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PRESERVATION OF DRINKING WATER:
EXAMPLES AND APPLICATIONS OF NEW TECHNOLOGIES FOR THE QUALITY AND QUANTITATIVE MONITORING OF THE RESOURCE.

FOOD SAFETY AND HEALTHY LIVING INTERNATIONAL SUMMER SCHOOL

September 5-8, 2022
Brasov, Romania

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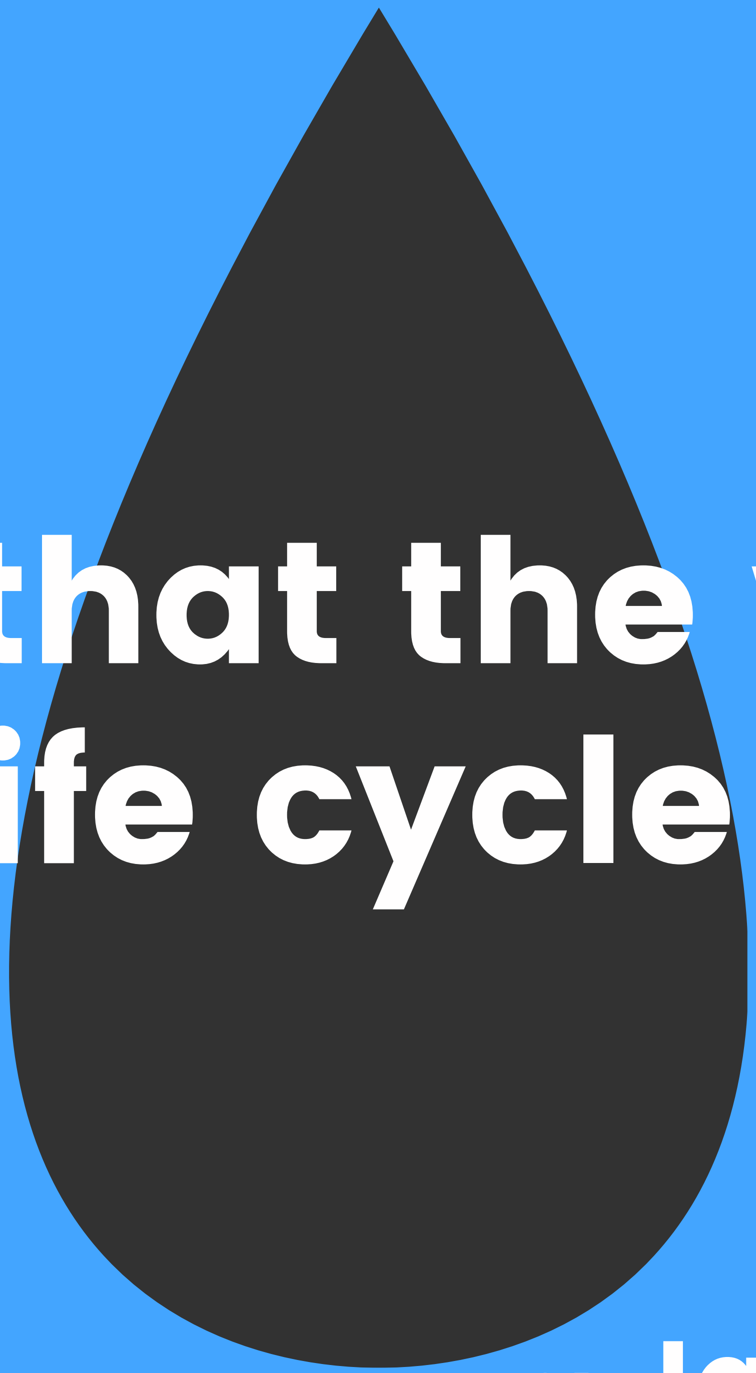


“We forget that the water cycle and the life cycle are one.”

~ Jacques Yves Cousteau

Directive (EU) 2020/2184 of the European Parliament and of the Council of 16 December 2020 on the quality of water intended for human consumption

What is **drinking water?**

water intended for human consumption means:

- all water, either in its original state or after treatment, intended for drinking, cooking, food preparation or other domestic purposes in both public and private premises, regardless of its origin and whether it is supplied from a distribution network, supplied from a tanker or put into bottles or containers, including spring waters;
- all water used in any food business for the manufacture, processing, preservation or marketing of products or substances intended for human consumption

pH - HYDROGEN ION CONCENTRATION	It is a quantity that indicates how aggressive, acid (pH below 7) or basic (pH above 7) a water is. Recommended value between 6.5 and 9.5.
EC - CONDUCTIVITY	It is the ability of a solution to conduct electricity and is measured in Siemens micro units per centimeter (µScm-1) at a temperature of 20°C. Recommended value of 2.500 µScm-1.
HARDNESS	It is closely related to the presence of calcium and magnesium ions in solution. The most commonly used unit of measurement is the French Degree (°F), which corresponds to 10 mg/l of calcium carbonate. Recommended value between 15 and 50°F.
COLOUR, ODOUR, TASTE, AND TURBIDITY	Acceptable to consumers and no abnormal change

What is drinking water?

Ammonium	10 μg/l	It is an element present in rocks, minerals and soil, and its occurrence in water is mainly due to natural processes of dissolution from minerals and rocks.
Arsenic	10 μg/l	It is an element present in rocks, minerals and soil, and its occurrence in water is mainly due to natural processes of dissolution from minerals and rocks.
Chloride	250 mg/l	The chloride ion is widely distributed in nature in the form of sodium (NaCl), potassium (KCl) and calcium (CaCl2) salts. Chloride increases the electrical conductivity of water.
Sulphate	250 mg/l	They occur naturally in numerous minerals and for that reason can also be found in drinking water.
Nitrate	50 mg/l	They are compounds present in water either as a result of natural phenomena (decomposition cycle of nitrogenous substances) or as a consequence of human activities.

Directive (EU) 2020/2184 of the European Parliament and of the Council of 16 December 2020 on the quality of water intended for human consumption

Why drinking water is important?

When a community gets access to safe water, some of the benefits are:

- The improvement Water Supply Quality, Sanitation, and Hygiene
- Increase the Amount of Healthy Food Available
- Improve Poor Communities
- Better School Attendance
- Gender Equality
- Reduce Conflict

Global water crisis facts

UNDP

6 CLEAN WATER AND SANITATION

Despite improvements in recent years, **water scarcity affects more than 40% of people**. This situation is projected to rise as temperatures do. **By 2050**, it is projected that at least **one in four people will suffer recurring water shortages.**

Protecting and restoring water-related ecosystems is essential!

THE GLOBAL GOALS

884 million

people still lacked even basic drinking water

2 billion

people are affected by water stress

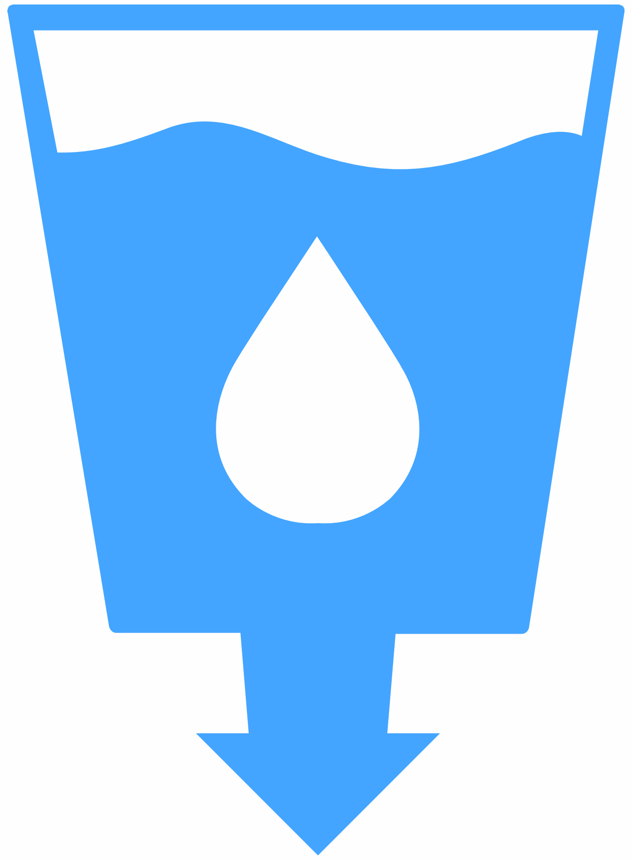
80 percent

of countries have developed or have set up an integrated water resources management

70 percent

of the world's wetlands have been destroyed in the last century

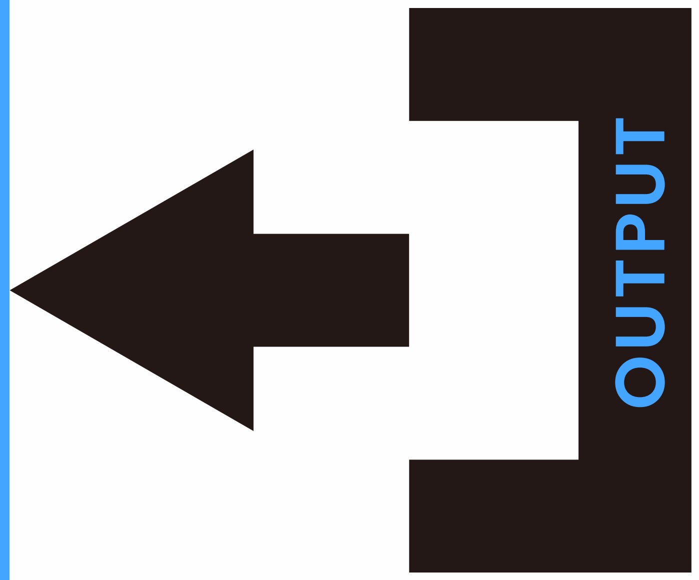
Goal targets to 2030



- achieve universal and equitable access to safe and affordable drinking water for all
- improve water quality by reducing pollution, eliminating dumping and minimizing release of hazardous chemicals and materials
- implement integrated water resources management at all levels
- protect and restore water-related ecosystems, including mountains, forests, wetlands, rivers, aquifers and lakes

The **Valseriana** case study (Northern Italy)

An interesting example regarding the application of new techniques for preserving water resource from both a **quantitative and qualitative** point of view is the one carried out in the **2018-2019 biennium** on the Nossana and Ponte del Costone springs.



