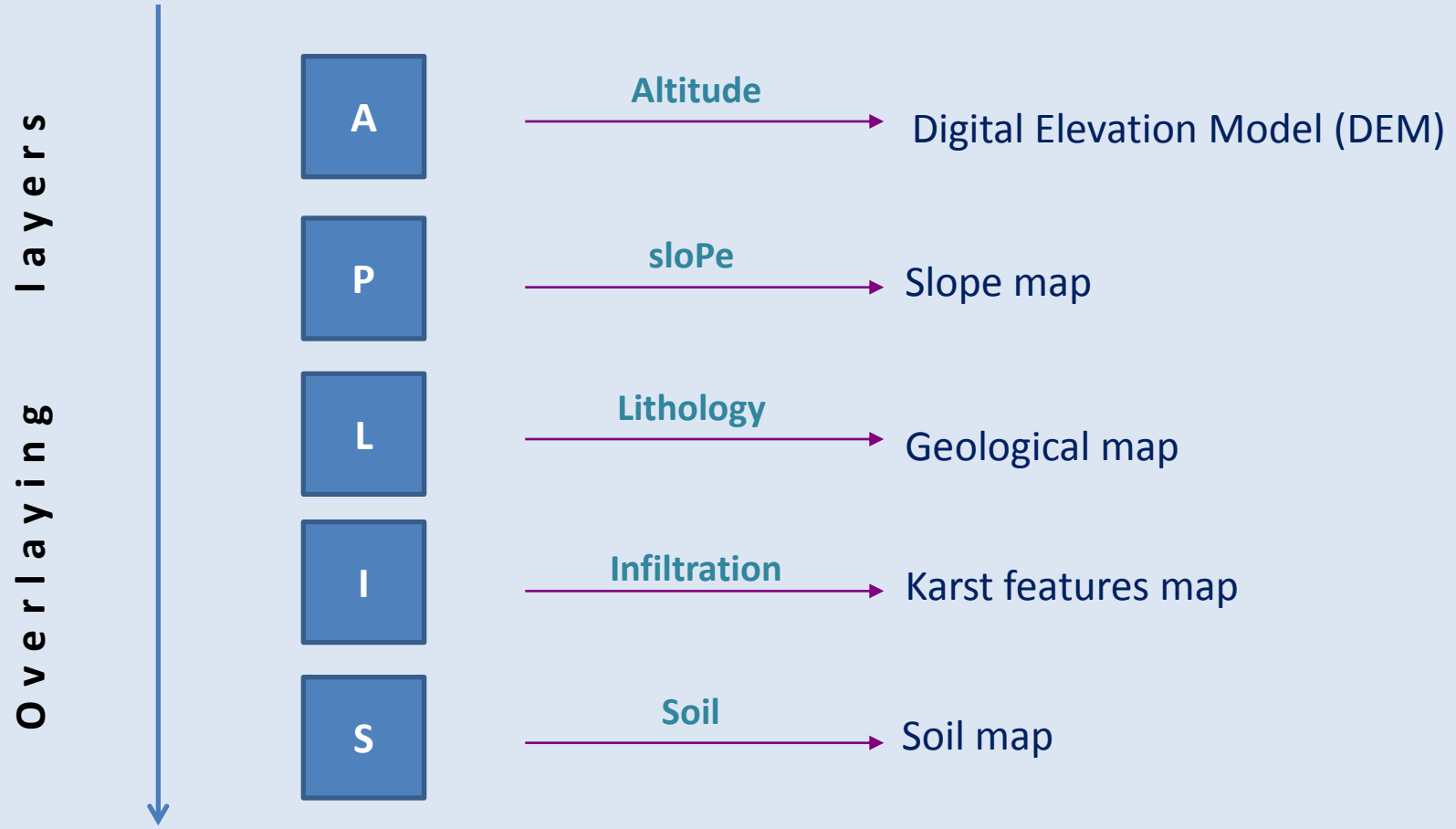
The **APLIS method** permits:

- To estimate the *mean rate of annual recharge* in carbonate aquifers, based on intrinsic variables of aquifers
- To establish the *spatial distribution* of the recharge rates on basis of the intrinsic characteristics aquifers. This aspect is fundamental for the appropriate management and protection of groundwater, with respect to both its quantity and its quality
- To estimate the *average annual resources*

Andreo, B.; Vías, J.M.; Durán, J.J.; Jiménez, P.; López Geta, J.A. y Carrasco, F (2008): Methodology for groundwater recharge assessment in carbonate aquifers: application to pilot sites in southern Spain. Hydrogeology Journal 16: 911-925.

- APLIS method -

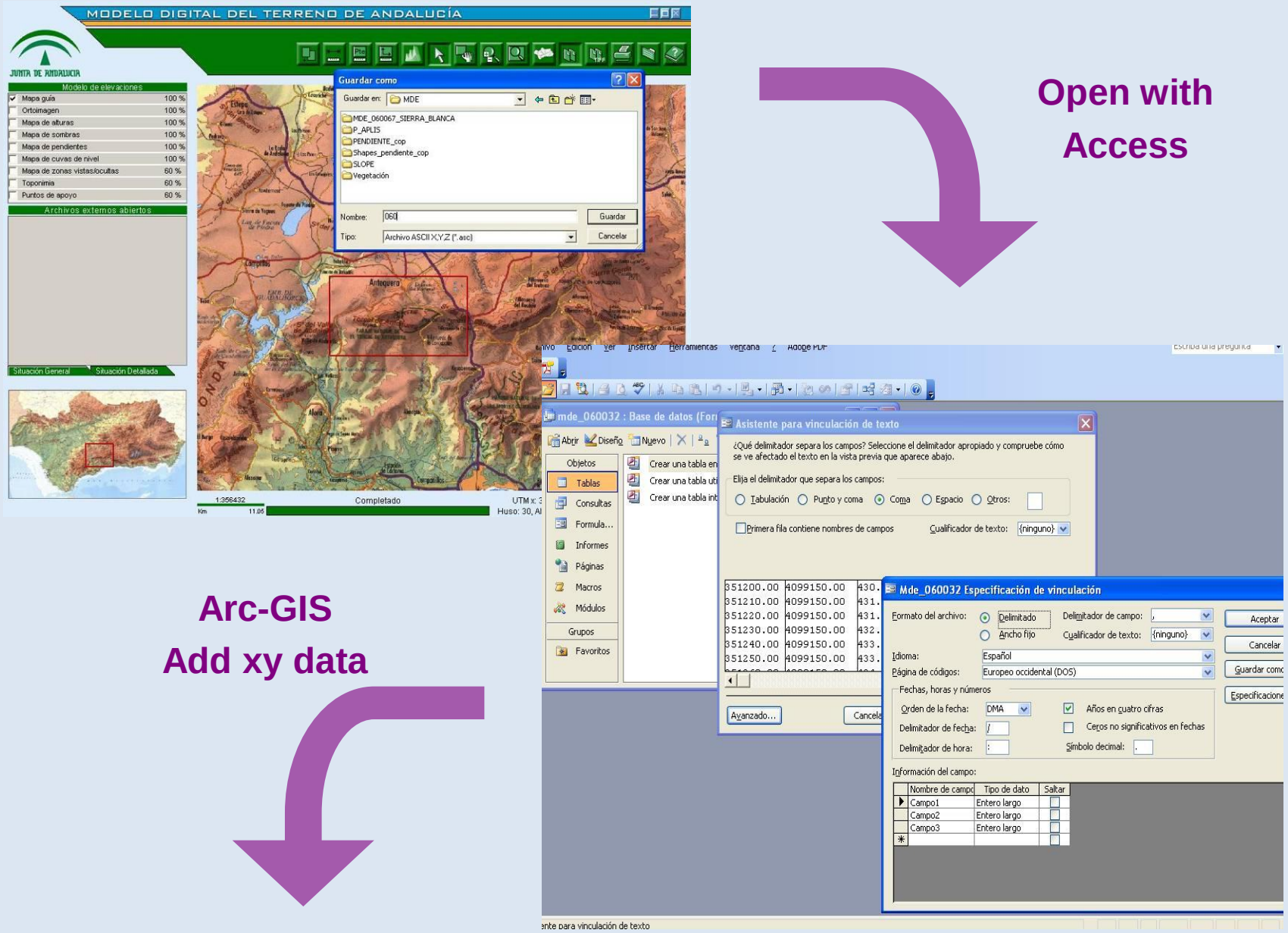
Geographic Information System GIS



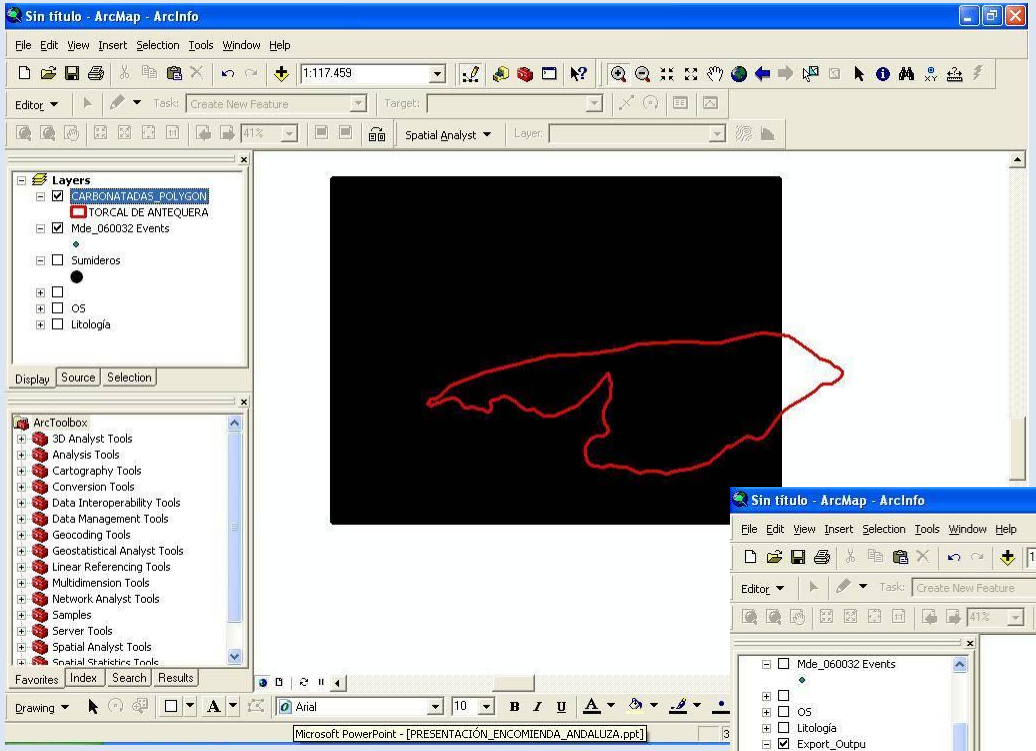
Recharge rate

- Methodological procedure -

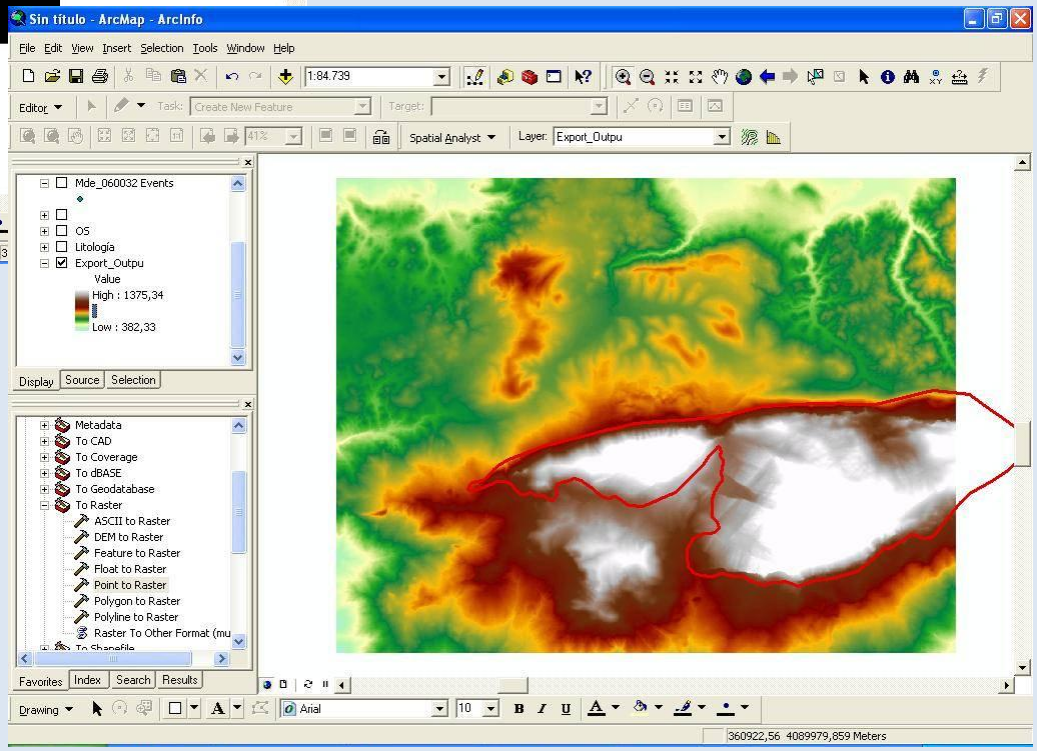
Digital Elevation Model (DEM)