- Water chemical-physical monitoring and resident time dating of groundwater
- New index-based approach to assess the vulnerability of karst springs
- Estimation of the effects of Climate Change on springs discharge until 2100

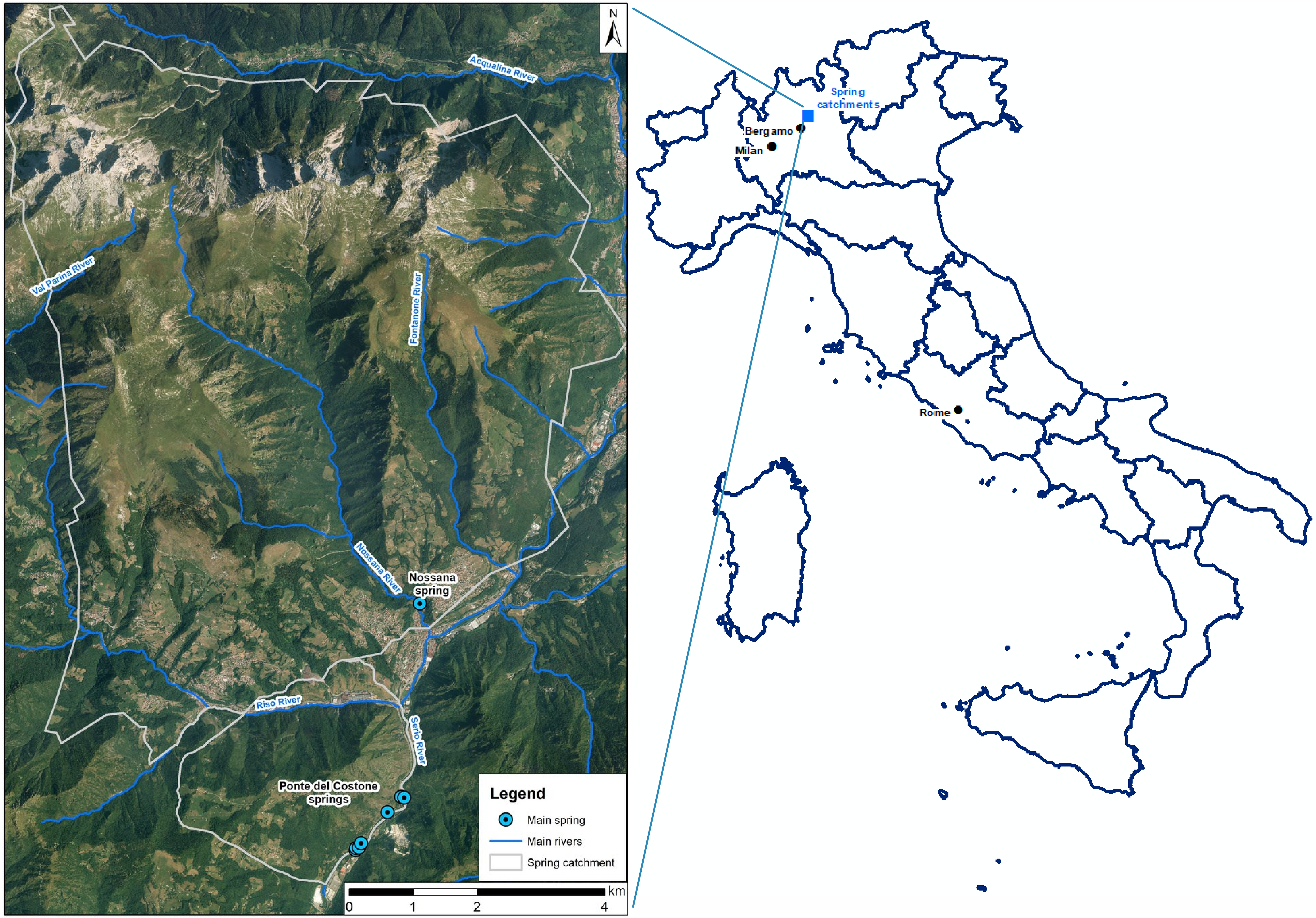
Study Area

- The springs are located in Northern Italy, in the Central Pre-Alps within the Province of Bergamo, Lombardy Region

- Nossana catchment: 80 km2

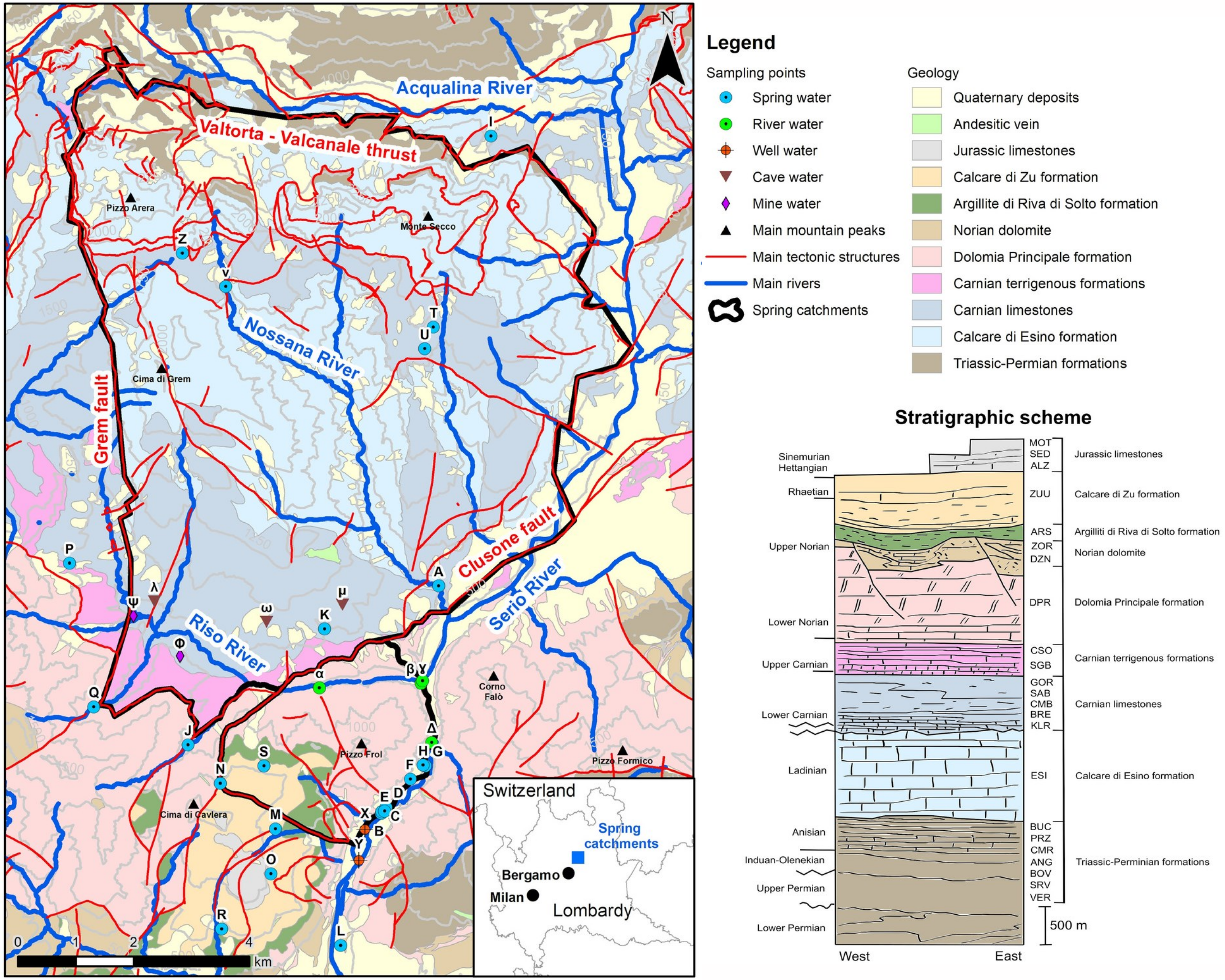
- Ponte del Costone catchment: 10 km2

- High differences in altitude. **Nossana**: from 447 m a.s.l. to 2512 m a.s.l. **Ponte del Costone**: from 427 m a.s.l. to 1161 m a.s.l.



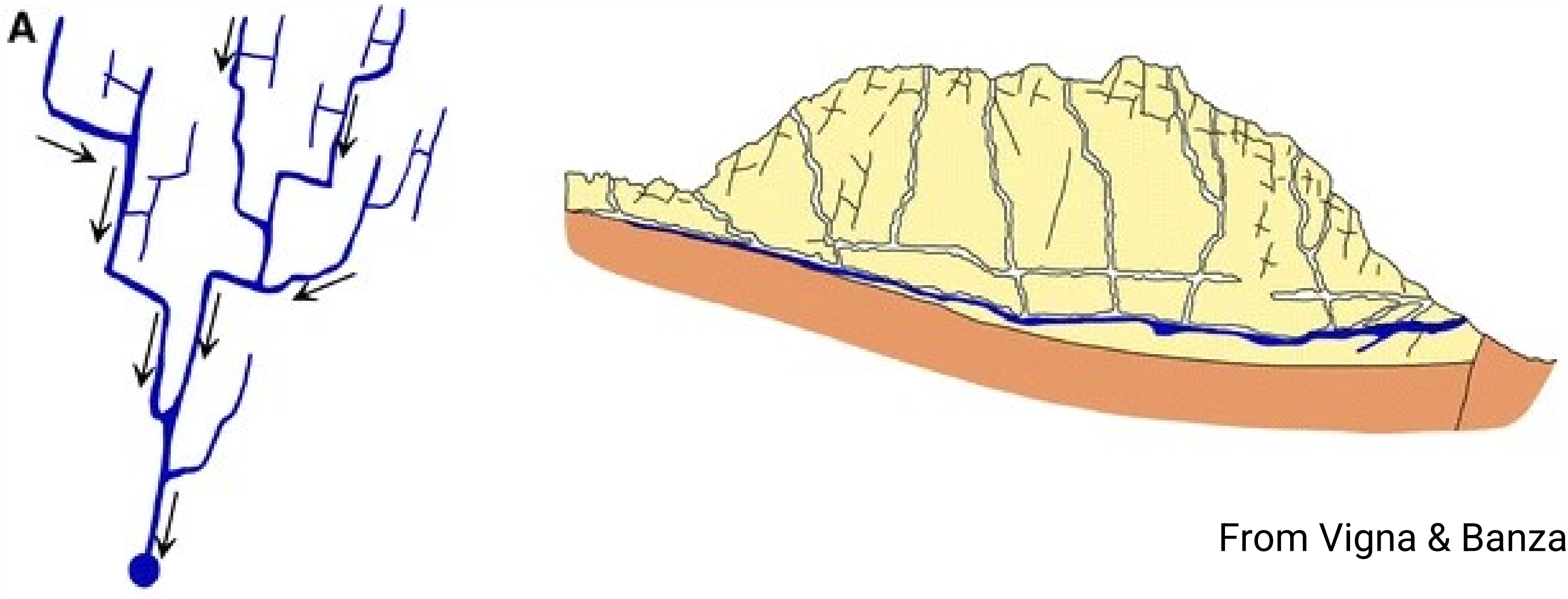
Study Area

- The whole environment is dominated by calcareous-dolomitic carbonate series
- The Nossana aquifer is set in the Calcare di Esino formation (Ladin - Carnic age)
- The water system of Ponte del Costone is formed by 13 springs distributed in about 1 km along the Serio river and it has the Dolomia Principale Formation (Noric age) as reservoir rock
- The average precipitation is close to 2000 mm/year with peaks of about 3000 mm/year (Ceriani et al., 2000)

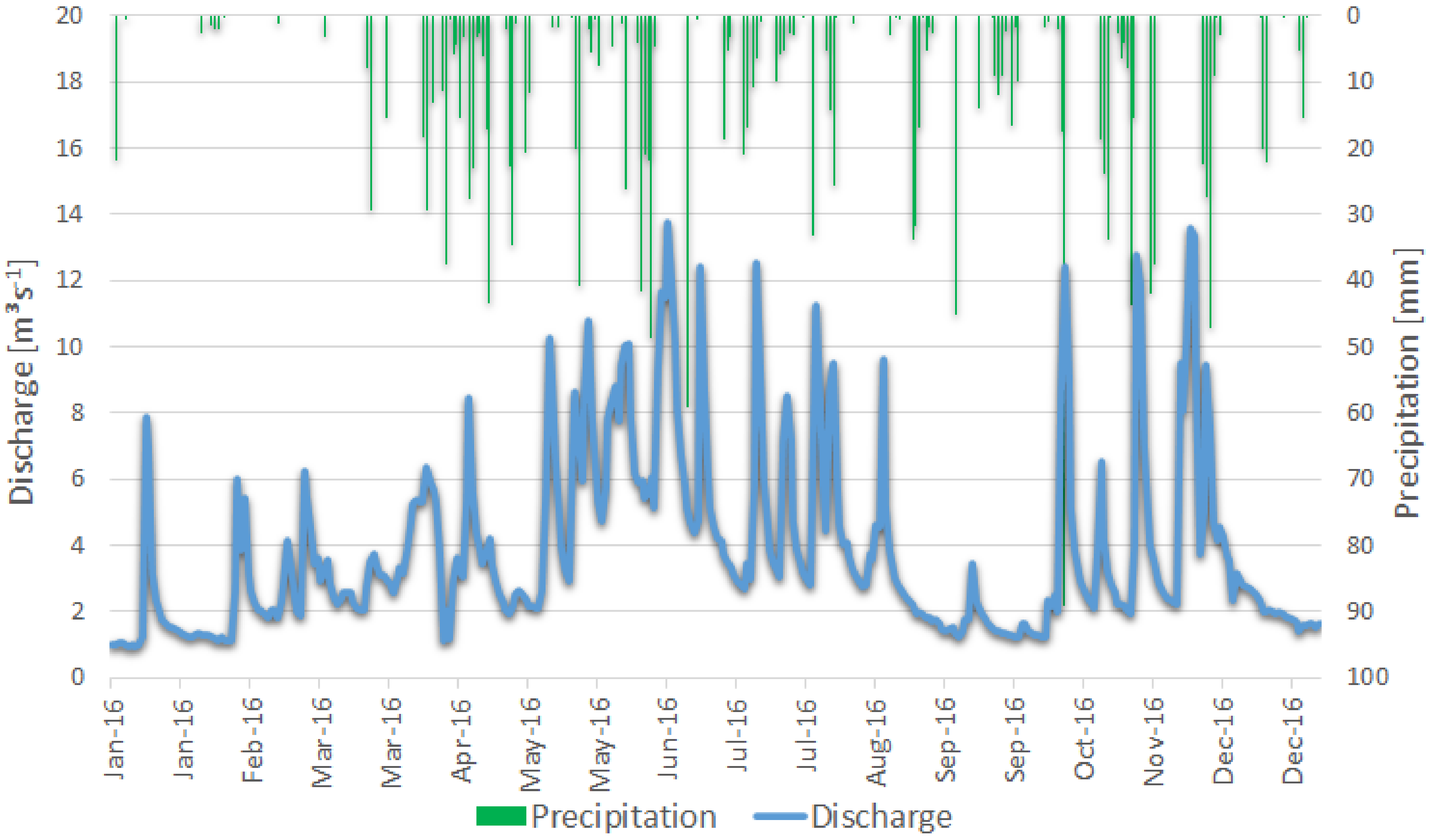


Study Area

Credits: Eco di Bergamo



From Vigna & Banzato, 2015

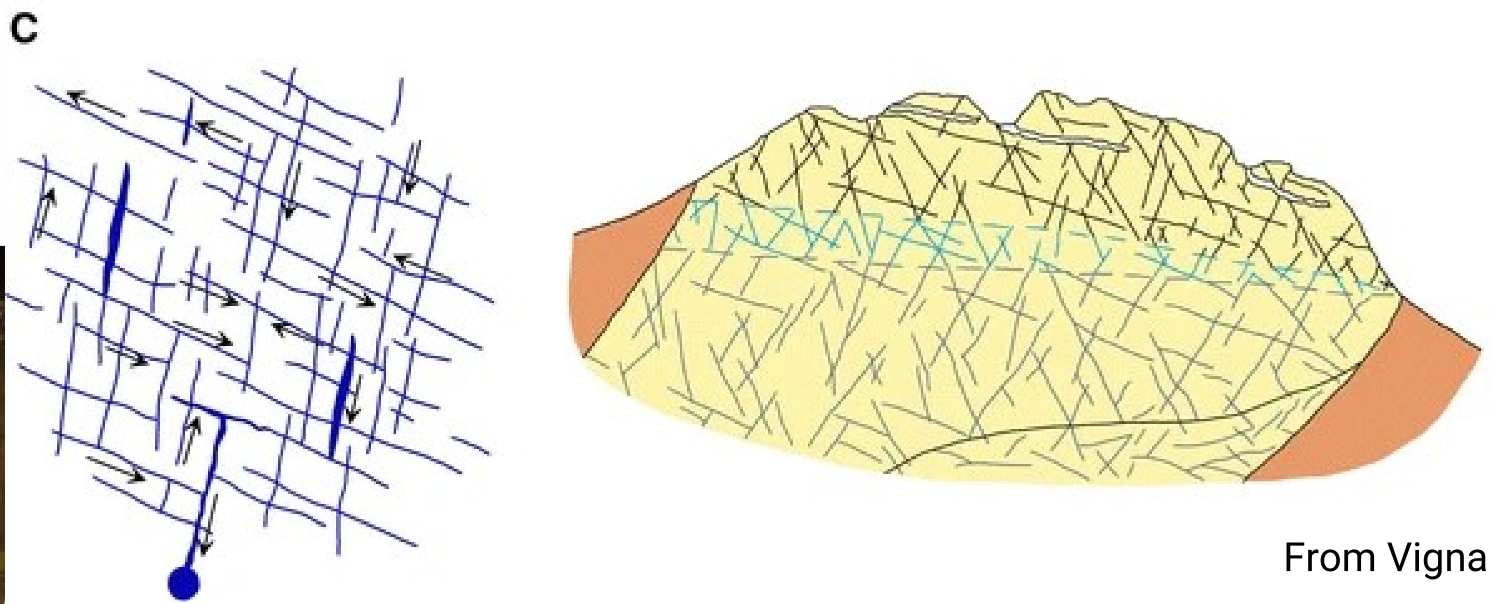


- The springs are managed by the public company UniAcque S.p.A. and feed more than 315,000 people
- Characterized by a **dominant drainage system**
- Nossana spring discharge 0.5 - 18 m^3s^{-1}

Nossana spring

Study Area

Credits: UniAcque S.p.A.



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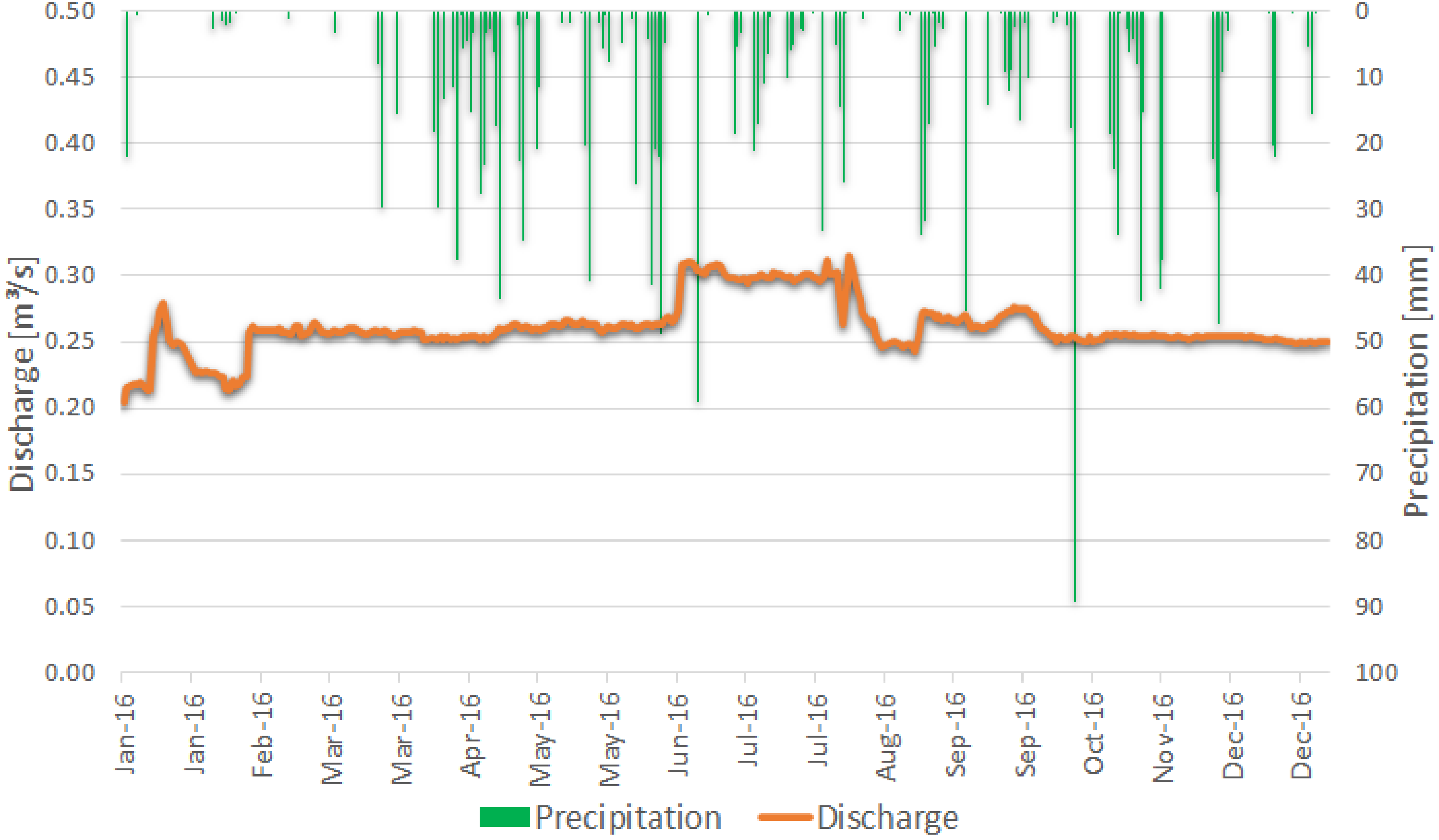


- The Ponte del Costone cumulative discharge 0.15 - 0.45 m3s-1
- System with dispersive circulation
- Three main groups distributed along Serio river: Galleria del Costone, Merlo, and Bosco (from South to North)

Ponte del Costone springs

Water chemical-physical monitoring

1 - SAMPLING CAMPAIGN (MAY 2018 - JULY 2019)

34 sampling points were set up. 23 points are related to **natural spring** waters, 4 points to **surface waters**, 2 points to **wells** , 3 points to waters from **karst caves**, and 2 points to the Val del Riso **mine**

3 - HYDROCHEMICAL CHARACTERIZATION

- Through the use of PHREEQC (Parkhurst & Appelo, 2013), **pCO2** and Saturation Indices were calculated with respect to calcite (**SIc**) and dolomite (**SId**)
- Using Instant Clue software (Nolte et al., 2018), a **Hierarchical Cluster analysis** was performed considering major cations (Ca2+, Mg2+, K+, and Na+), major anions (HCO3-, Cl-, NO3-, and SO42-), alkalinity (CaCO3), temperature, CO2 partial pressure, SIc and SId, and electrical conductivity [μS/cm]