- Methodological procedure -

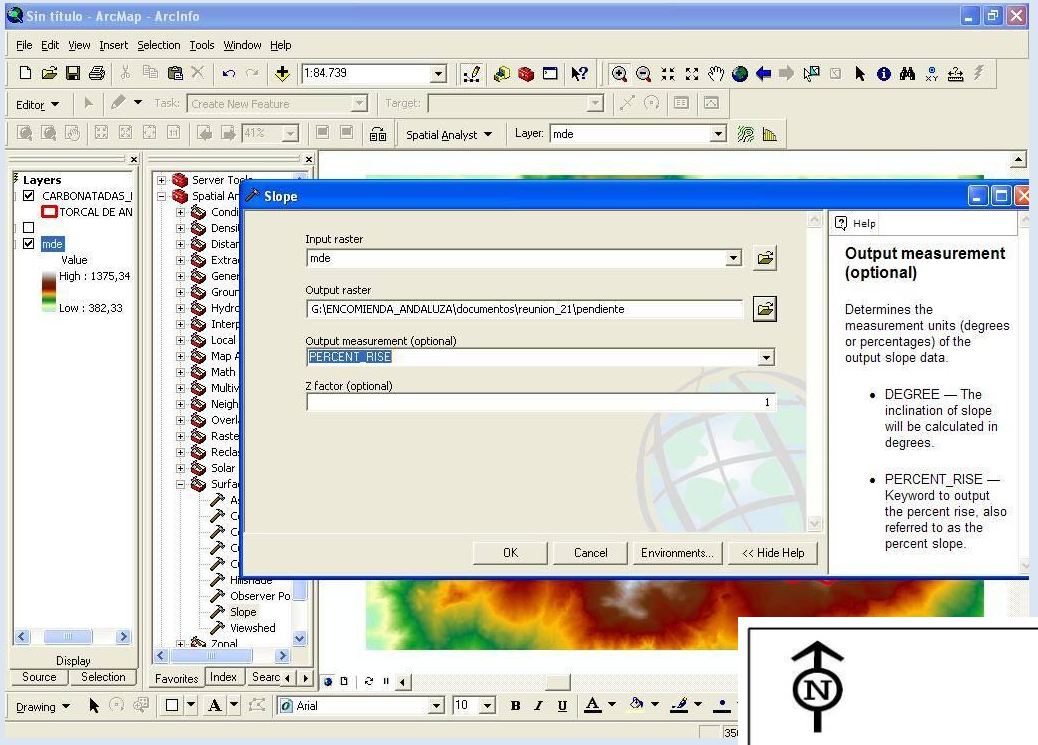


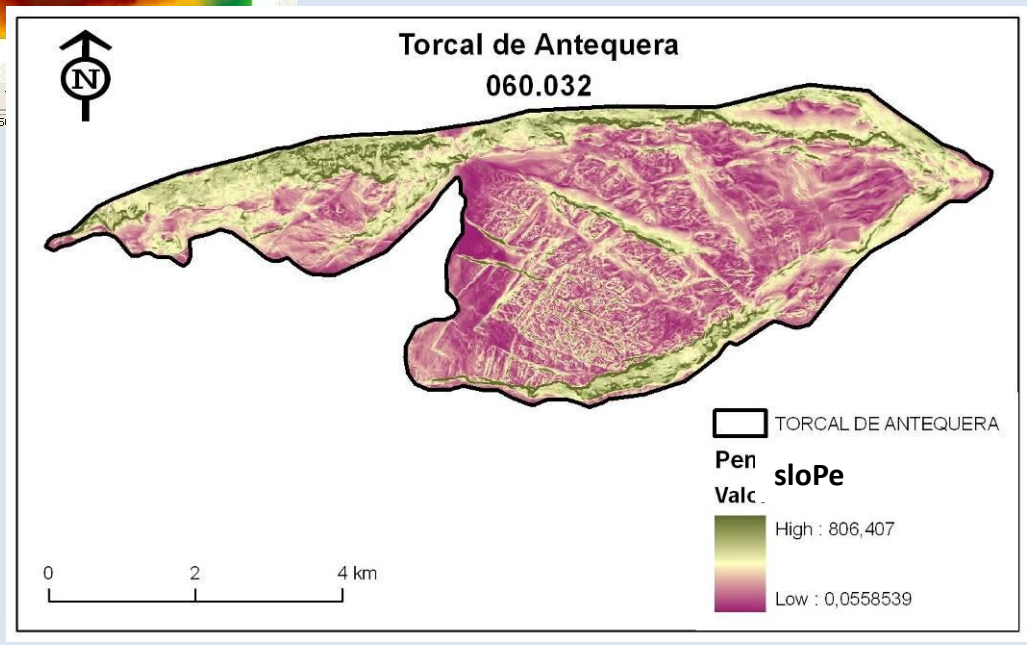
Convert to *raster*



sloPe map

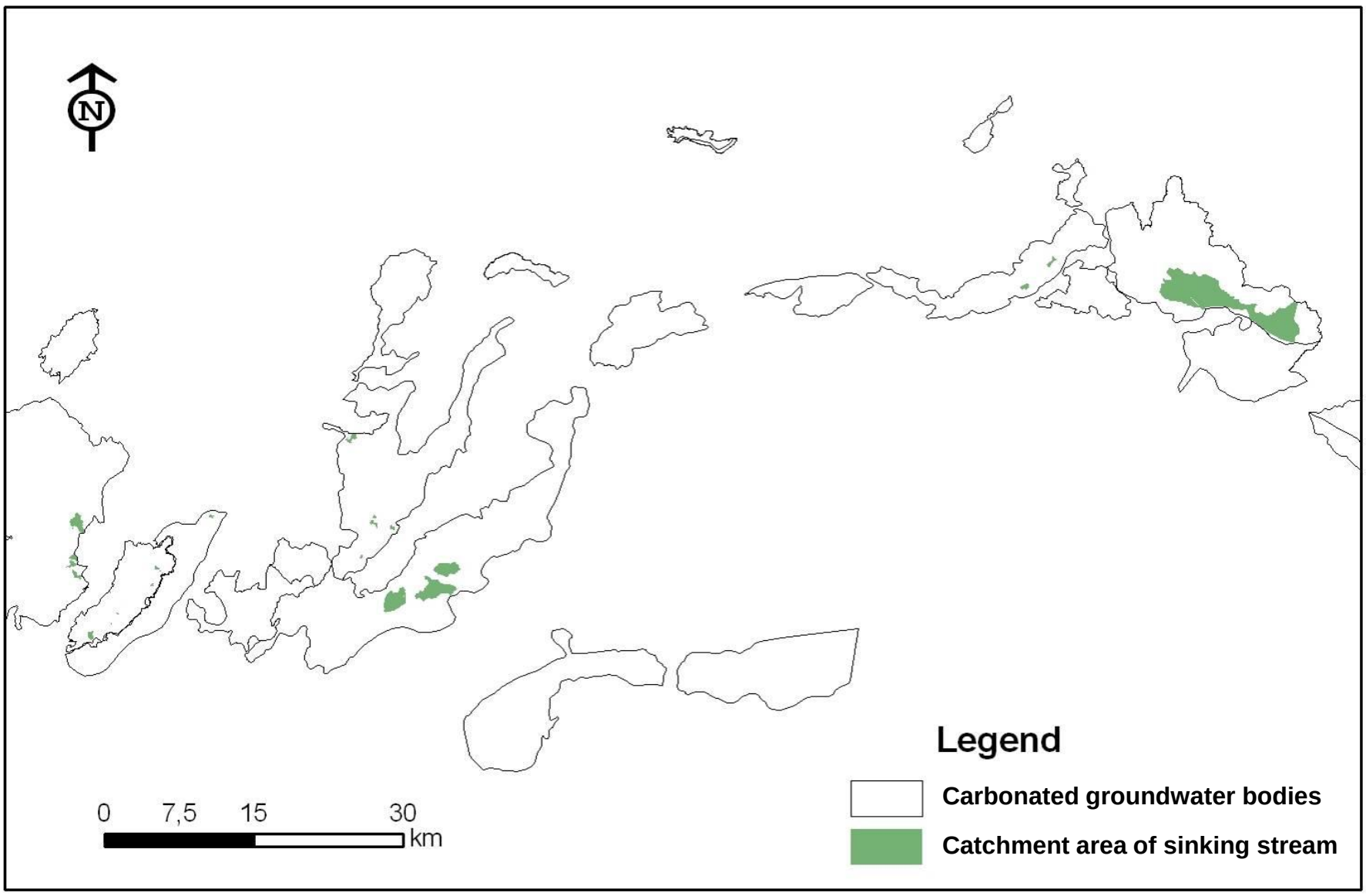
- Methodological procedure -



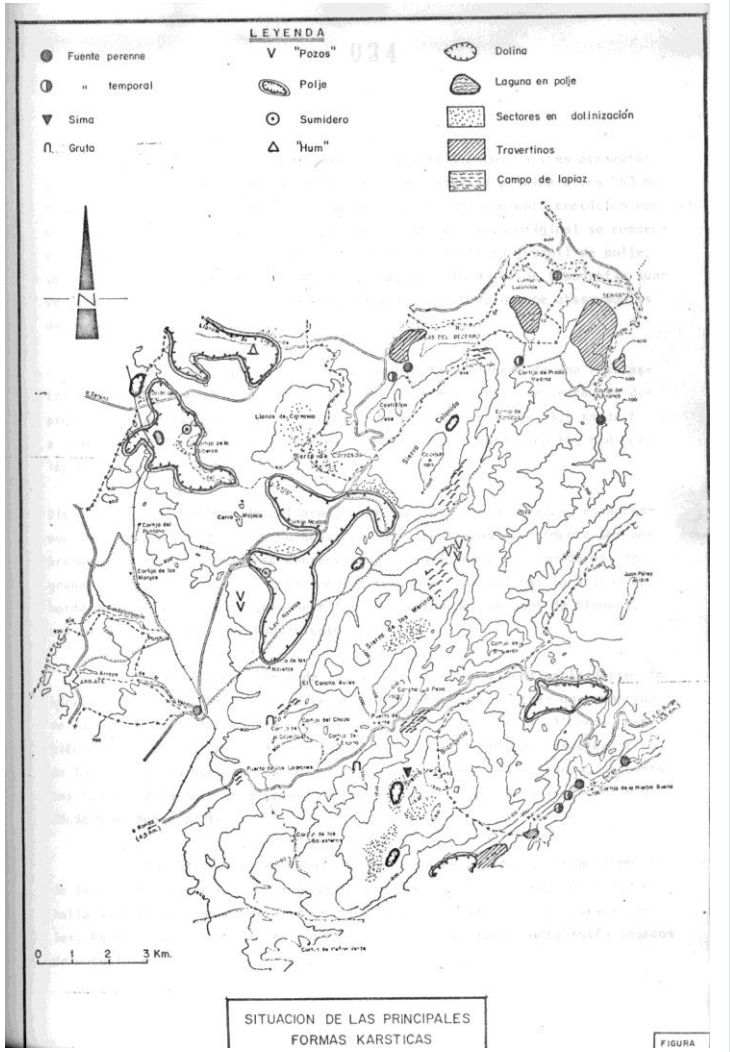


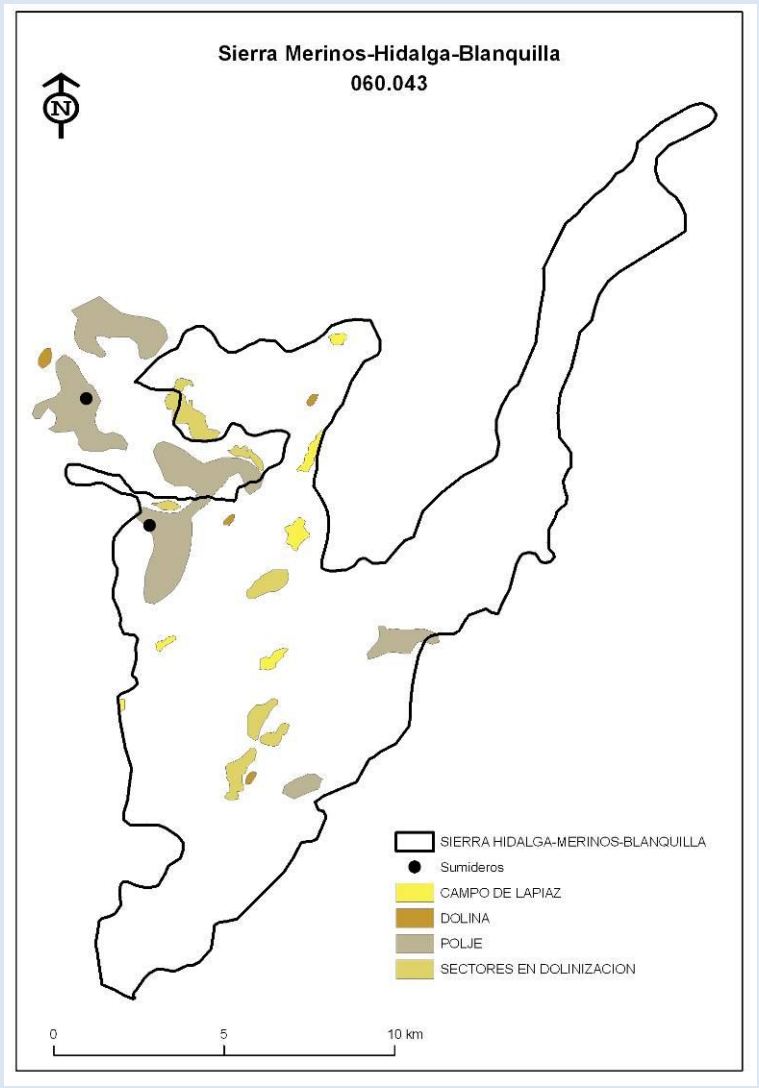
Key aspect: areas of concentrated infiltration

(Case example: Málaga province, S Spain)



Regional/local geomorphological maps (some unpublished)
Source for *I factor*





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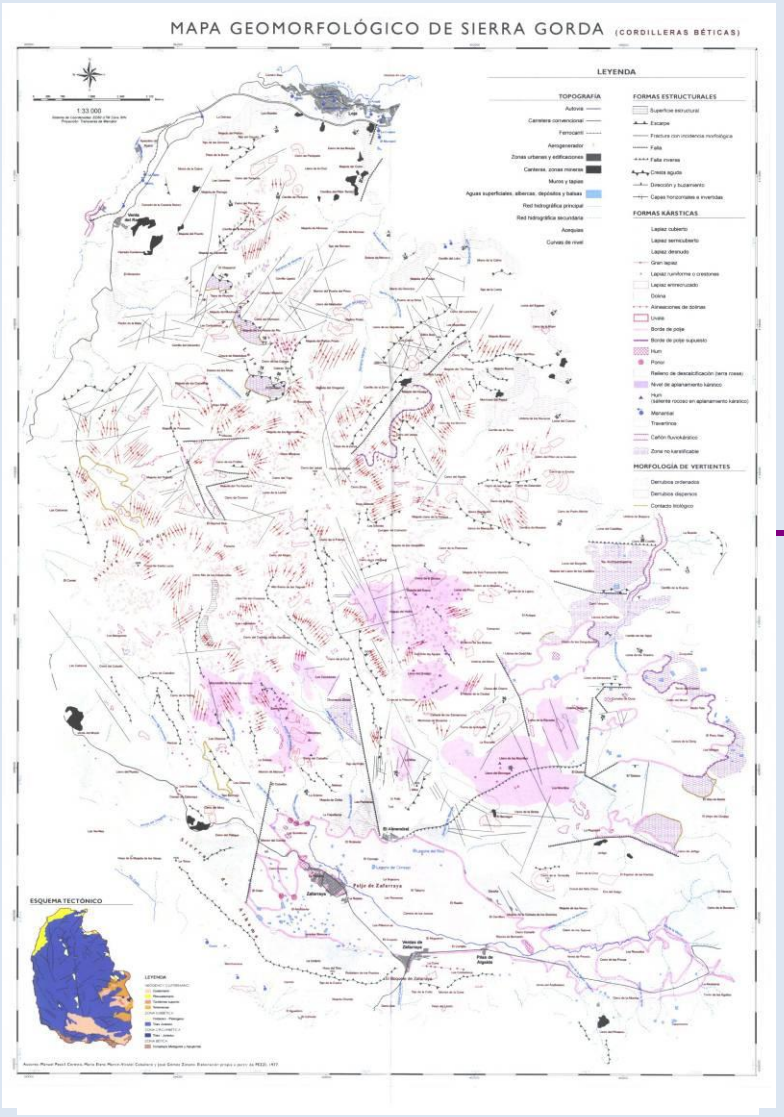

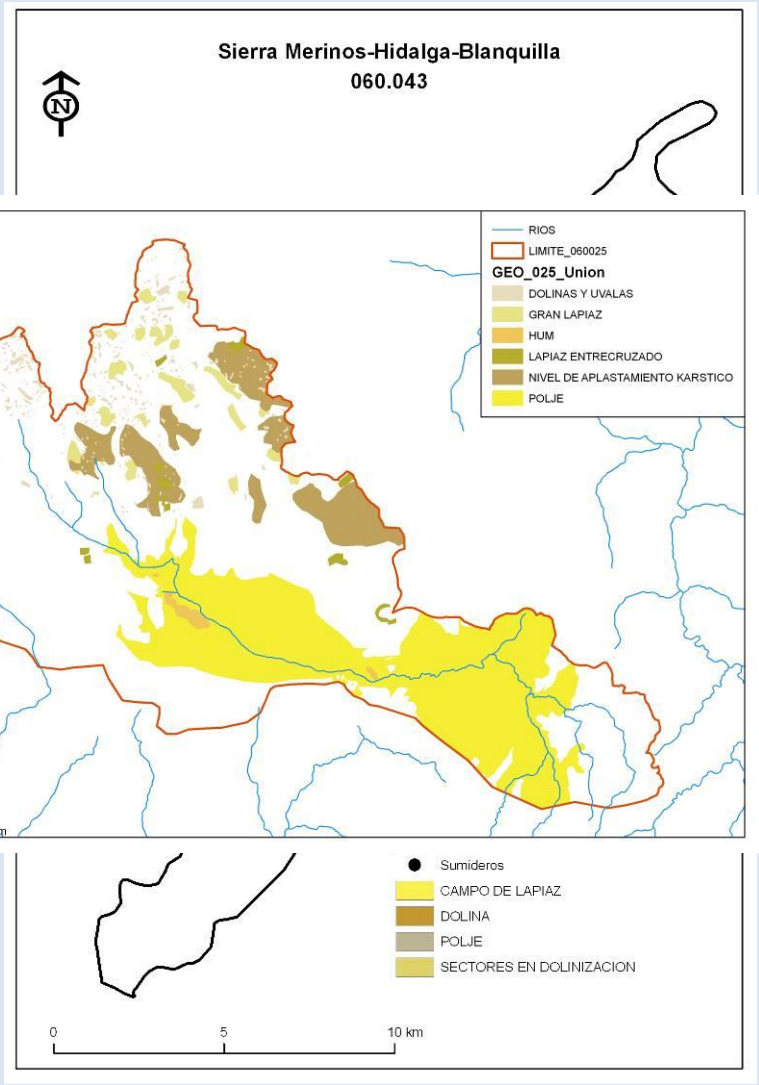

Regional/local geomorphological maps (some unpublished)

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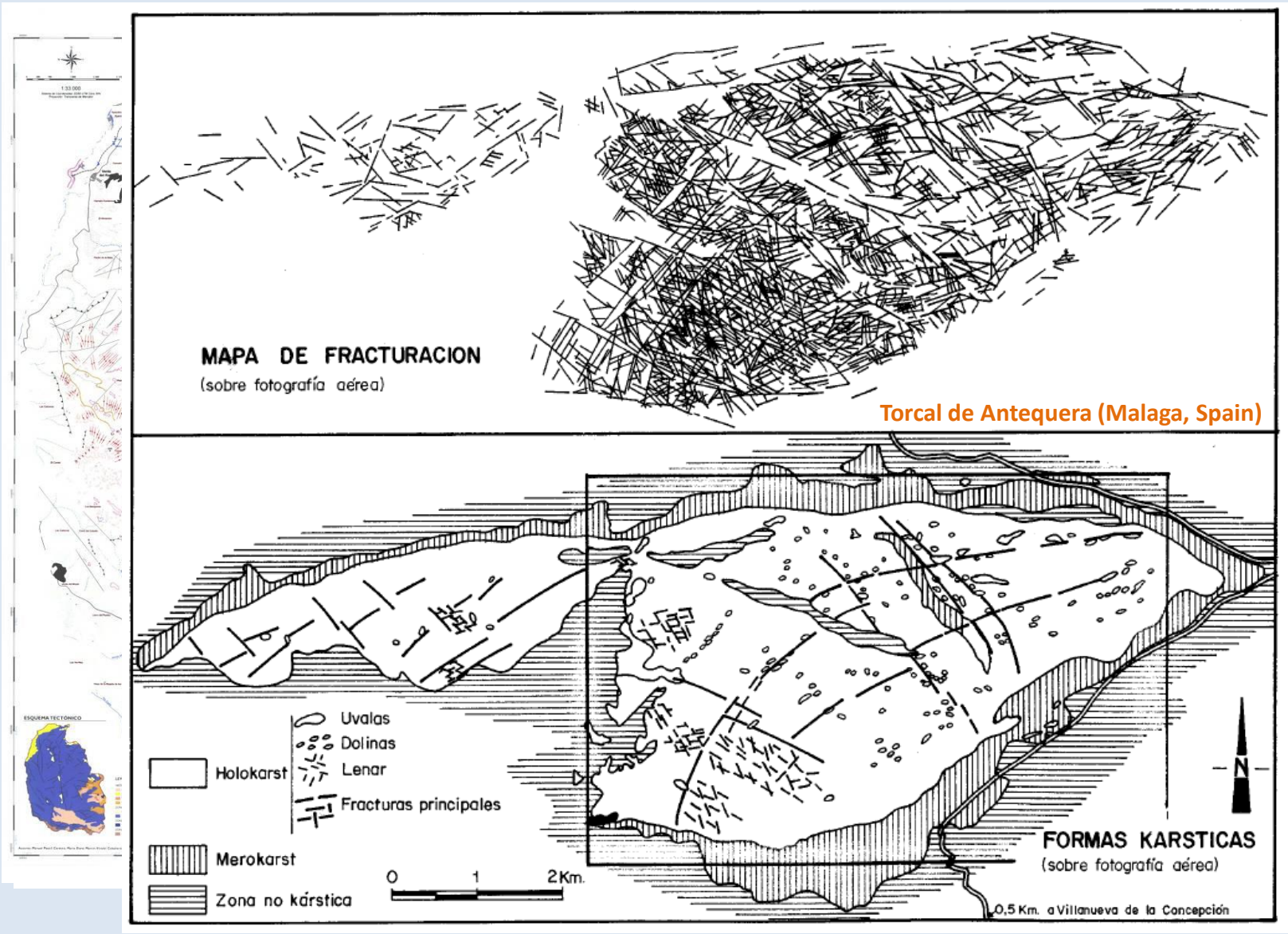


- Case example: Torcal de Antequera (Malaga, Spain) -

Methodological approach

Categorizing/rating the parameters → Overlaying layers → Running the recharge algorithm

Altitude (m) (A)	Rating
≤300	1
(300–600]	2
(600–900]	3
(900–1,200]	4
(1,200–1,500]	5
(1,500–1,800]	6
(1,800–2,100]	7
(2,100–2,400]	8
(2,400–2,700]	9
>2,700	10

Slope (%) (P)	Rating
≤ 3	10
(3 - 5]	9
(5 - 10]	8
(10 - 15]	7
(15 - 20]	6
(20 - 30]	5
(30 - 45]	4
(45 - 65]	3
(65 - 100]	2
> 100	1

Lithology (L)	Rating
Limestones and dolostones karstified	10 or 9
Limestones and dolostones fracturated, slighted karstified	8 or 7
Limestones and dolostones fissured	6 or 5
Gravels and sands	4
Conglomerates	3
Plutonic and metamorphic rocks	2
Shales, silts, clays	1

Infiltration landforms (I)	Rating
Abundant infiltration landforms	10
Moderate infiltration landforms	5
Scarce infiltration landforms	1

Soil (S)	Rating
Leptosols	10
Arenosols and xerosols	9
Calcareous regosols and fluvisols	6
Euthricregosols and solonchaks	7
Cambisols	6
Euthriccambisols	5
Histosolsandluvisols	4
Chromicluvisols	3
Planosols	2
Vertisols	1

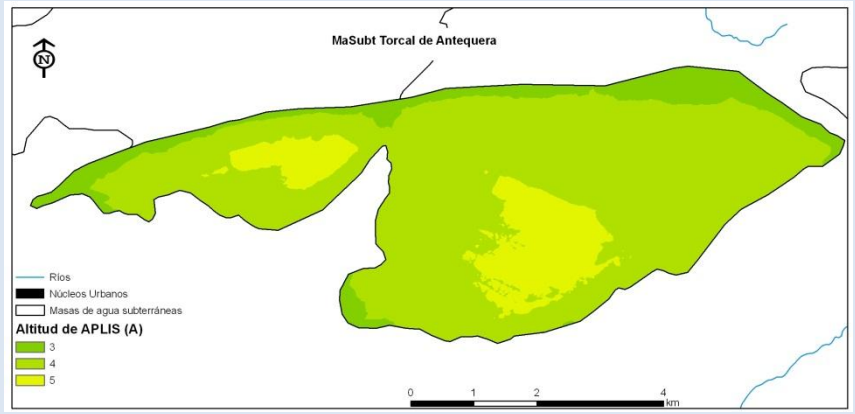
Correction factor (F_h)	Rating
Aquifer	1
Other	0.1

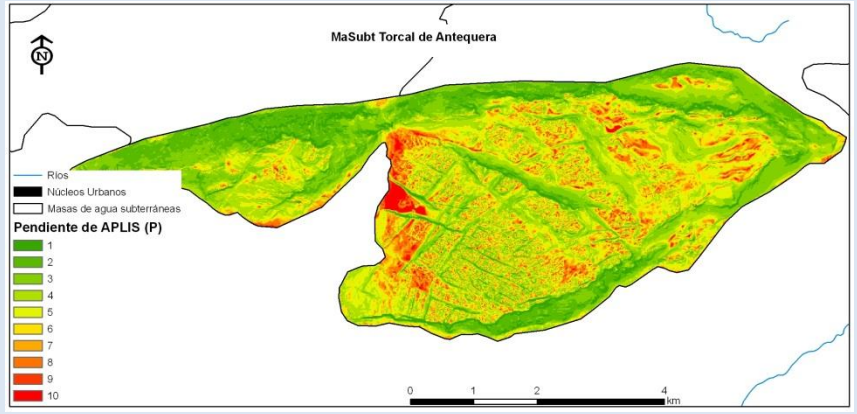
$$R = [(A + P + 3 \cdot L + 2 \cdot I + S) / 0.9]. F_h$$

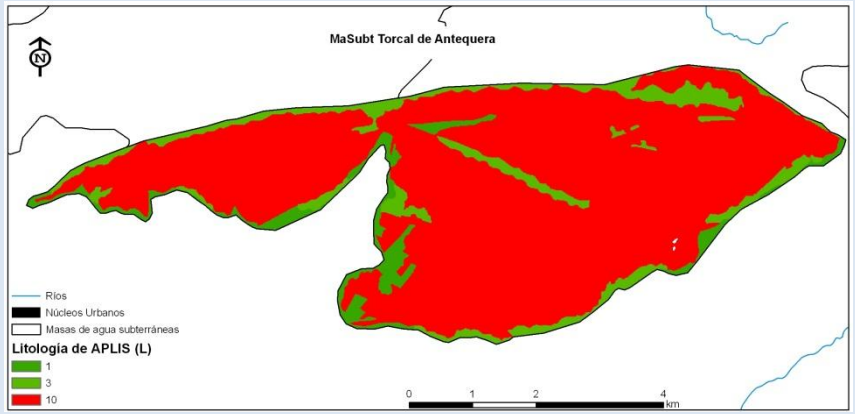
Recharge rate (% *)	Class
≤ 20	Very low
20 - 40	Low
40 - 60	Moderate
60 - 80	High
> 80	Very high