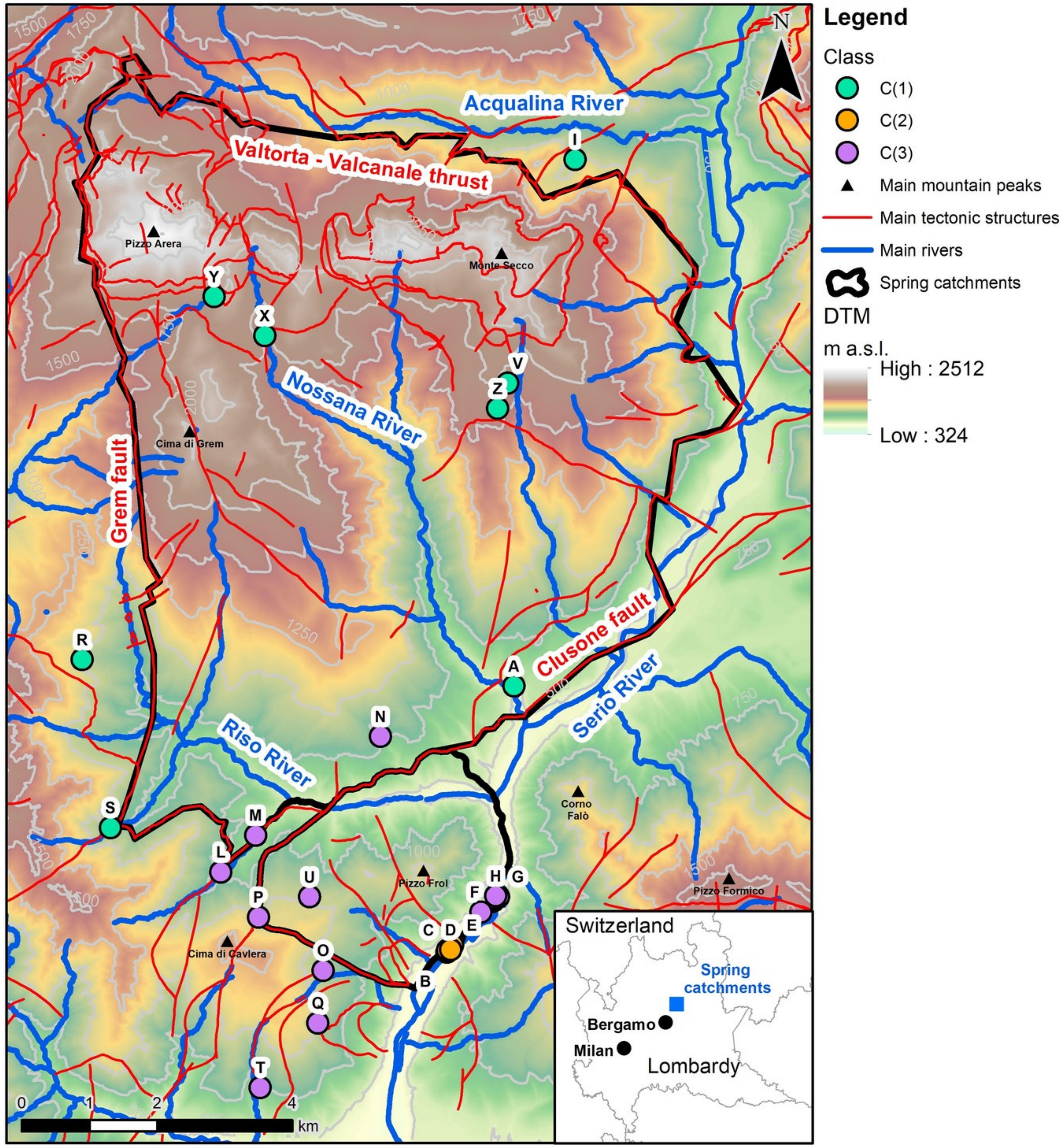
2 - HYDROCHEMICAL AND ISOTOPIC ANALYSIS

- **Chemical analyses** were performed at UniAcque S.p.A. laboratories via ion chromatography (IC) and inductively coupled plasma mass spectrometry (ICP-MS)
- **Stable isotopes analyses** (18O, 2H, and 13C) were performed in the laboratory of the Université d'Avignon et des Pays de Vaucluse (France) using an isotope ratio mass spectrometer (IRMS).
- the **3H/3He analyses** have been commissioned to the laboratories of the Institute of Environmental Physics and Oceanography at the University of Bremen (Germany) (Sültenfuß et al., 2009).

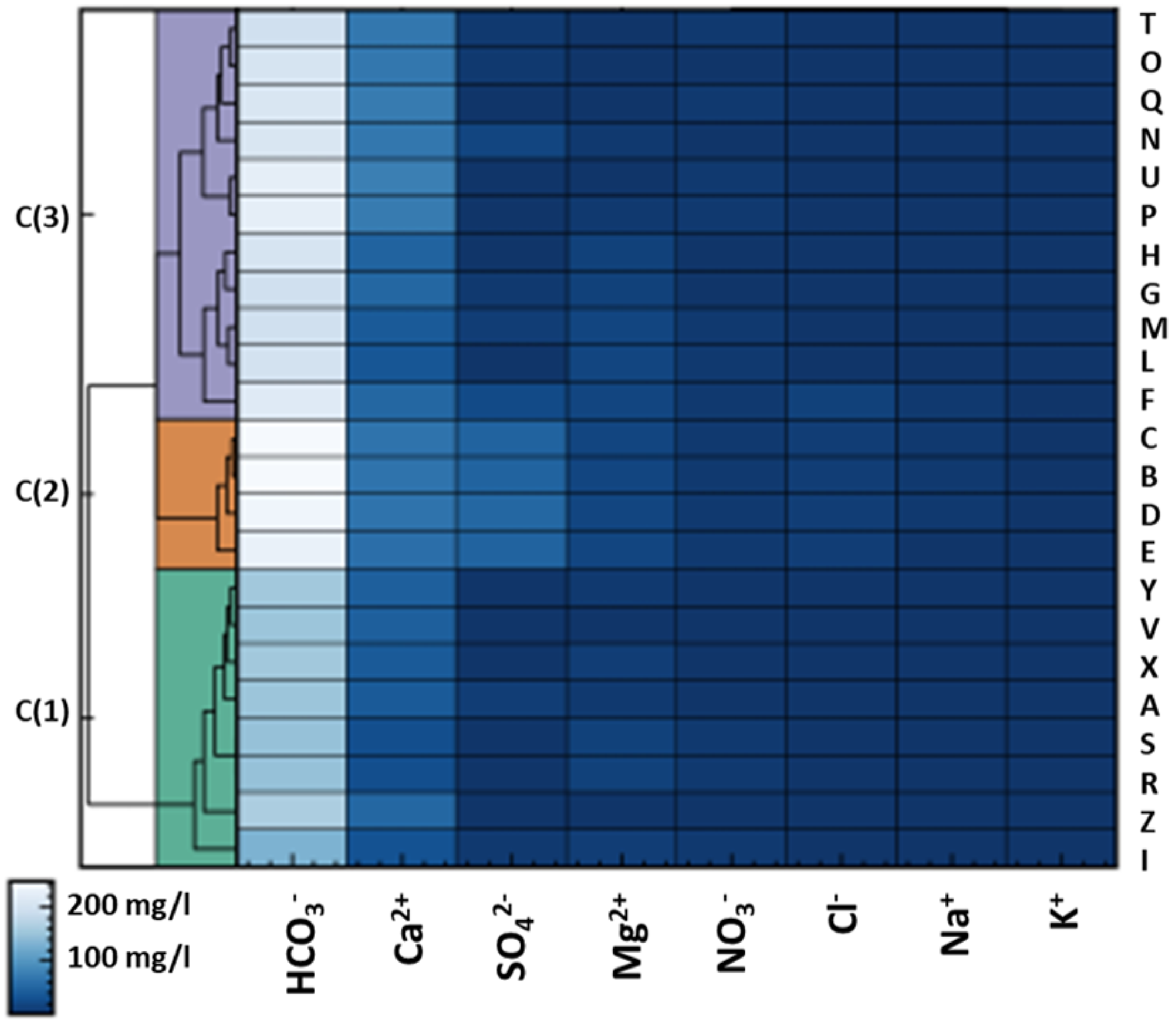
4 - FLOW DYNAMICS FEATURES WITHIN THE WATER SYSTEMS

Through comparison of the results of chemical and isotopic analysis, a **hypothesis** was proposed about **how the flow dynamics** within the two water systems **work**

Hierarchical clustering analysis



Water classes	Ca^{2+}	Mg^{2+}	Na^{+}	K^{+}	HCO_3^-	Cl^-	NO_3^-	SO_4^{2-}
C(1) 8 samples	37.7	9.0	0.6	0.3	150.2	1.0	3.9	3.6
C(2) 4 samples	63.5	19.9	4.9	1.3	240.6	9.4	5.1	48.9
C(3) 11 samples	58.7	9.6	1.6	0.8	207.7	2.8	5.4	7.8