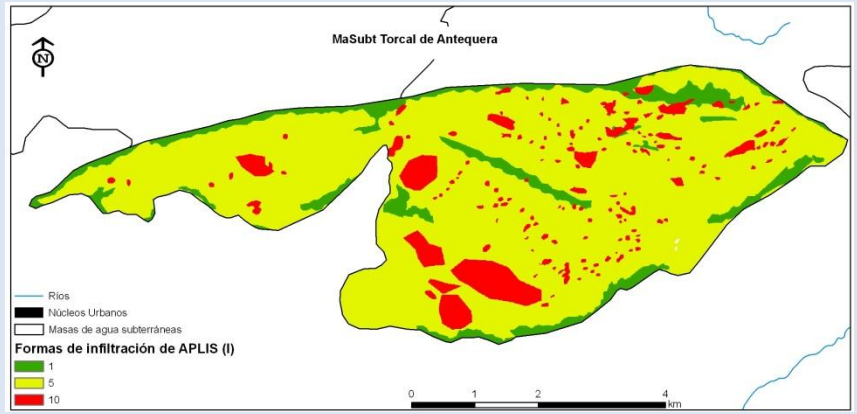
(*) In % of the annual mean rain

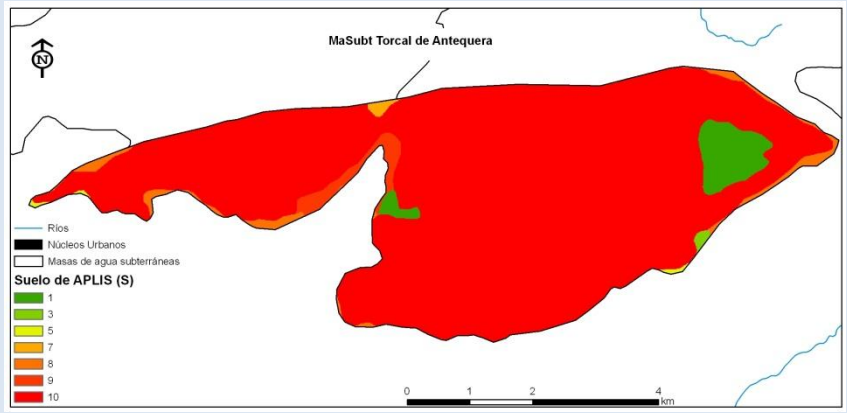
- Case example: Torcal de Antequera -

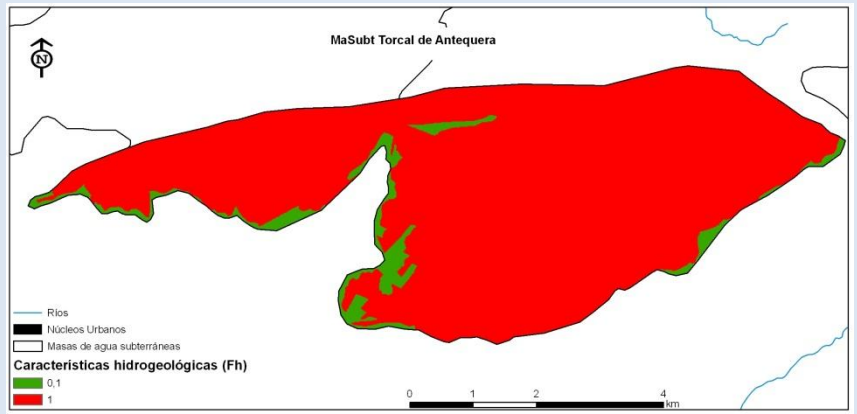


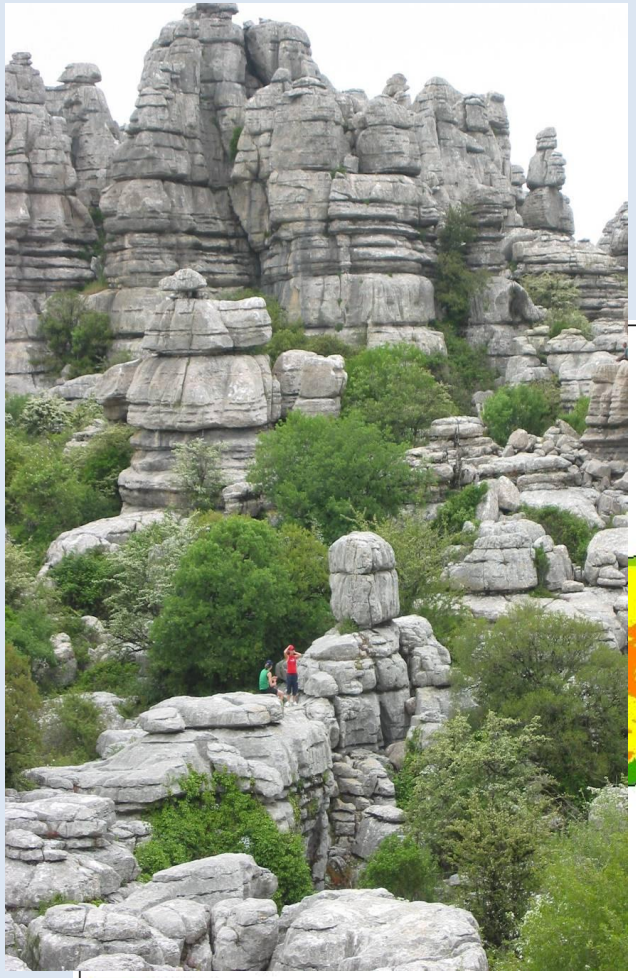








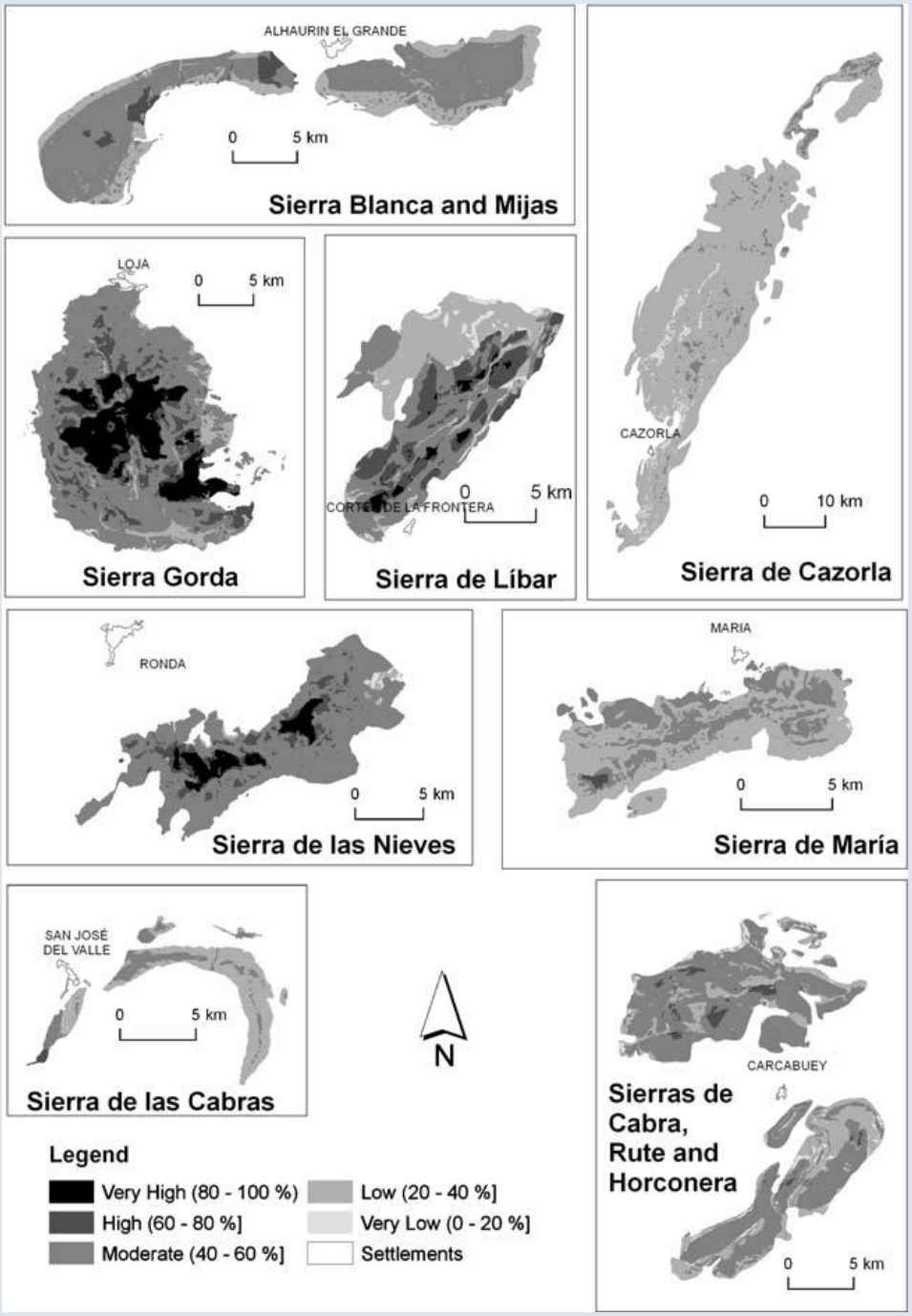


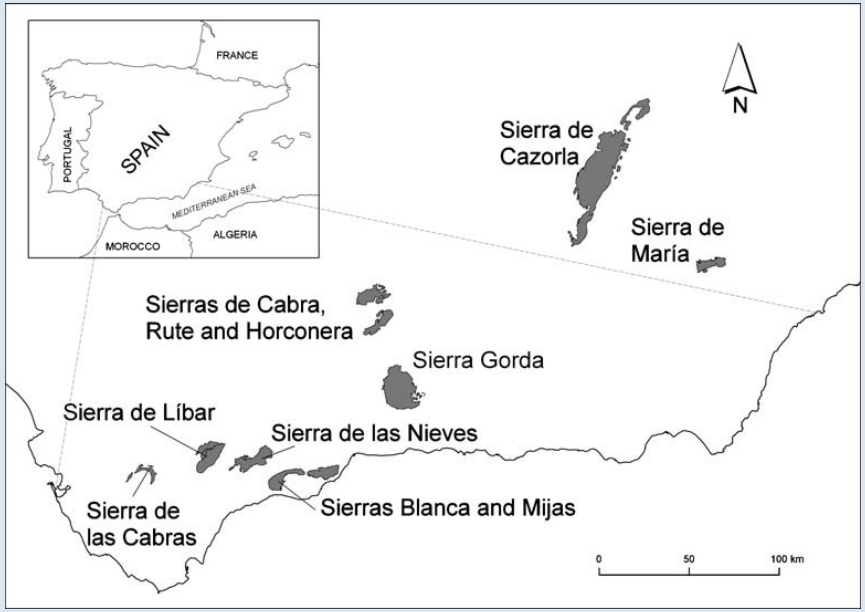


Torcal de Antequera

Spatial distribution of the recharge rate

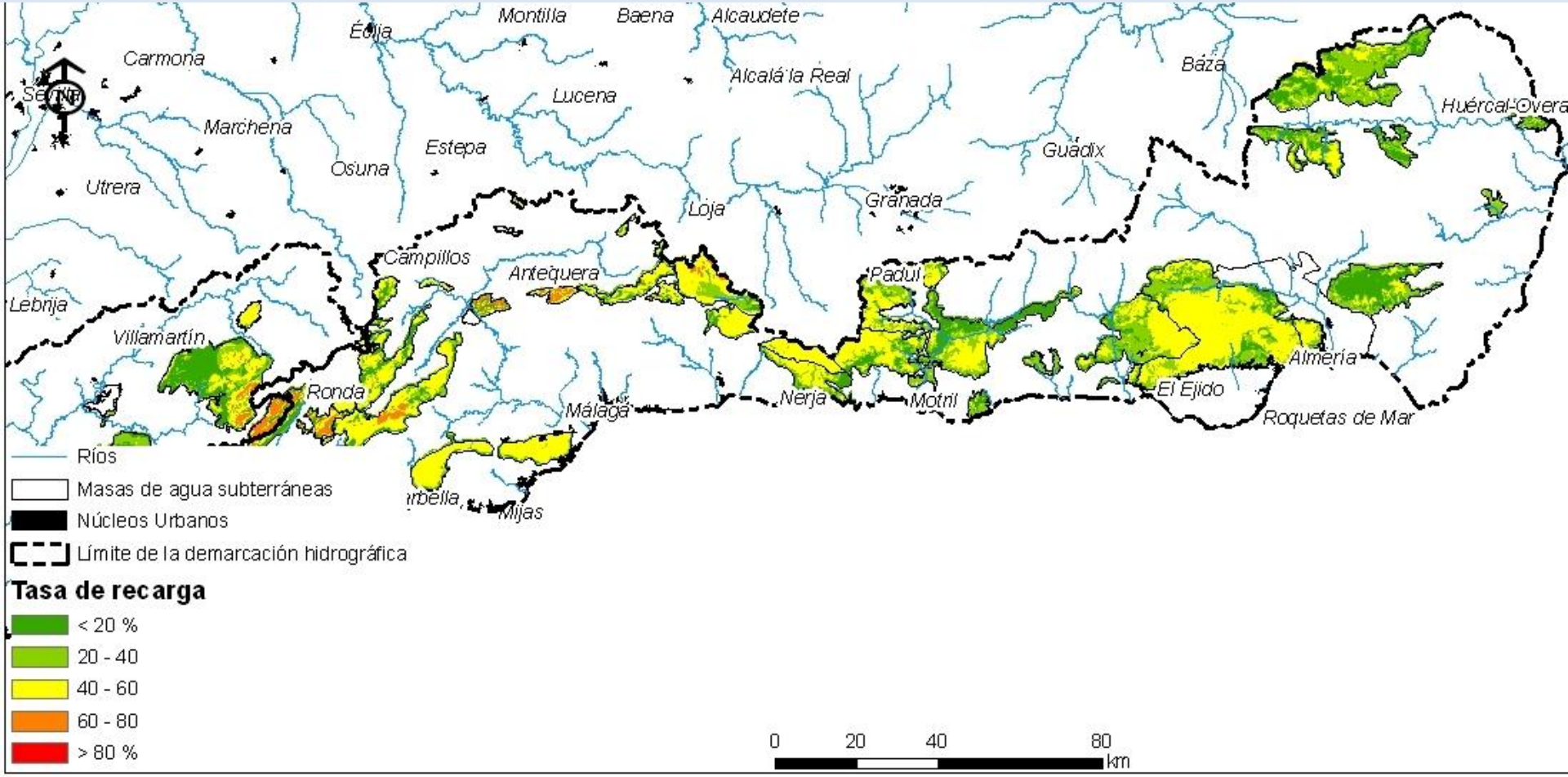
- Recharge maps obtained by APLIS method -



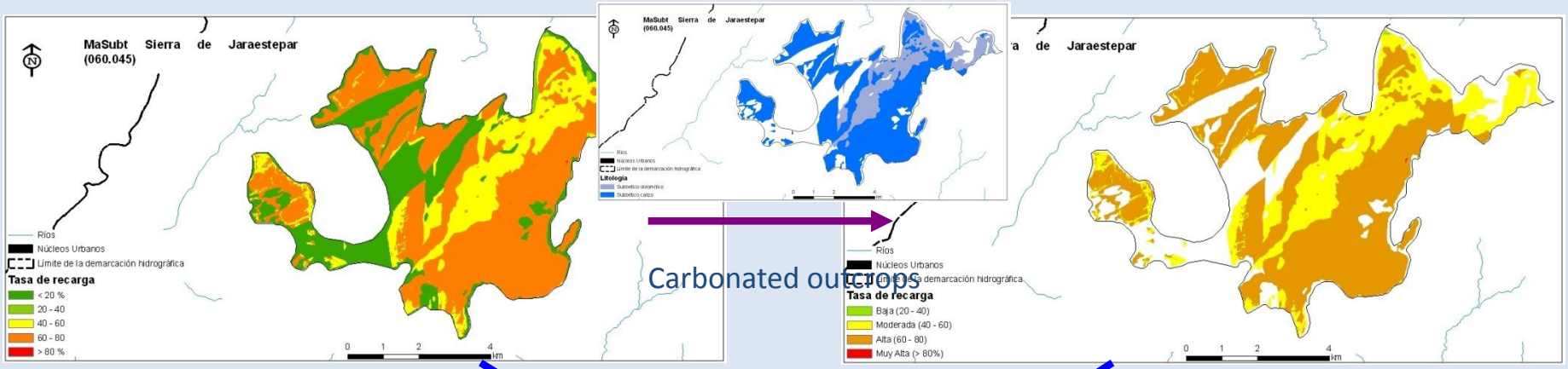


Recharge maps of Carbonate Groundwater Bodies in S Spain

(Andalusian Water Agency)

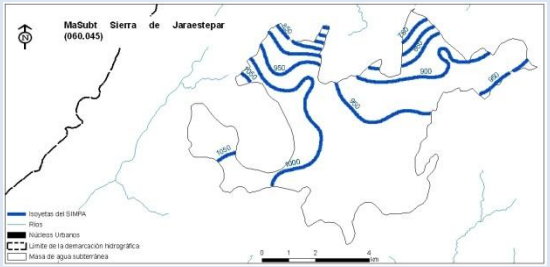


- Groundwater resource assessment by APLIS method-



Recharge map

Precipitation (isohyets)



Annual average resources

Average resources on carbonated outcrops

SIG software

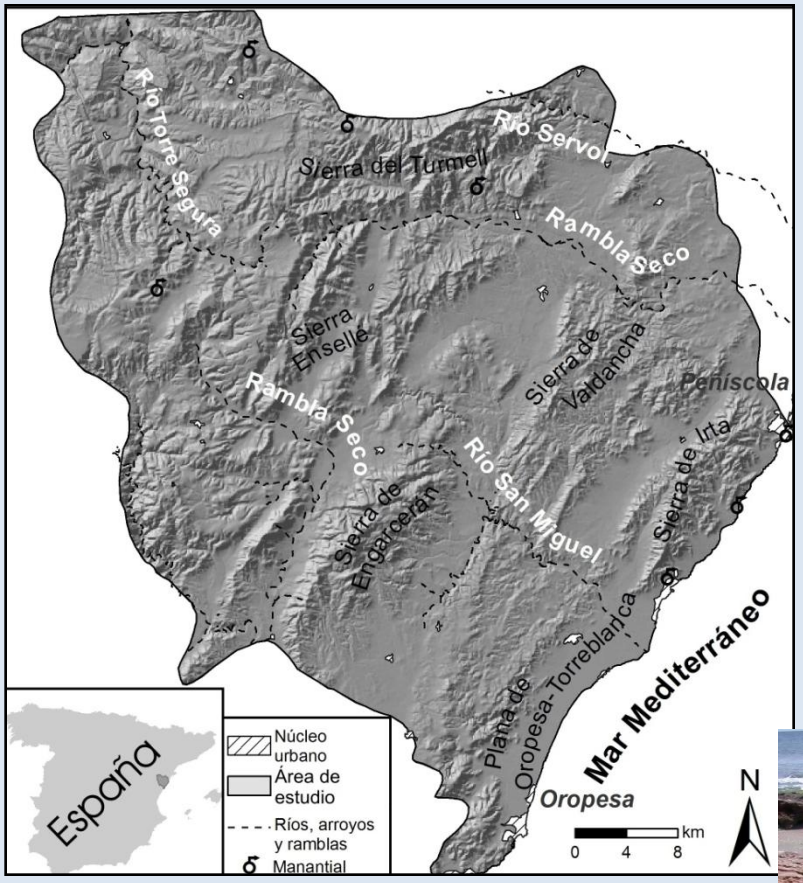
19,13 hm^3/y

18,74 hm^3/y

- Resource assessment by APLIS method-

			Aquifer	
Code	Name	Precipitation (mm/y)	Recharge rate (%)	Resources (hm3/y)
060,002	SIERRA DE LAS ESTANCIAS	354	28,48	38,2
060,007	BÉDAR-ALCORNIA	353	33,09	2,3
060,012	MEDIO-BAJO ANDARAX	230	35,95	4,5
060,013	CAMPO DE DALÍAS-SIERRA DE GÁDOR	379	37,48	100,6
060,014	OESTE DE SIERRA DE GÁDOR	392	35,59	38,7
060,015	DELTA DEL ADRA	333	33,99	1,8
060,016	ALBUÑOL	483	25,48	3,2
060,017	SIERRA DE PADUL SUR	538	38,28	8,9
060,018	LANJARÓN-SIERRA DE LÚJAR-MEDIO GUADALFEO	542	24,12	33,7
060,019	SIERRA DE ESCALATE	442	33,88	3,1
060,020	CARCHUNA-CASTELL DE FERRO	507	24,23	3,2
060,024	SIERRA ALMIJARA	631	42,88	19,0
060,025	SIERRA GORDA-ZAFARRAYA	772	44,17	53,2
060,028	SIERRA DE GIBALTO-ARROYO MARÍN	787	34,01	2,0
060,029	SIERRA DE ENMEDIO-LOS TAJOS	727	38,01	7,7
060,030	SIERRA DE ARCHIDONA	589	40,08	1,8
060,031	SIERRA DE LAS CABRAS-CAMAROLOS-SAN JORGE	673	39,25	18,8
060,032	TORCAL DE ANTEQUERA	641	58,88	10,8
060,033	LLANOS DE ANTEQUERA-VEGA DE ARCHIDONA	416	49,45	0,4
060,034	FUENTE DE PIEDRA	477	47,14	1,2
060,035	SIERRAS DE TEBA-ALMARGEN-CAMPILLOS	459	45,24	2,2
060,036	SIERRA DEL VALLE DE ABDALAJÍS	465	43,25	8,0
060,038	SIERRA DE MIJAS	658	40,33	25,7
060,041	SIERRA DE CAÑETE SUR	588	34,13	8,1
060,043	SIERRA HIDALGA-MERINOS-BLANQUILLA	717	42,47	44,5
060,044	SIERRA DE LÍBAR	1044	37,20	22,8
060,045	SIERRA DE JARASTEPAR	960	45,18	19,1
060,046	SIERRA DE LAS NIEVES-PRIETA	846	55,00	77,0
060,048	DOLOMÍAS DE RONDA	810	43,80	6,5
060,050	SIERRA DE LOS FILABRES	362	27,55	12,9
060,051	MACAEL	404	18,54	3,9
060,052	SIERRA DE ALMAGRO	270	23,70	2,5
060,055	SIERRA ALHAMILLA	203	19,25	8,7
060,061	SIERRA DE ALBUÑUELAS	547	37,39	30,7
060,062	SIERRA DE LAS GUÁJARAS	592	34,98	37,7
060,063	SIERRA ALBERQUILLAS	541	32,18	20,2
060,064	SIERRA TEJEDA	762	38,05	19,3
060,067	SIERRA BLANCA	786	40,19	31,9
062,002	SIERRA DE LIBAR	1313	56,85	36,8
062,003	SIERRA DE LIJAR	670	43,69	7,1
062,004	SIERRA DE GRAZALEMA - PRADO DEL REY	1050	26,45	111,9
062,006	SIERRA VALLEJA	636	41,45	1,6
062,007	SIERRA DE LAS CABRAS	843	28,56	15,6