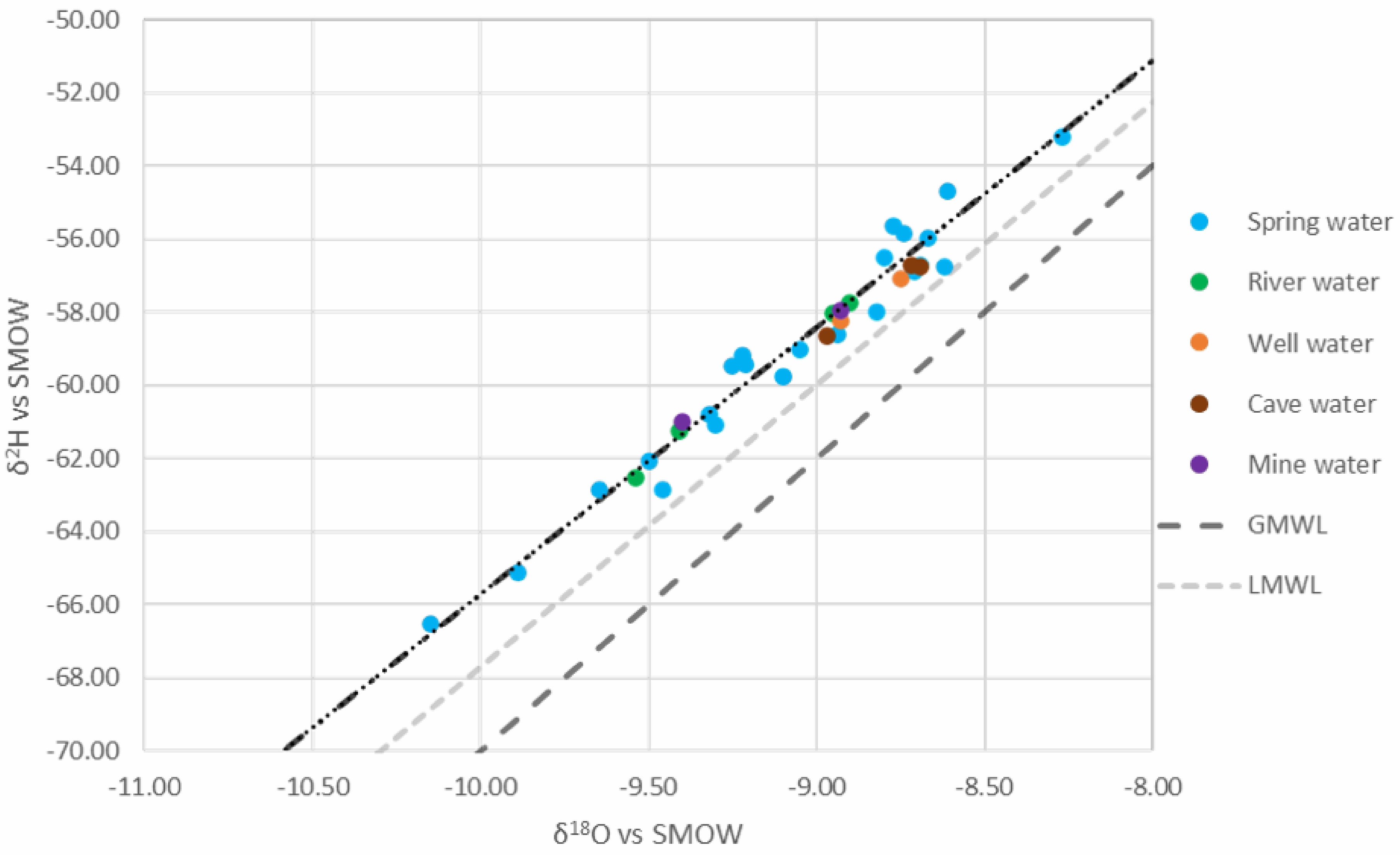


Isotopic features and Resident time estimation

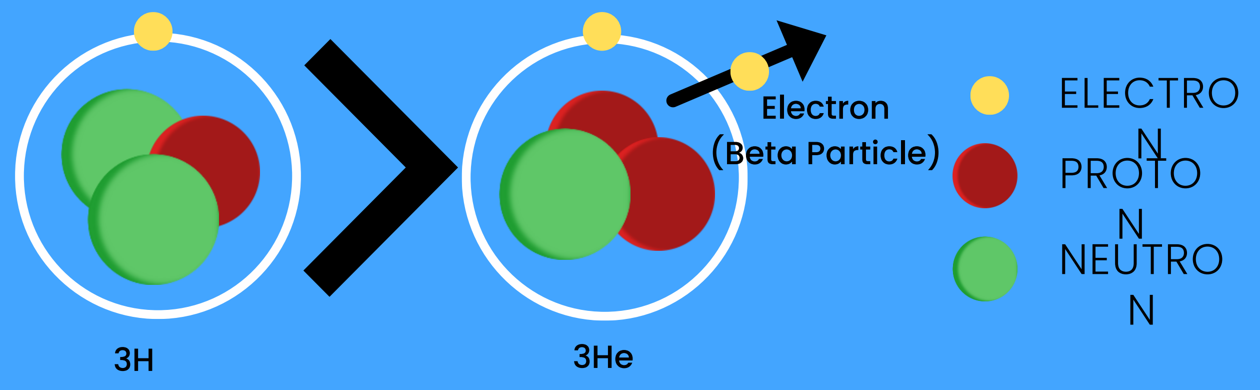
- Study area Meteoric Water Line:

$$\delta\,^2H = 7.71\,^{18}O + 9.40$$

- **Deuterium enrichment** given by re-evaporation due to effect of secondary valleys (Riso Valley)



- Tritium decays by emitting electrons (β-) into Helium-3, so it can be used for dating. (half-life of 12.32 y, total decay in 246 y)



- **10 years for Nossana, 30 years for Ponte del Costone**
- **For the main springs cyclical renewal of the resource is not clear**

	Sampling 2015		Sampling 2019	
Spring name	**Age (years)**	**Recharge year**	**Age (years)**	**Recharge year**
Camplano	1.50	2014	0.96	2018
Valle Rogno	8.10	2007	5.24	2014
Nossana	7.90	2008	13.10	2006
Costone 2	29.30	1986	32.48	1987

- The chemical composition of the waters reflects the carbonate context and is completely controlled by the **spatial distribution** of the different geological formations, by the **different degree of susceptibility to karst dissolution** of the rocks that characterize the study area, and by the **altitude**.
- It was estimated the age of the reserve (or **residence time**) for **Nossana** of about **10 years**, while for the **Ponte del Costone** springs of about 30 years
- For these main springs, **the cyclical renewal of the resource is not evident**; rather, the water reserve ages in the 2015 - 2018 comparison.

Vulnerability assessment of **karst aquifers**

DEFINIZIONE DI VULNERABILITà

GOALS

- define an integrative methodology that represent the conditions of intrinsic vulnerability of the middle Valseriana (Northern Italy);
- delineate an approach that does not require a lot of data and expensive investigations available in order to make it applicable in mountain contexts: COPA+K method;
- validate this new proposed approach through isotopic data.

DATA

Geological data

The geological, geomorphological, and elevation data of the area were obtained from the Geoportale della Regione Lombardia (Regione Lombardia, 2020)

Karst network development

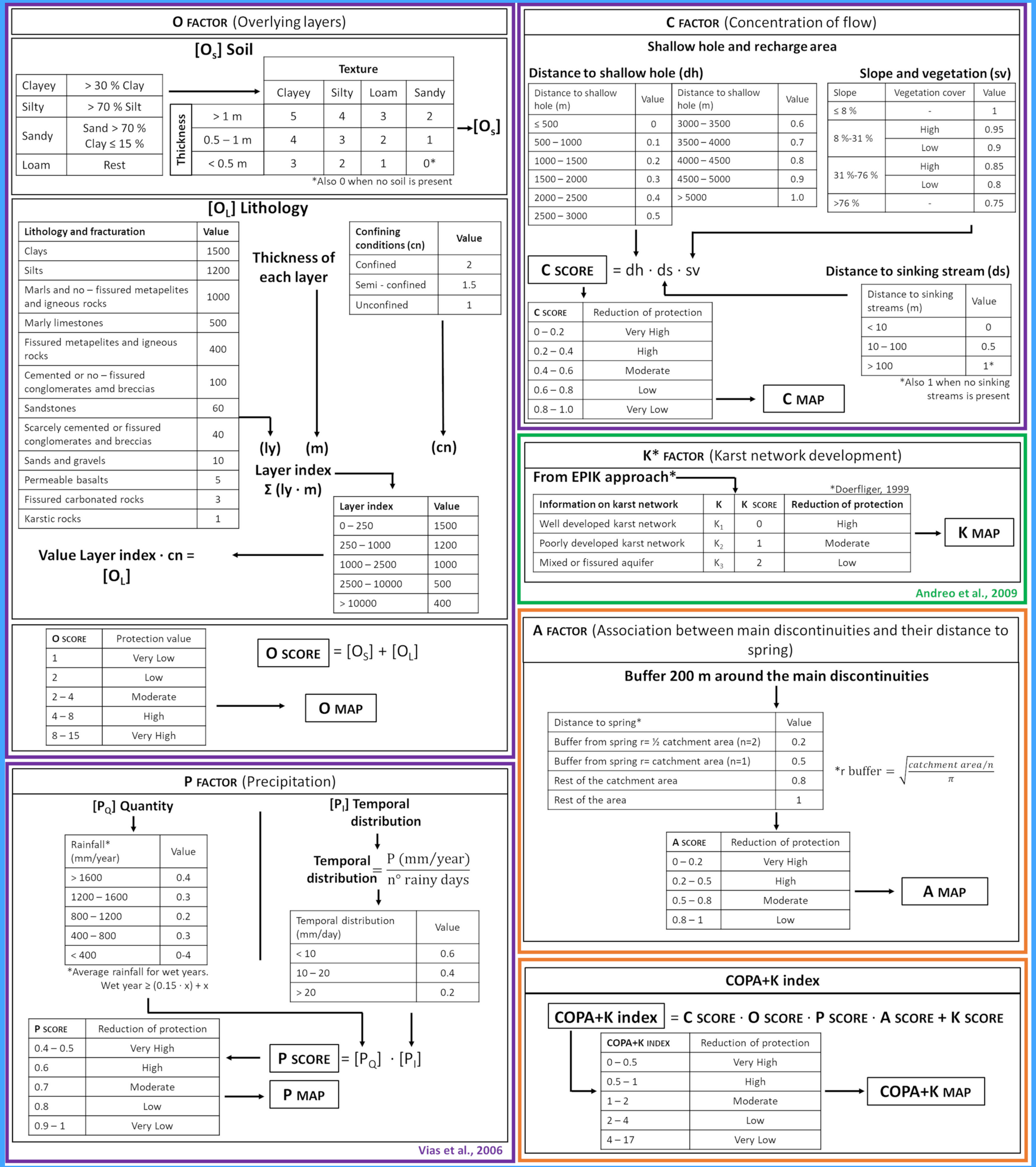
For the development of the karst network and the evaluation of the propensity to karstification of the area, the work of FSLo (2011) was relied on

Meteorological data

The meteorological data were obtained from the open-data section of the Environmental Regional Agency (ARPA Lombardia, 2020)

Isotopic data

The stable isotope data ($\delta 18O$ and $\delta 2H$) related to the waters of Nossana and Ponte del Costone springs and Serio river



O FACTOR (Overlying layers)

$[O_s]$ Soil

Clayey	> 30 % Clay
Silty	> 70 % Silt
Sandy	Sand > 70 % Clay ≤ 15 %
Loam	Rest

Thickness	Texture			
	Clayey	Silty	Loam	Sandy
> 1 m	5	4	3	2
0.5 – 1 m	4	3	2	1
< 0.5 m	3	2	1	0*

→ $[O_s]$

*Also 0 when no soil is present

$[O_L]$ Lithology

Lithology and fracturation	Value
Clays	1500
Silts	1200
Marls and no – fissured metapelites and igneous rocks	1000
Marly limestones	500
Fissured metapelites and igneous rocks	400
Cemented or no – fissured conglomerates amd breccias	100
Sandstones	60
Scarcely cemented or fissured conglomerates and breccias	40
Sands and gravels	10
Permeable basalts	5
Fissured carbonated rocks	3
Karstic rocks	1

Thickness of each layer

Confining conditions (cn)	Value
Confined	2
Semi - confined	1.5
Unconfined	1

(ly) **(m)** **(cn)**

Layer index
Σ (ly · m)

Layer index	Value
0 – 250	1500
250 – 1000	1200
1000 – 2500	1000
2500 – 10000	500
> 10000	400

Value Layer index · cn = $[O_L]$

O SCORE	Protection value
1	Very Low
2	Low
2 – 4	Moderate
4 – 8	High
8 – 15	Very High

O SCORE = $[O_S] + [O_L]$

O MAP

P FACTOR (Precipitation)

$[P_Q]$ Quantity

Rainfall* (mm/year)	Value
> 1600	0.4
1200 – 1600	0.3
800 – 1200	0.2
400 – 800	0.3
< 400	0-4

*Average rainfall for wet years.
Wet year ≥ (0.15 · x) + x

$[P_I]$ Temporal distribution

$$\text{Temporal distribution} = \frac{\text{P (mm/year)}}{\text{n° rainy days}}$$

Temporal distribution (mm/day)	Value
< 10	0.6
10 – 20	0.4
> 20	0.2

P SCORE = $[P_Q] \cdot [P_I]$

P SCORE	Reduction of protection
0.4 – 0.5	Very High
0.6	High
0.7	Moderate
0.8	Low
0.9 – 1	Very Low

P MAP

Vias et al., 2006

C FACTOR (Concentration of flow)

Shallow hole and recharge area

Distance to shallow hole (dh)

Distance to shallow hole (m)	Value	Distance to shallow hole (m)	Value
≤ 500	0	3000 – 3500	0.6
500 – 1000	0.1	3500 – 4000	0.7
1000 – 1500	0.2	4000 – 4500	0.8
1500 – 2000	0.3	4500 – 5000	0.9
2000 – 2500	0.4	> 5000	1.0
2500 – 3000	0.5		

Slope and vegetation (sv)

Slope	Vegetation cover	Value
≤ 8 %	-	1
8 %-31 %	High	0.95
	Low	0.9
31 %-76 %	High	0.85
	Low	0.8
>76 %	-	0.75

C SCORE = dh · ds · sv

Distance to sinking stream (ds)

Distance to sinking streams (m)	Value
< 10	0
10 – 100	0.5
> 100	1*

*Also 1 when no sinking streams is present

C SCORE	Reduction of protection
0 – 0.2	Very High
0.2 – 0.4	High
0.4 – 0.6	Moderate
0.6 – 0.8	Low
0.8 – 1.0	Very Low

C MAP

K* FACTOR (Karst network development)

From EPIK approach*

*Doerfliger, 1999

Information on karst network	K	K SCORE	Reduction of protection
Well developed karst network	K_1	0	High
Poorly developed karst network	K_2	1	Moderate
Mixed or fissured aquifer	K_3	2	Low

K MAP

Andreo et al., 2009

A FACTOR (Association between main discontinuities and their distance to spring)

Buffer 200 m around the main discontinuities

Distance to spring*	Value
Buffer from spring r= ½ catchment area (n=2)	0.2
Buffer from spring r= catchment area (n=1)	0.5
Rest of the catchment area	0.8
Rest of the area	1

$$^{*}\text{r buffer} = \sqrt{\frac{catchment\ area/n}{\pi}}$$

A SCORE	Reduction of protection
0 – 0.2	Very High
0.2 – 0.5	High
0.5 – 0.8	Moderate
0.8 – 1	Low

A MAP

COPA+K index

COPA+K index = C SCORE · O SCORE · P SCORE · A SCORE + K SCORE

COPA+K INDEX	Reduction of protection
0 – 0.5	Very High
0.5 – 1	High
1 – 2	Moderate
2 – 4	Low
4 – 17	Very Low

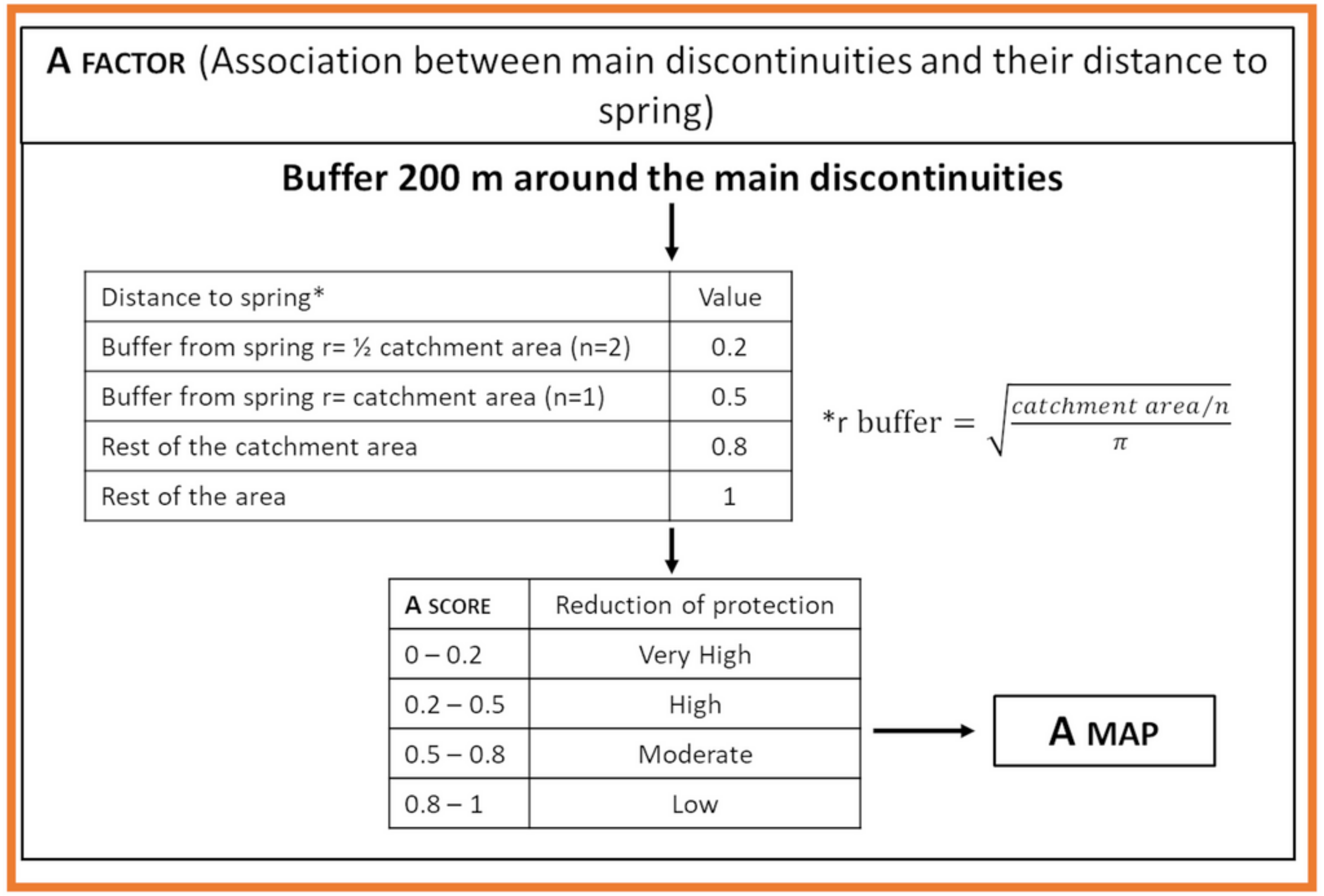
COPA+K MAP

- **C** CONCENTRATION OF FLOW
- **O** OVERLAYING LAYERS
- **P** PRECIPITATION
- **A** ASSOCIATION BETWEEN MAIN DISCONTINUITIES AND THEIR DISTANCE TO SPRING
- **K** KARST NETWORK DEVELOPMENT

COPA+K method
C x O x P x A + K

A factor

Association between discontinuities and their distance to spring



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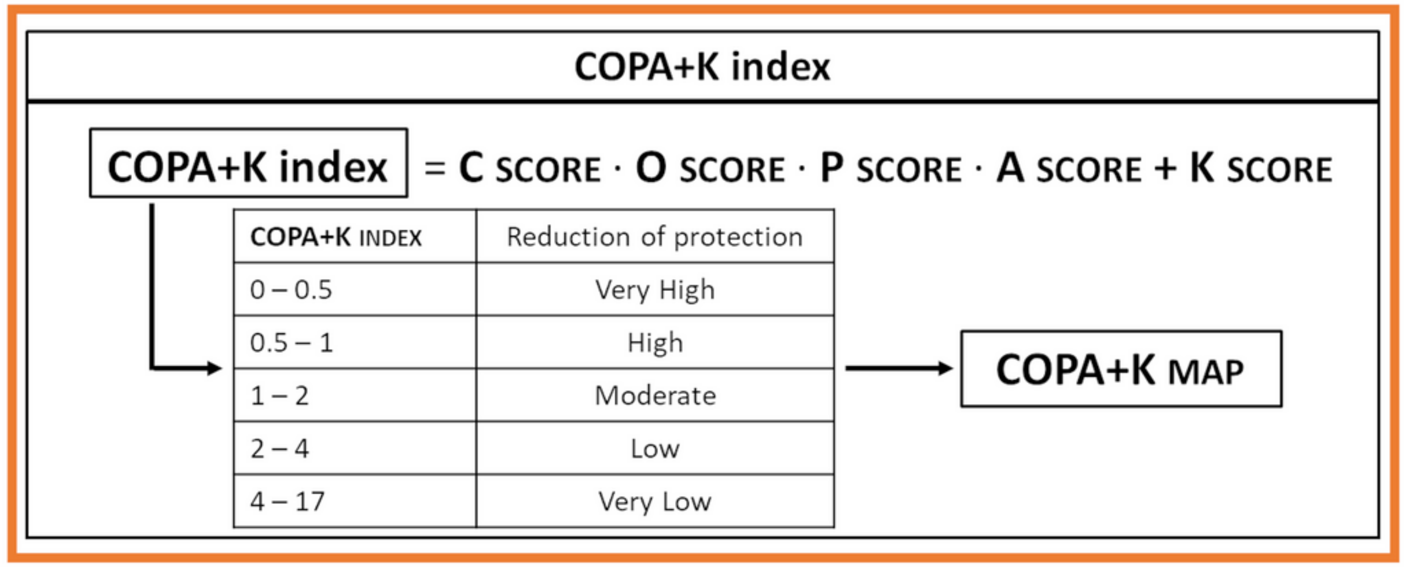
A MAP