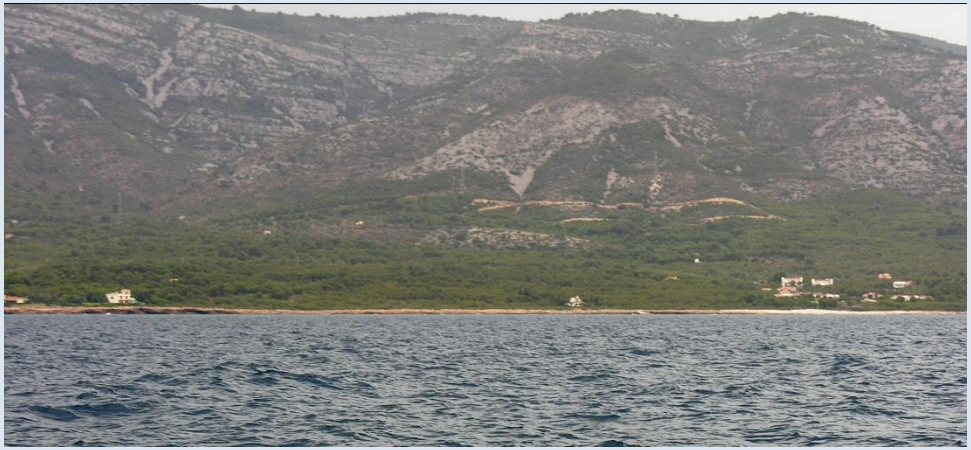
MAESTRAZGO AQUIFER SYSTEM



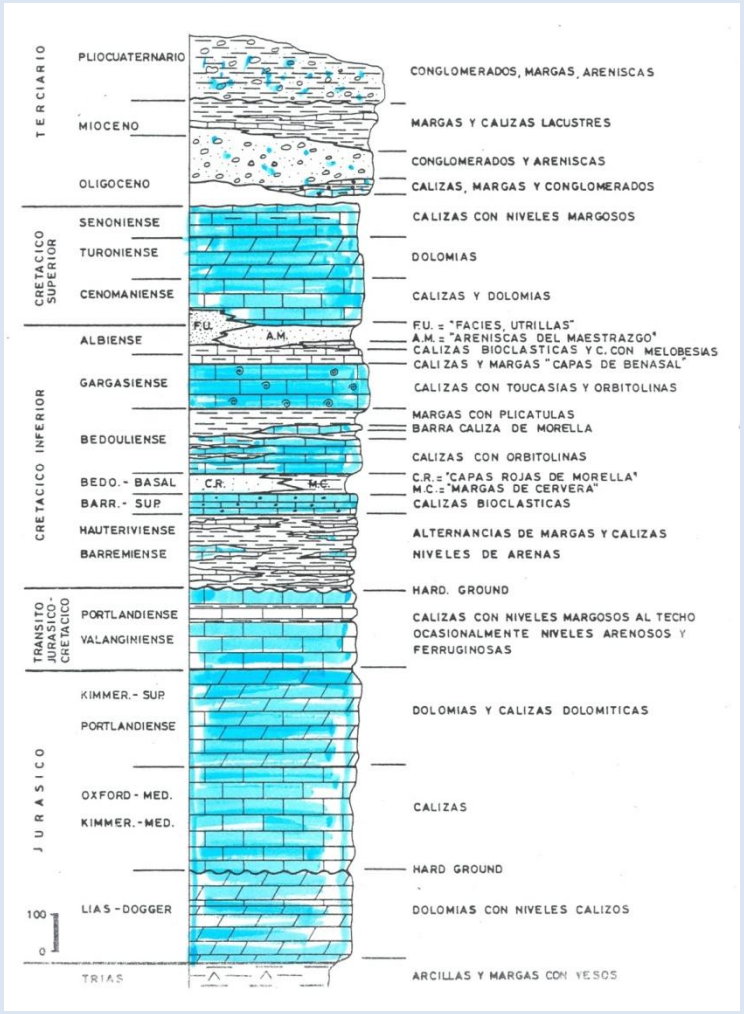
Surface : 2.400 km^2

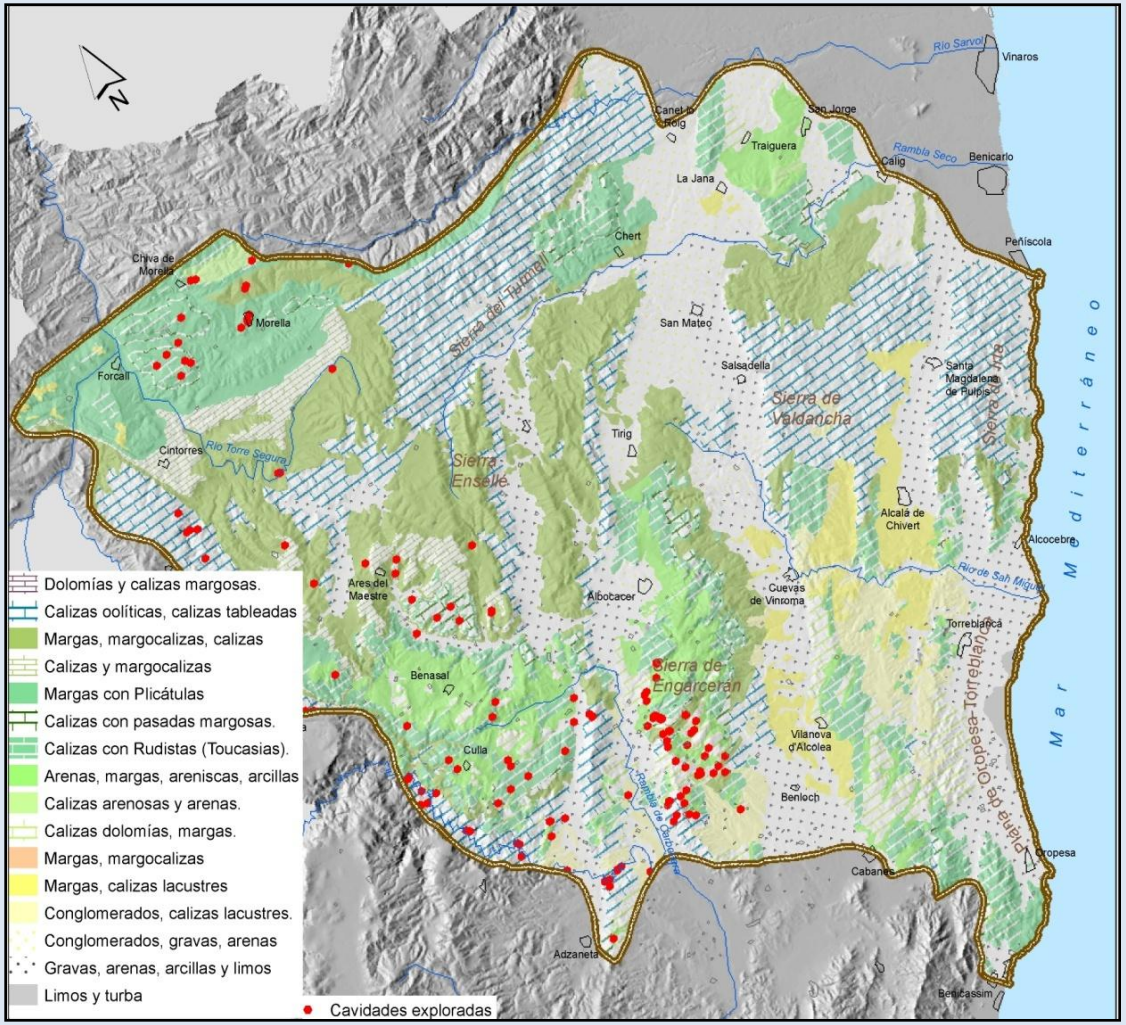
Sierras (*mountains*) del Turmell, Valdancha, Engarcerán, Irta y Ensellé

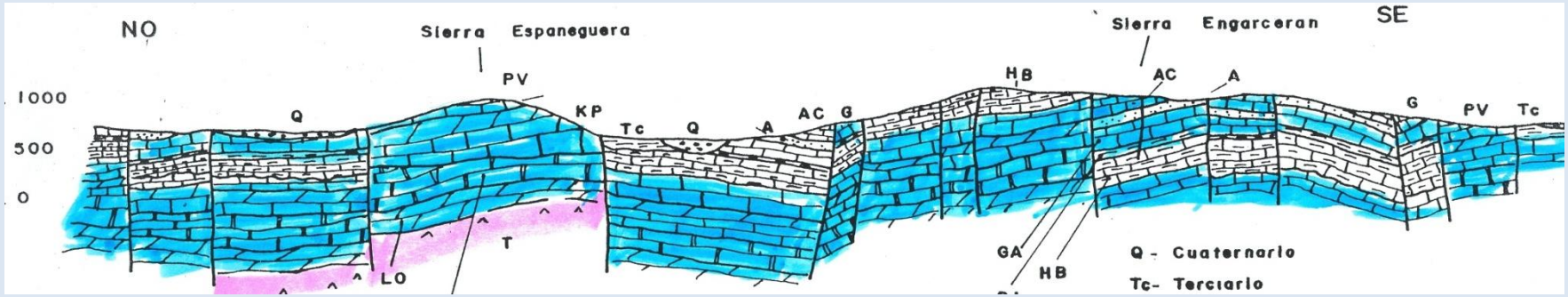
Rainfall: 620 mm / year



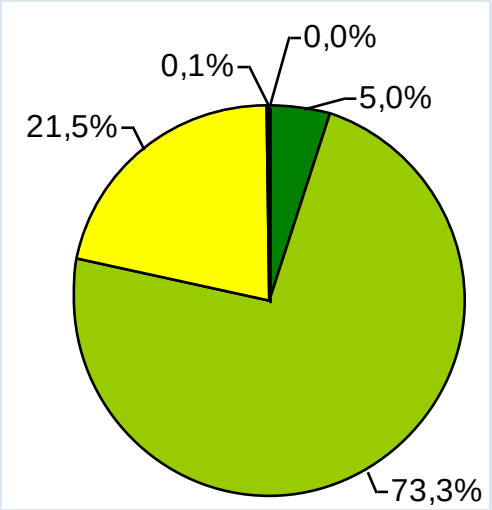
Characteristics of the test site

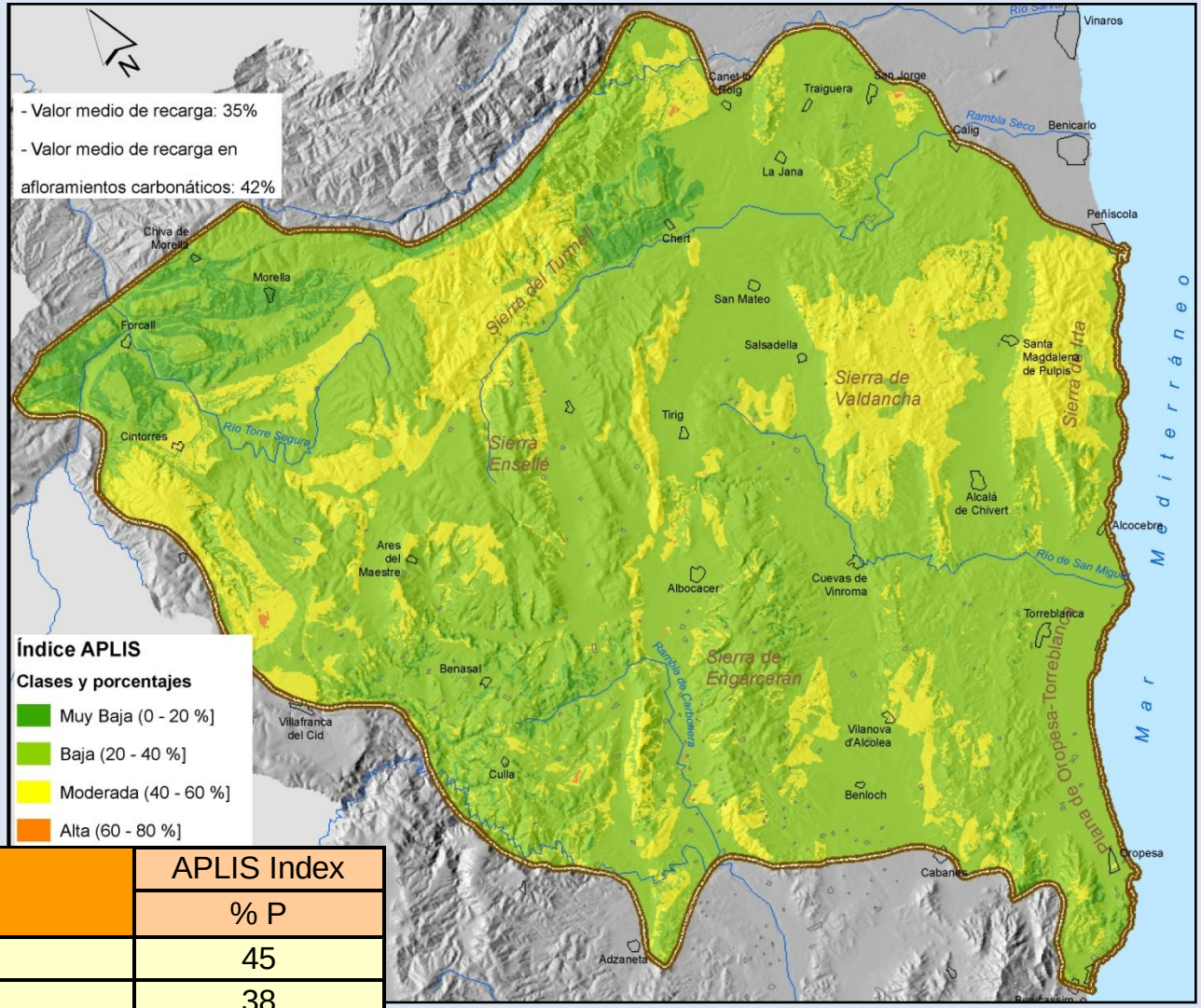






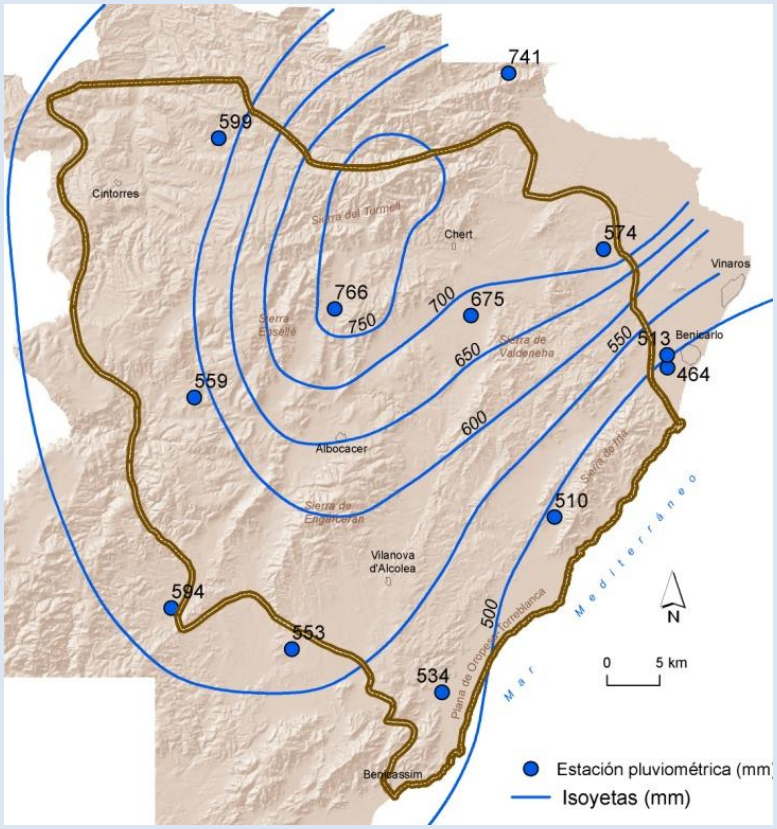
APLIS index

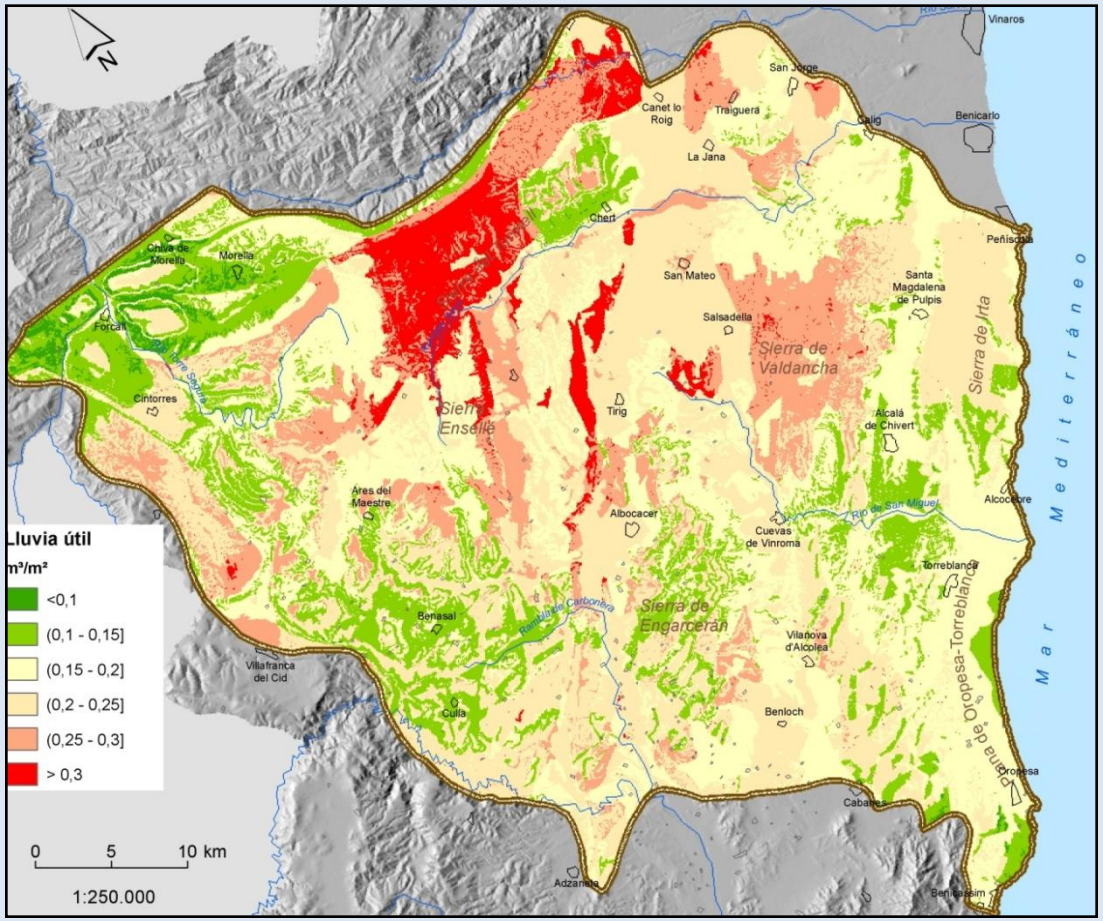




Outcrops	APLIS Index
	% P
Jurassic carbonate Aquifer	45
Cretaceous carbonate Aquifer	38
Neogene-quaternary sediments Aquifer	32
Low permeability materials	24
Total area	32