COPA+K index

COPA+K index = C SCORE · O SCORE · P SCORE · A SCORE + K SCORE

COPA+K INDEX	Reduction of protection
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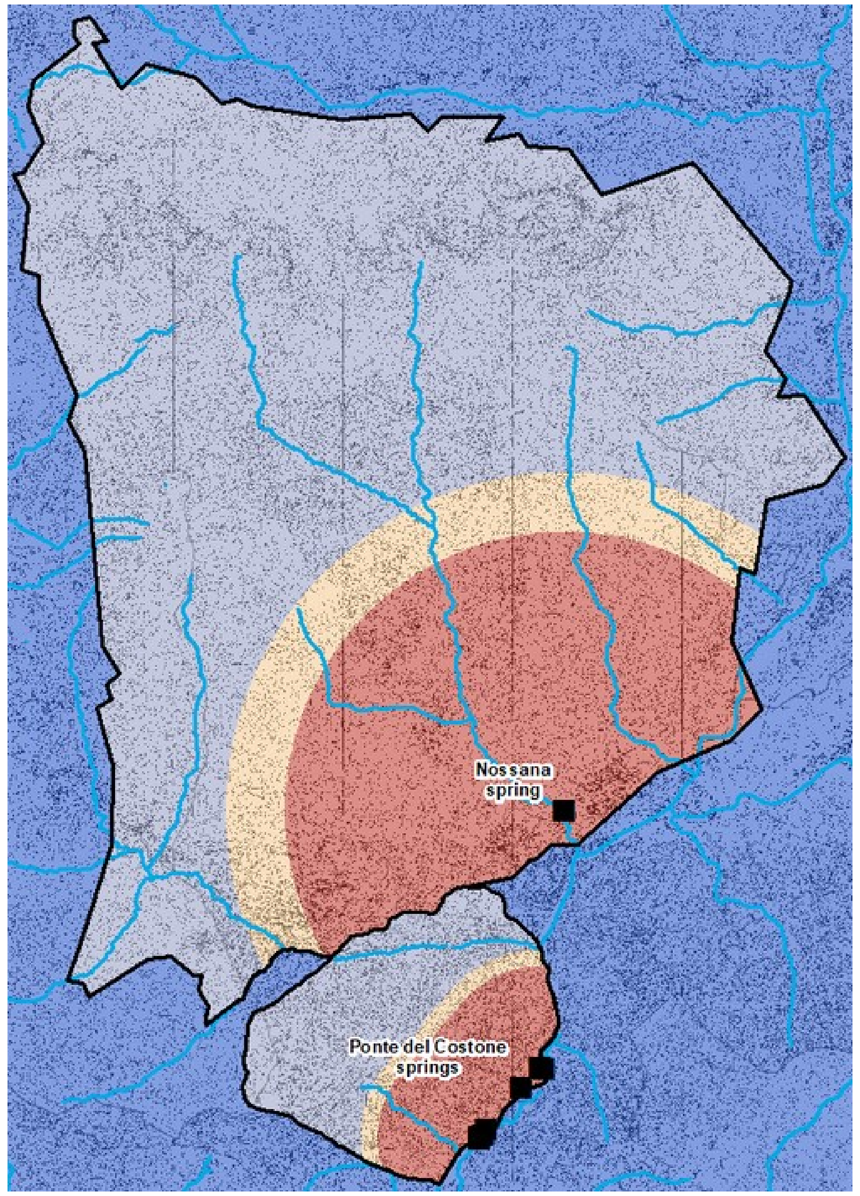
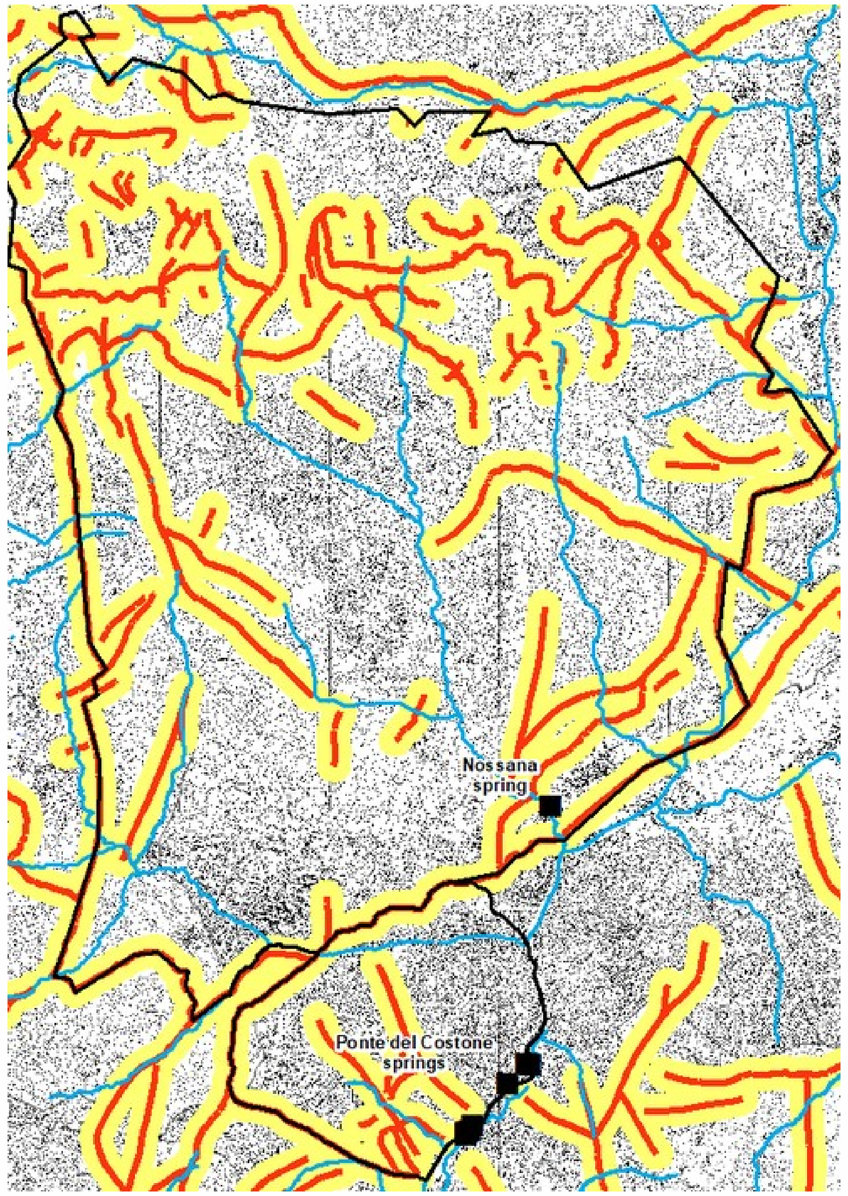
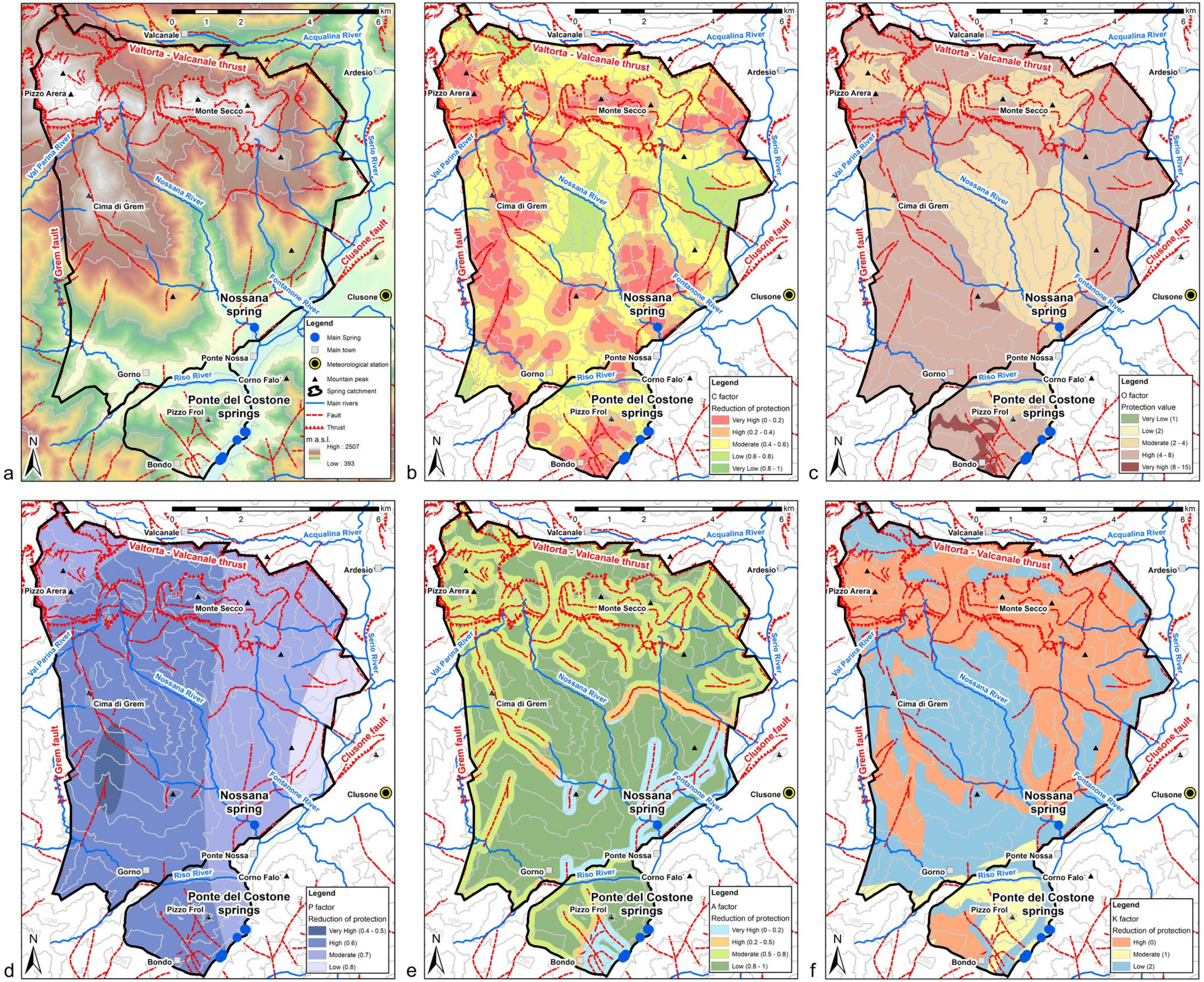
COPA+K MAP



Distances to spring



Buffer 200 m around main discontinuities



Factors

- a) Digital Elevation Model
- b) Concentration of flow
- c) Overlaying layers
- d) Precipitation
- e) Association between discontinuities and their distance to spring
- f) Karst network development

Results

35.6% to 23.6%

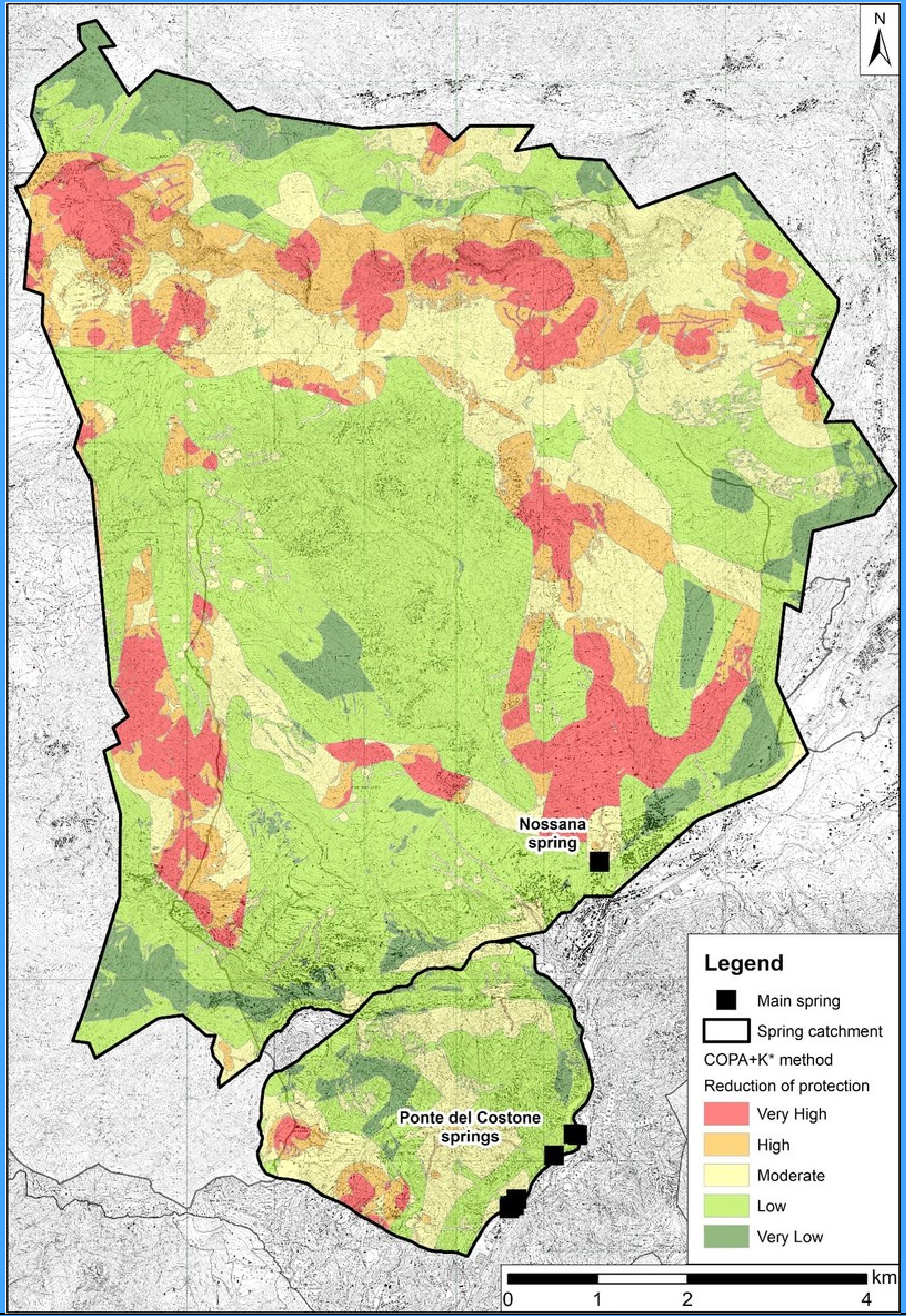
CONSIDERING THE MOST VULNERABLE CLASSES (VH AND H), THE VALUES MOVE FROM 35.6% (COP) TO 23.6% (COPA+K) OVER THE WHOLE STUDY AREA.