Estimation of water resources in El Maestrazgo aquifer





	Surface	Rainfall (P)		APLIS Index	Resources
	km²	mm	hm³/year	% P	hm³/year
Jurassic carbonate aquifer	502	627	315	45	142
Cretaceous carbonate aquifer	395	600	237	38	91
Neogene-quaternary sediments aquifer	381	580	221	32	71

DIKTAS Project (Dinaric Karst Transboundary Aquifer). Supported by NU, UNESCO and Governments of Balkans

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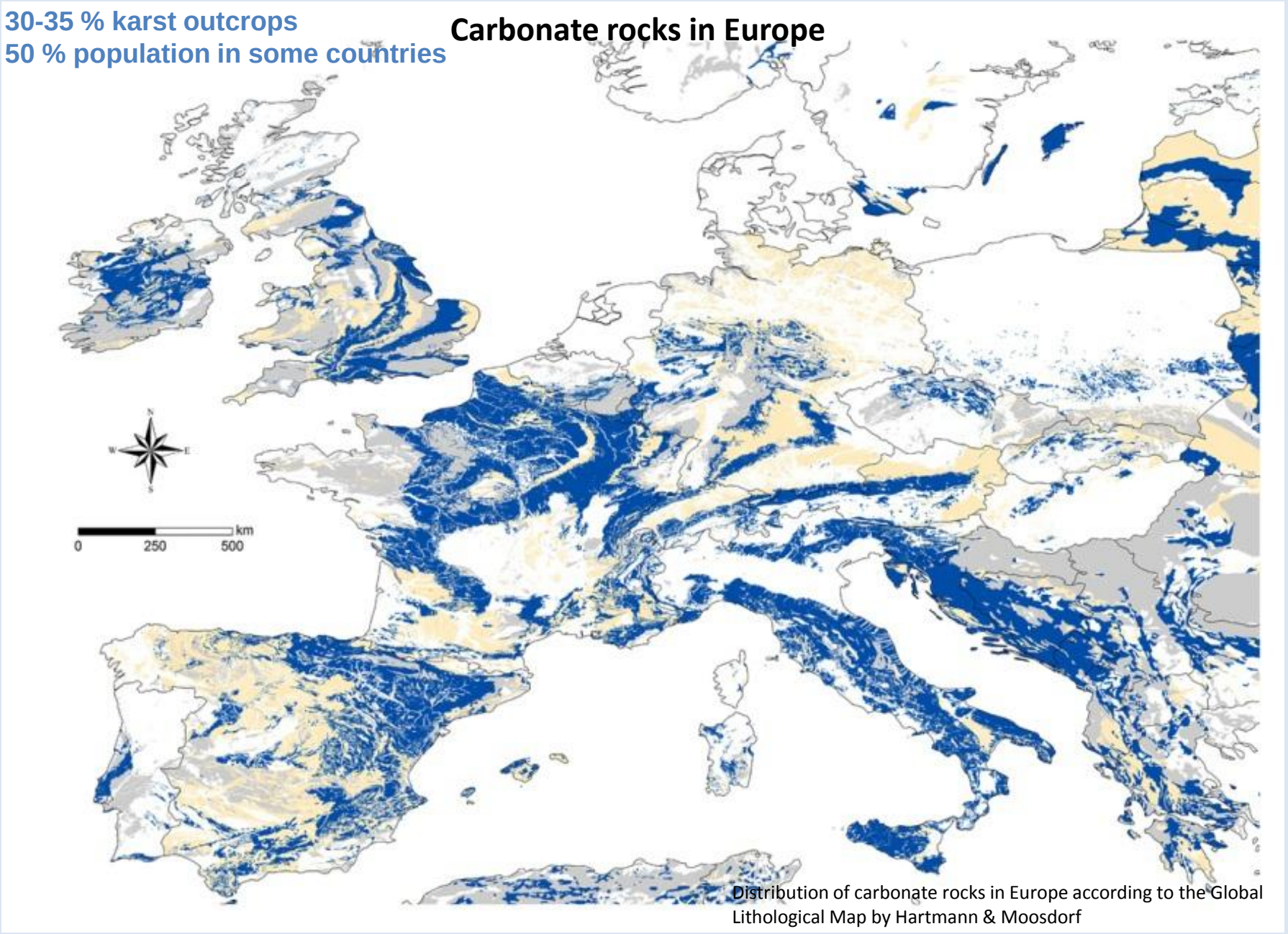
Ombla spring (Croatia)

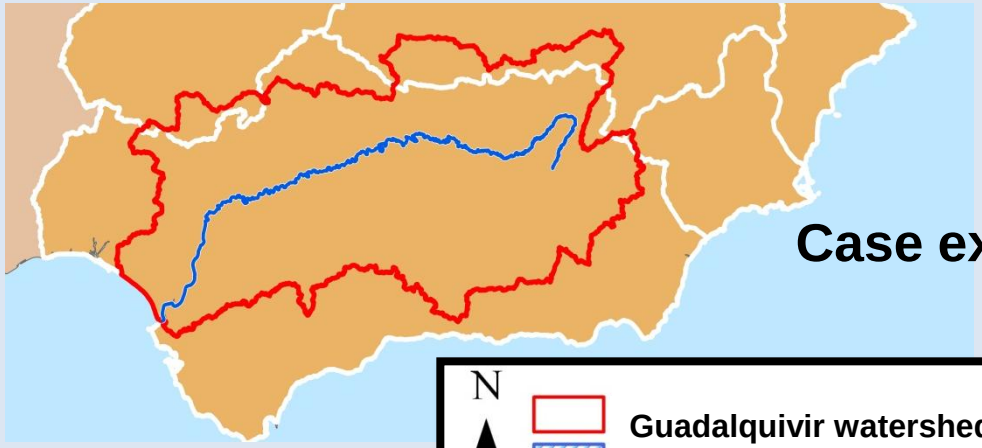
- Potential use of APLIS method -

30-35 % karst outcrops
50 % population in some countries

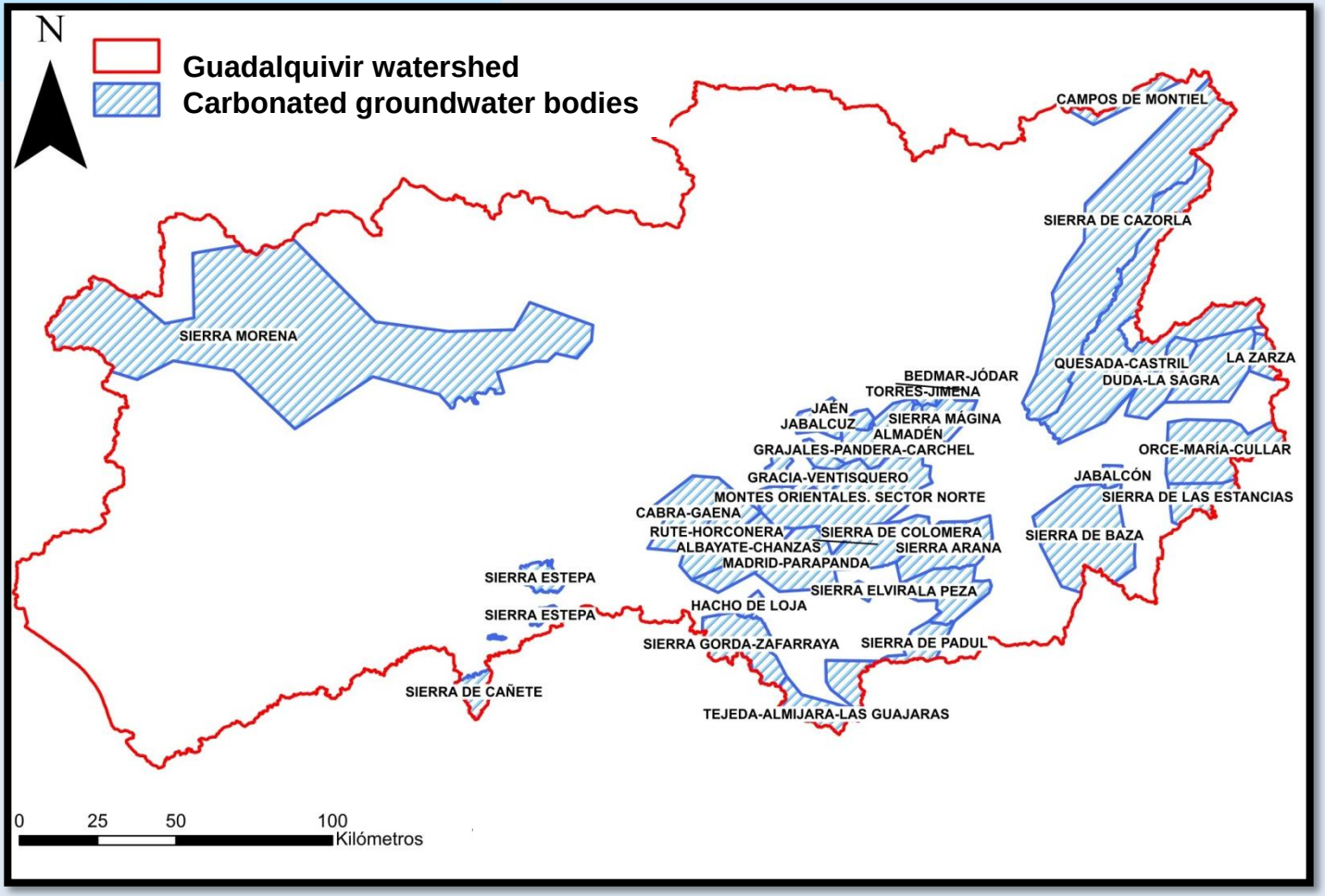


Distribution of carbonate rocks in Europe according to the Global Lithological Map by Hartmann & Moosdorf

- Potential use of APLIS method in Europe-

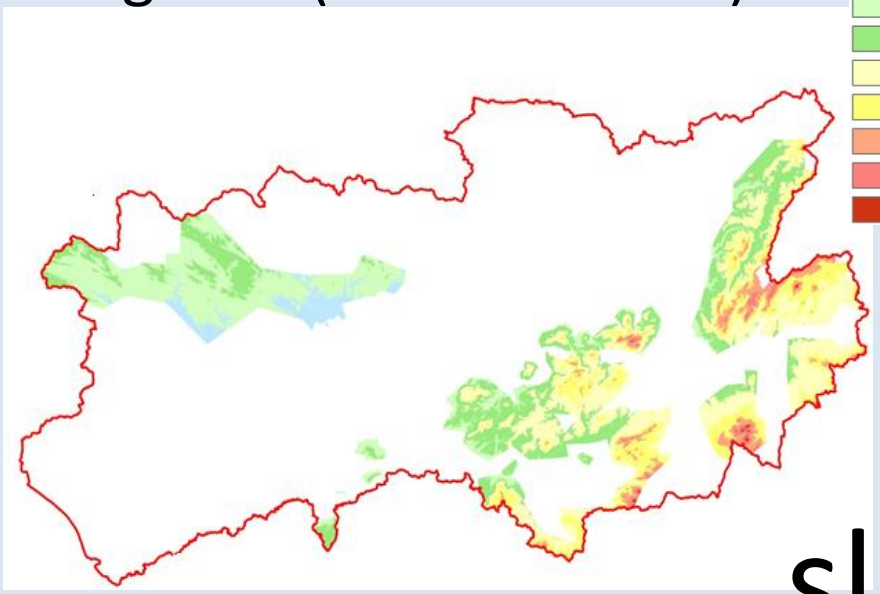


Case example in Guadalquivir River Basin

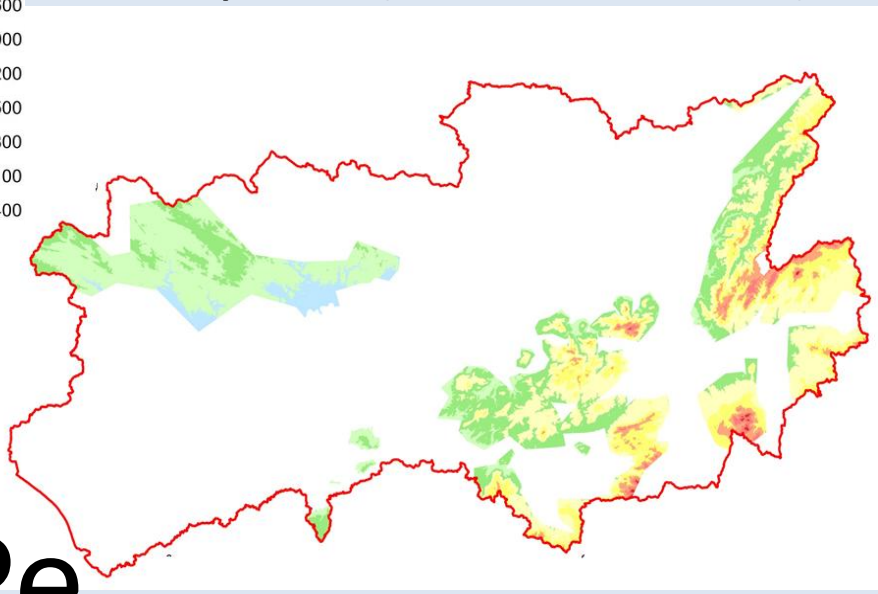


Altitude

Regional (DME 10X10 m)



European (DME 25X25 m)



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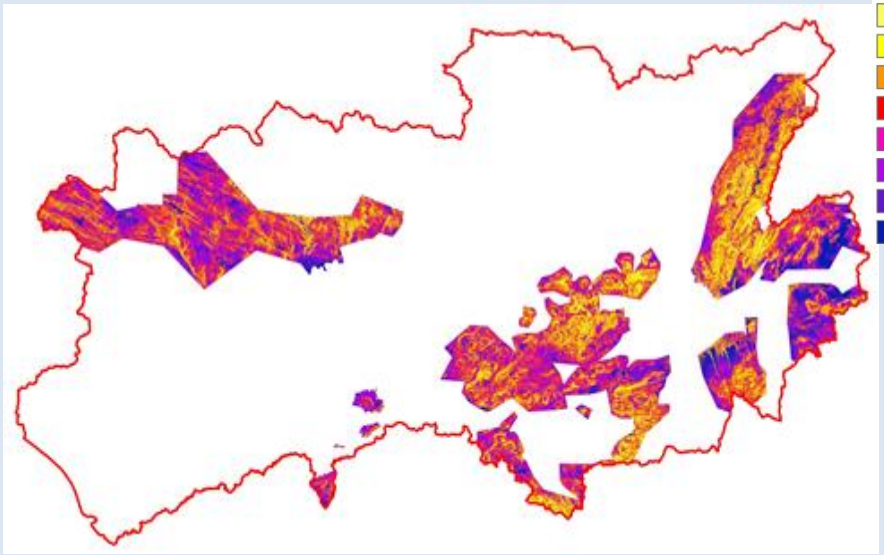
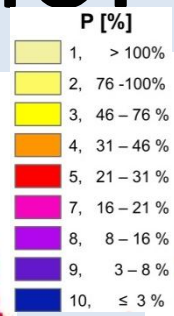
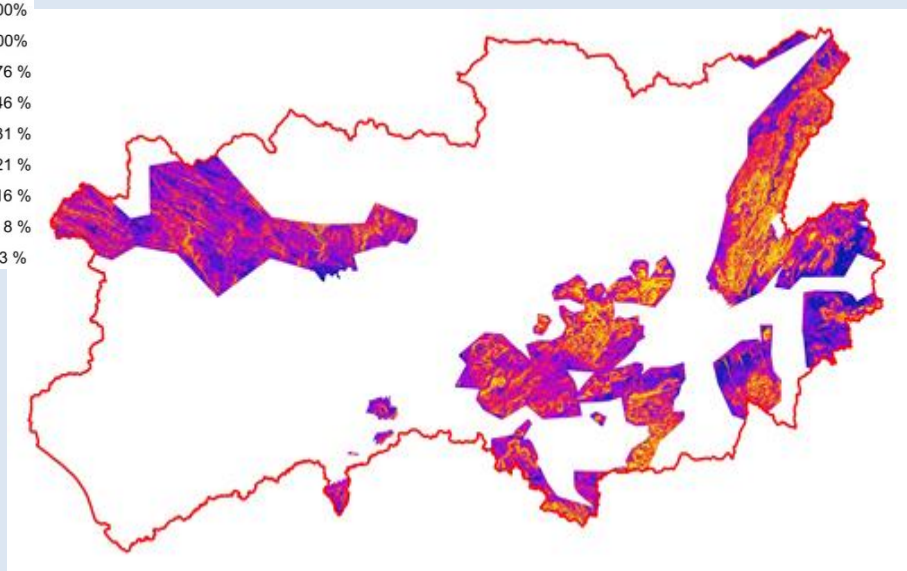
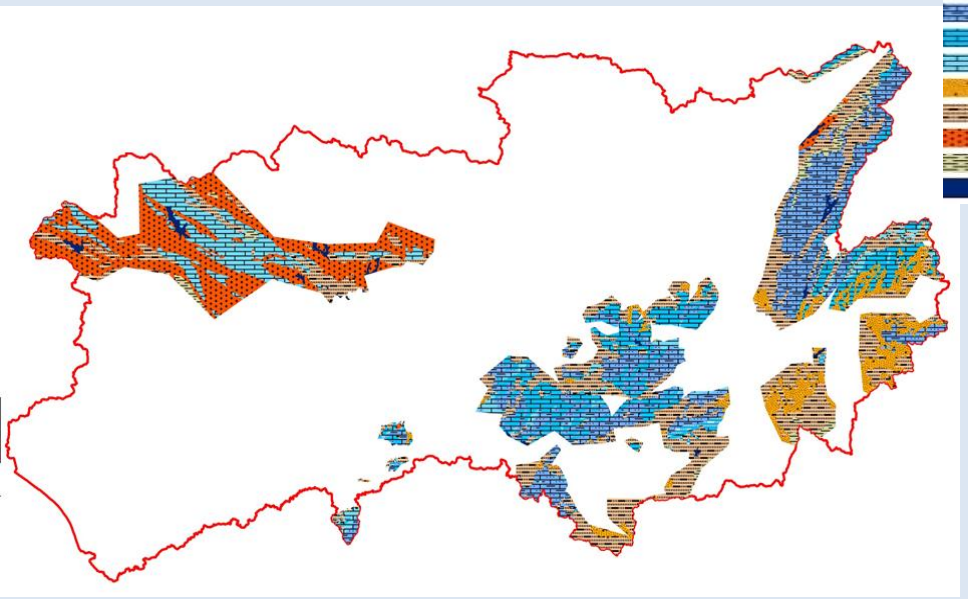




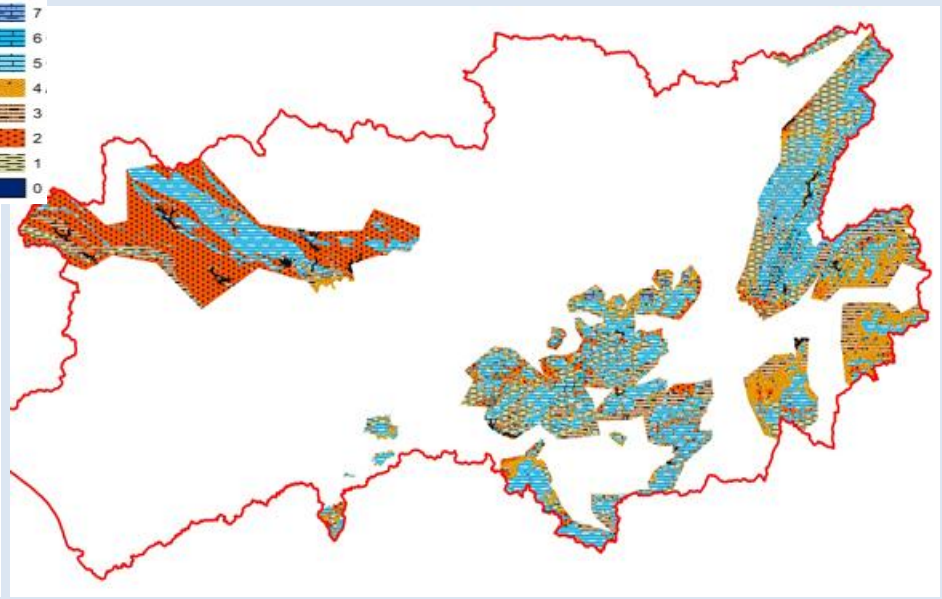


Lithology

Regional
(Geological map of Spain, 1:50.000)

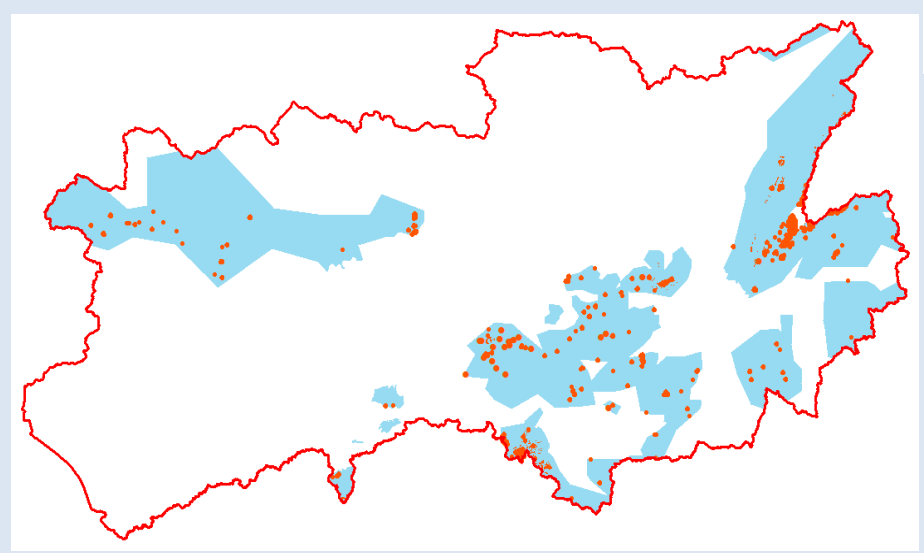


European
(OneGeology)

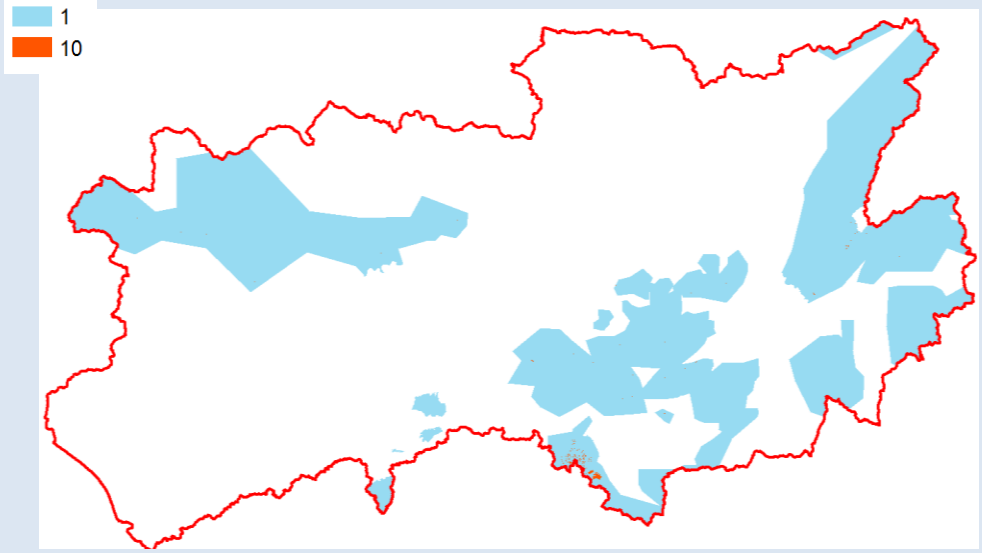


Infiltration

Regional maps
(1: 25 000)



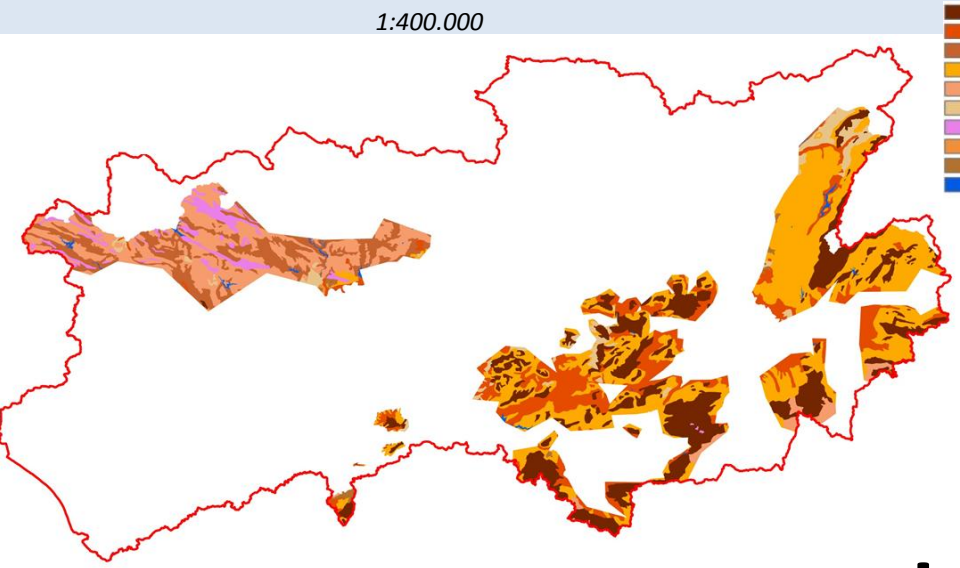
Map of Spanish karst
(1: 1 000 000)

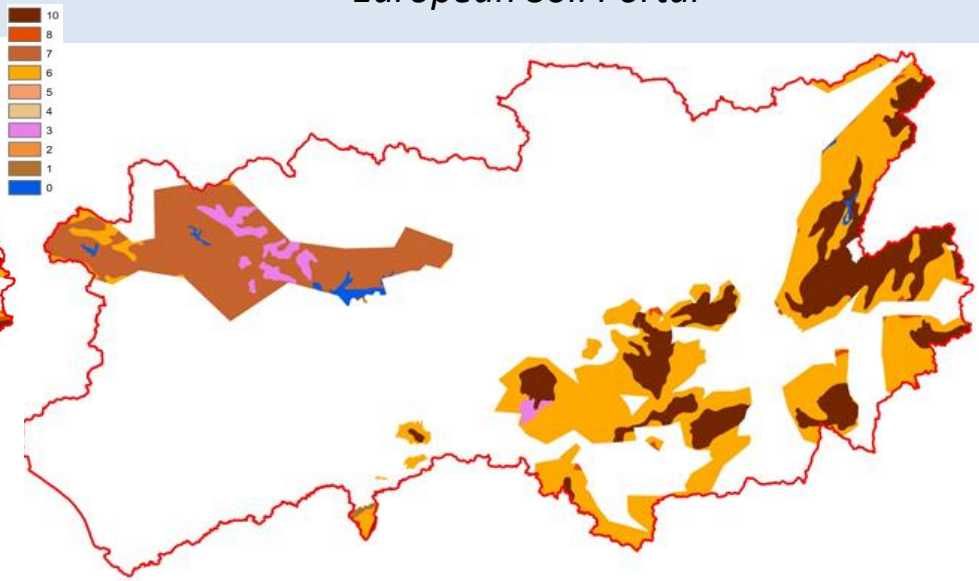


Soil

Regional *(Andalusian soil map)*

1:400.000

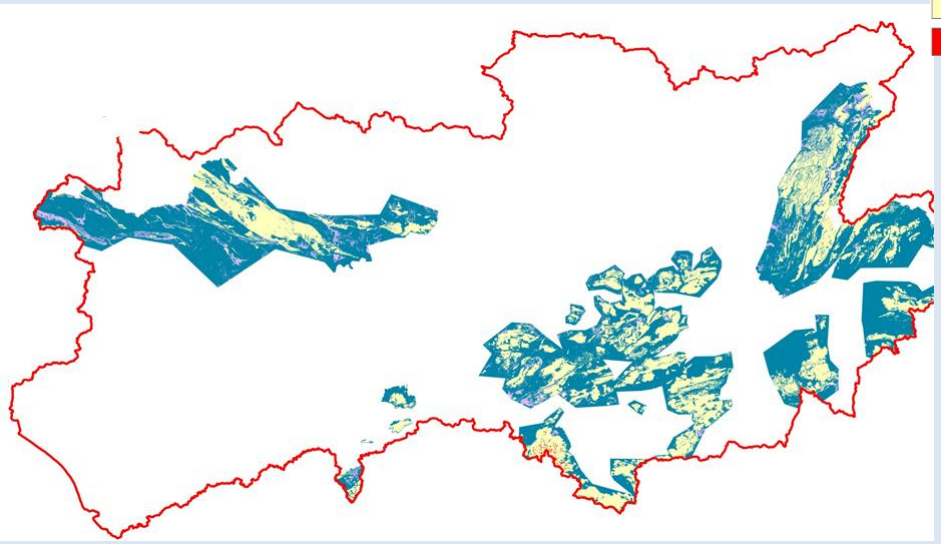




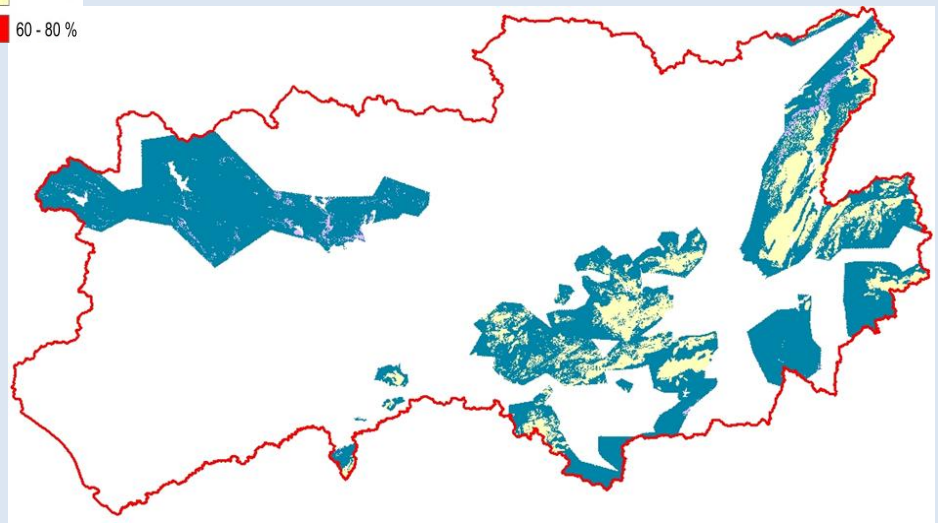
European *(Joint Research Center)*
European Soil Portal

Recharge

Regional



European



- Potential use of APLIS method in non European countries -

Hydrogeological Research in Haitises karst aquifer (Dominican Republic). Project founded by International Atomic Energy Agency

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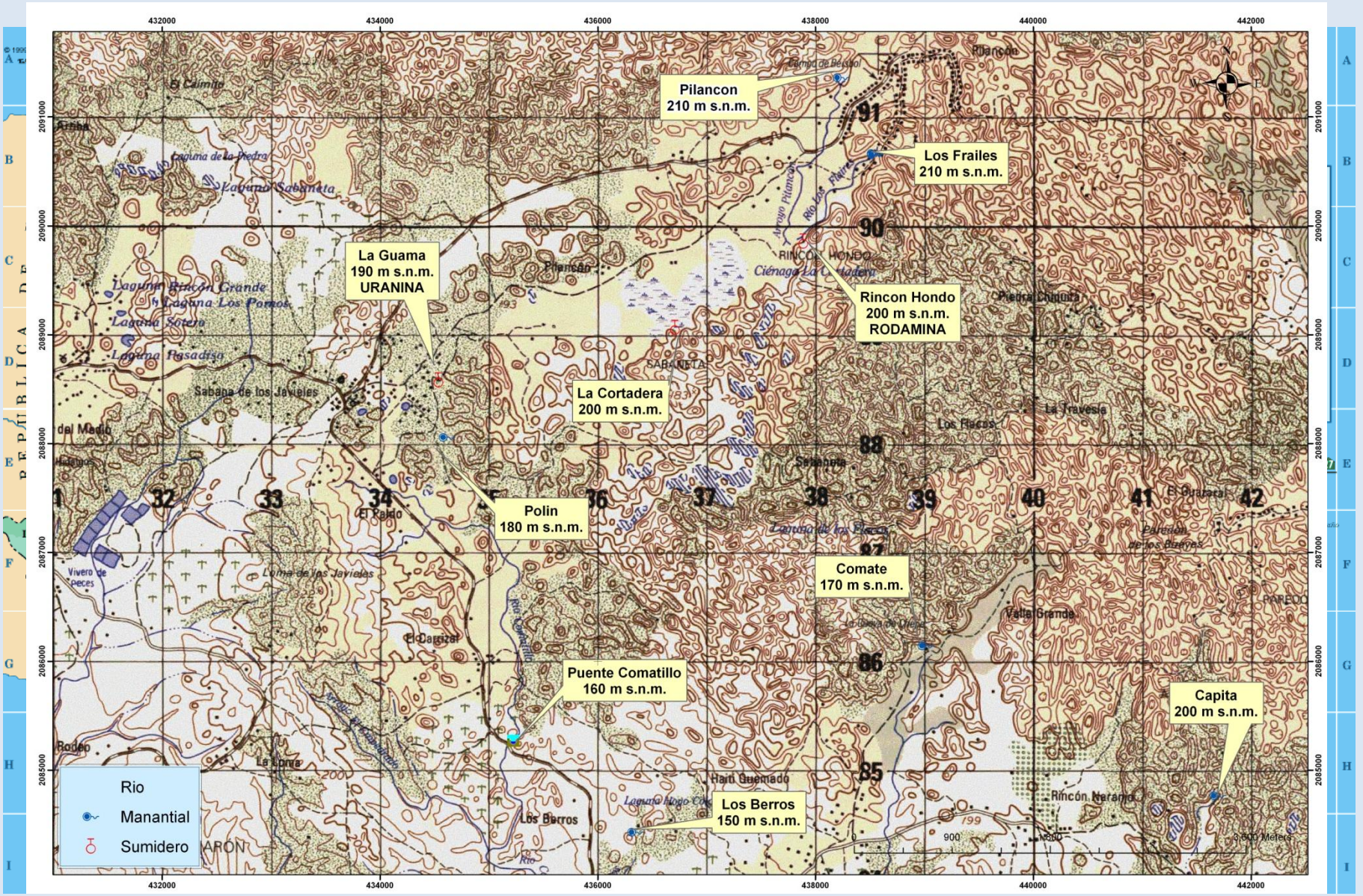
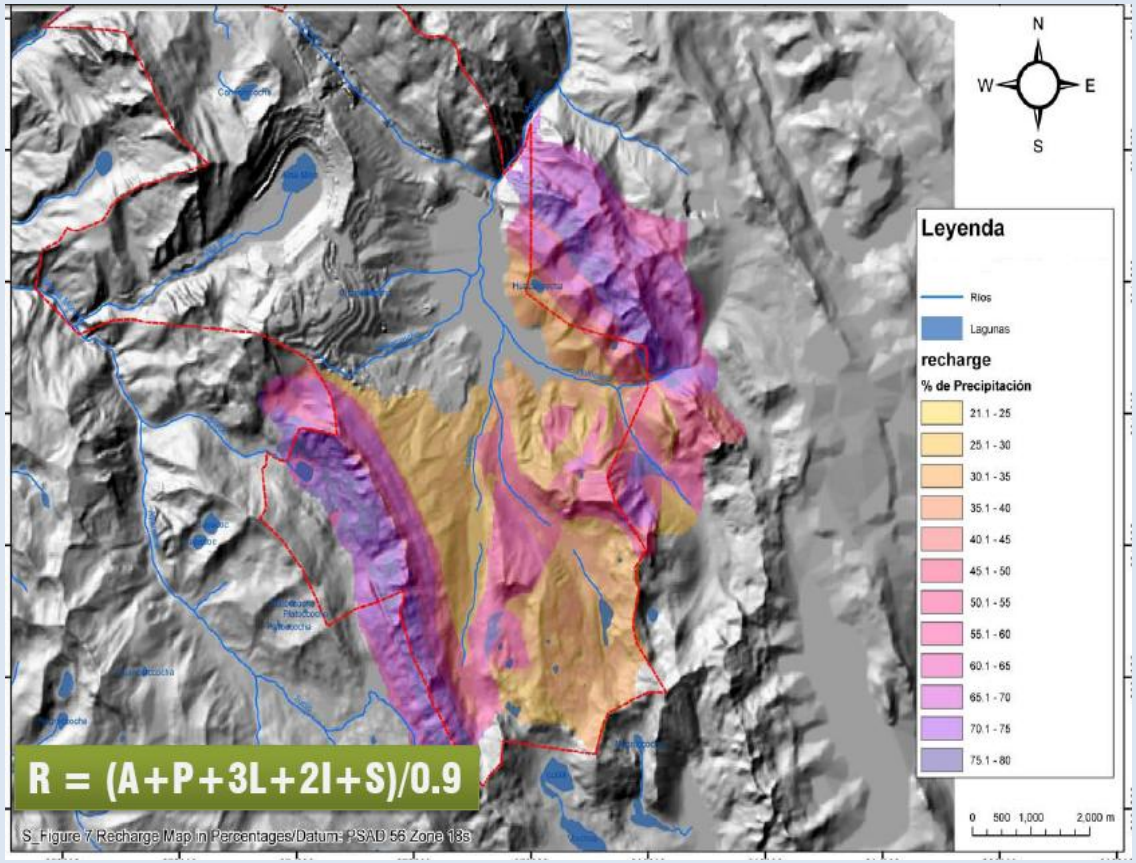


Groundwater recharge in Andes region (Perú)



Maocun Karst system Guilin (S China)
Experimental Site for IGCP 598 project of UNESCO

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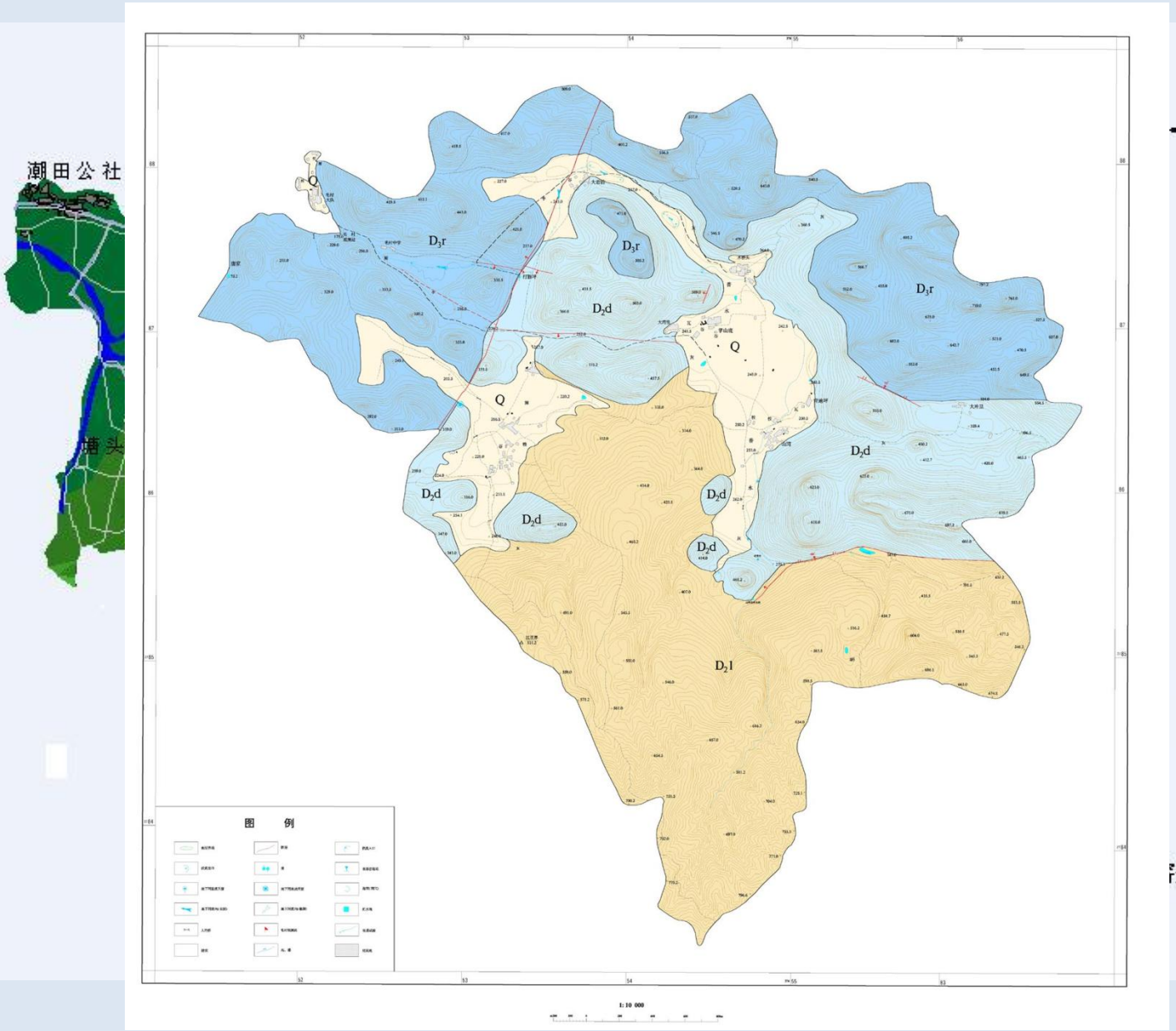

Maocun Karst system Guilin (S China)
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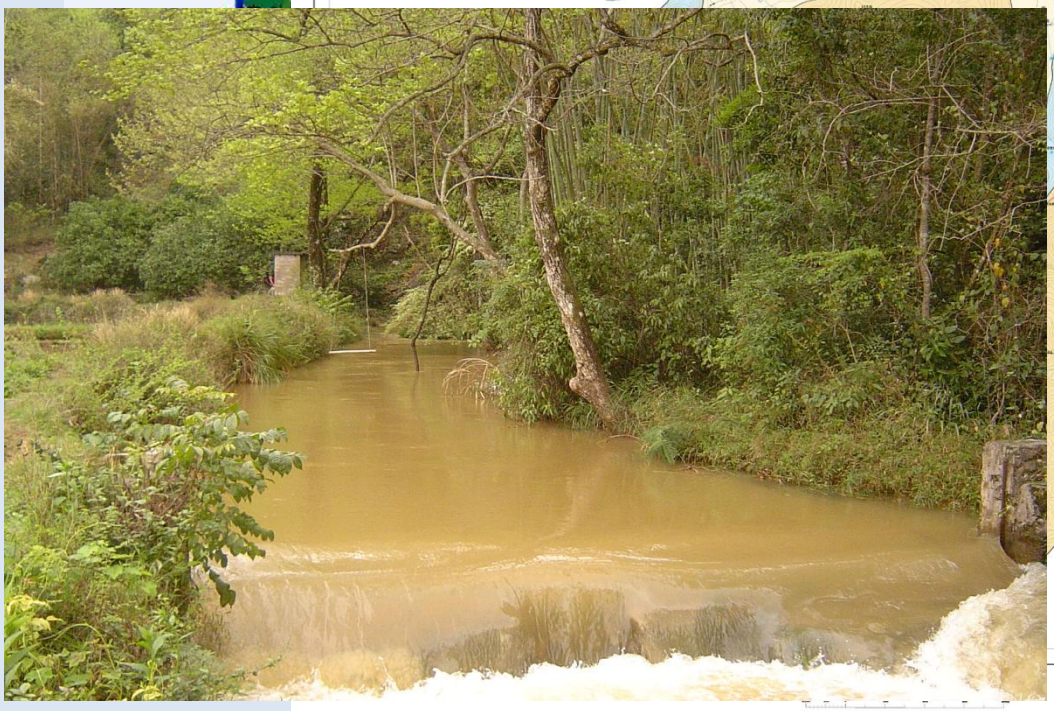
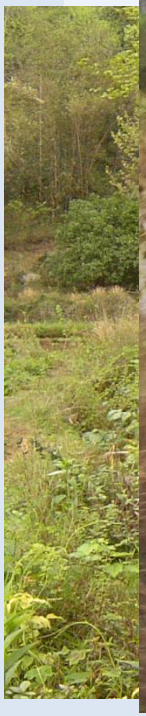


Maocun Karst system Guilin (S China)
Experimental Site for IGCP 598 project of UNESCO

APLIS has been applied in different countries: Indonesia, Iran, Oman, China, Slovenia, Greece, Peru, Cuba, Morocco.

It has been the basis of KARSLOP method for recharge assessment in karst aquifers in Montenegro



- FINAL REMARKS -

-APLIS method is potentially useful tool for groundwater recharge and water resource assessment and their spatial distributions in carbonate aquifers.

- APLIS has been successfully apply in karst aquifers from several worldwide countries. So, it can be applied in European countries or to obtain a global European map of recharge/resources of karst aquifers.

- Detailed Information of good quality permits reliable results. Field observation is always necessary.

-Results should be checked or validated by other conventional recharge assessment method in order to contrast the reliability of the results in terms of aquifer management and protection groundwater.

Thank for contribution to:
J.J. Durán and J.A. López Geta (Spanish Geological Survey, IGME)
A.I. MarÍn, D. Rizo and A. Lorenzo (ETC-SIA)

Gato (*Cat*) cave spring,
Sierra de Libar, S Spain)

Thank you for your attention

Organization

The 5th International Symposium on Karst will be organized by researchers from the Centre of Hydrogeology at the University of Malaga (CEHIUMA) and the Spanish Geological Survey (IGME), in the framework of their "Advanced Hydrogeological Studies" partnership.

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Steve Worthingthon (Worthington Groundwater, Canada)
Pierre Yves Jeanin (SISKA, Switzerland)

Place and Dates

The Symposium will be held in the city of Malaga (Spain) on 13 - 16 October 2014. Other dates of interest in the course of the Symposium's organization are:

- Deadline for receipt of abstracts: *15th October 2013*
- Notification of acceptance of abstracts: *15th December 2013*
- Deadline for receipt of completed manuscripts: *15th February 2014*
- Return of reviewed manuscripts: *15th March 2014*
- Deadline for receipt of final manuscript: *15th April 2014*

Registration

Registration fee:

- Before 15th February 2014: 300 euros
- After 15th February 2014: 350 euros

More Information

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MALAGA, SPAIN
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