The COPA+K method allows the identification of more restricted areas than COP.

+12.3%

THE PERCENTAGE DIFFERENCE INCREASED BY 12.3%, EMPHASIZING THE GREATER SUSCEPTIBILITY OF THE NOSSANA SYSTEM

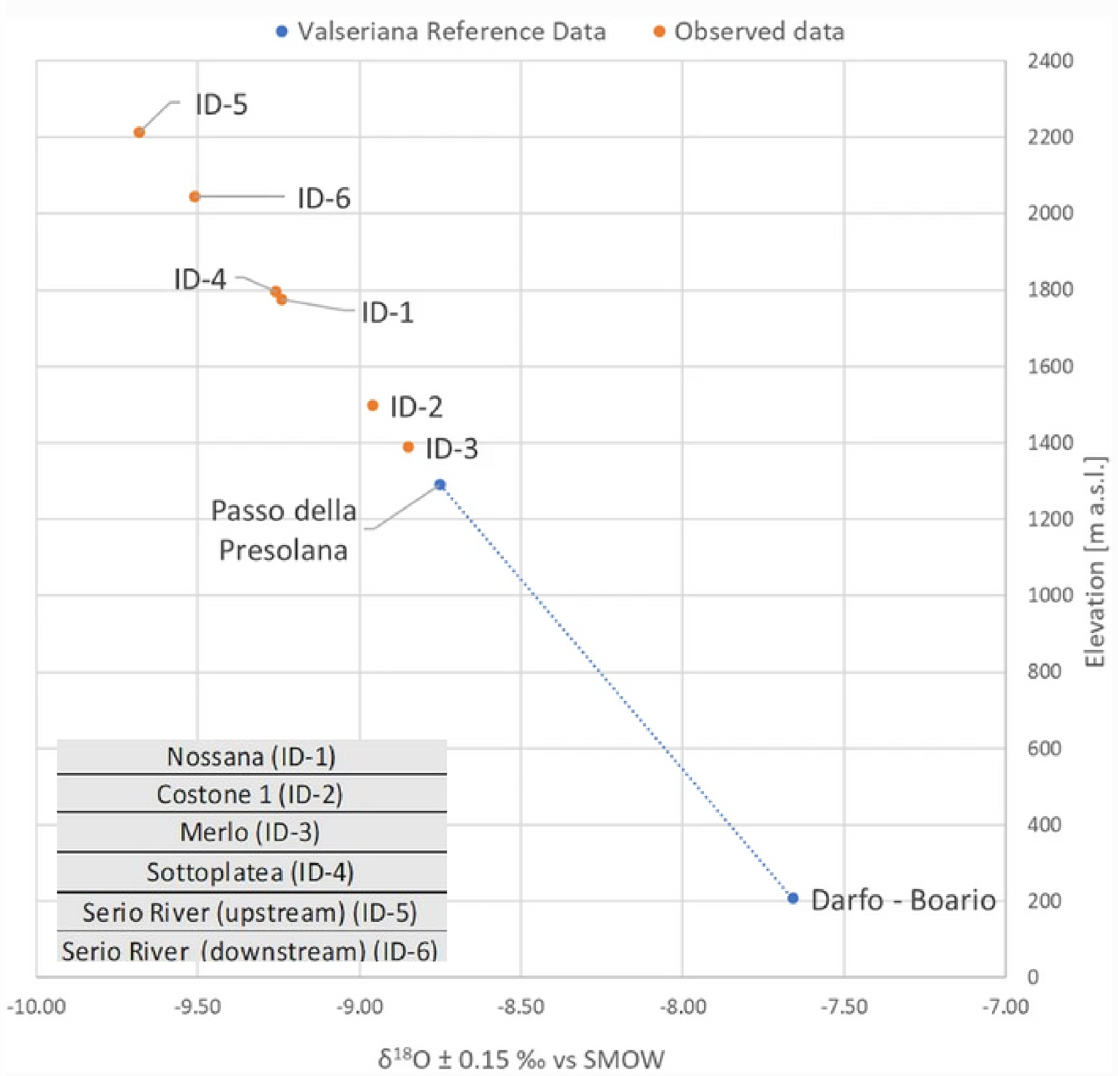
COPA+K made possible to better differentiate the areas of greatest vulnerability in the two considered catchments



Validation map process

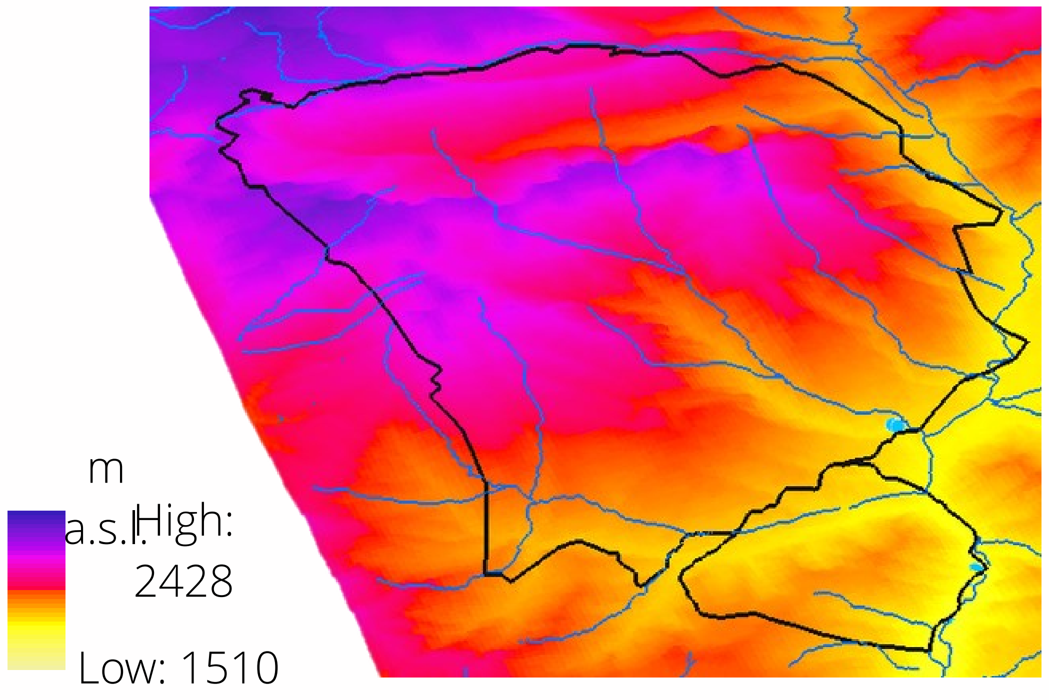
- From the relationship given by the **local isotopic** line, it was possible to estimate the mean elevation of recharge areas of the Nossana and Ponte del Costone springs;

Nossana spring --> 1776 m a.s.l.
Costone spring average --> 1561 m a.s.l.

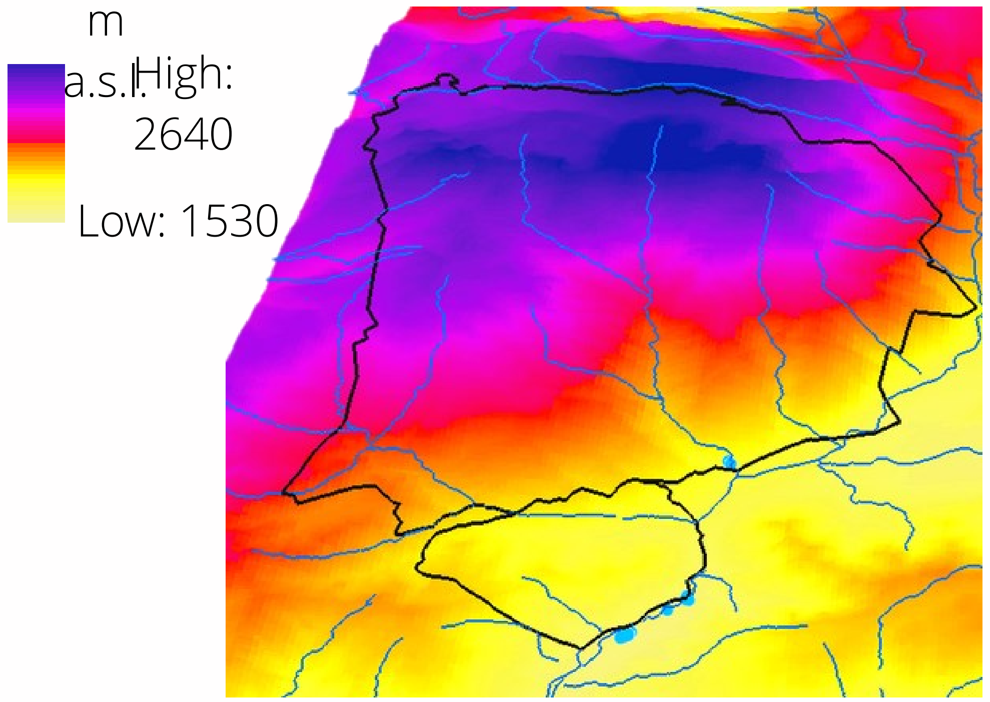


- Mean annual precipitation data from 10 ARPA meteorological stations were interpolated to obtain a gridded (50x50 m) altitude-dependent precipitation distribution --> TPS and IDW;

THIN PLATE SLINE



INVERSE DISTANCE WEIGHTING



- The elevation values of the high vulnerability areas and related precipitation amounts were extrapolated from the DTM and the precipitation distribution maps;

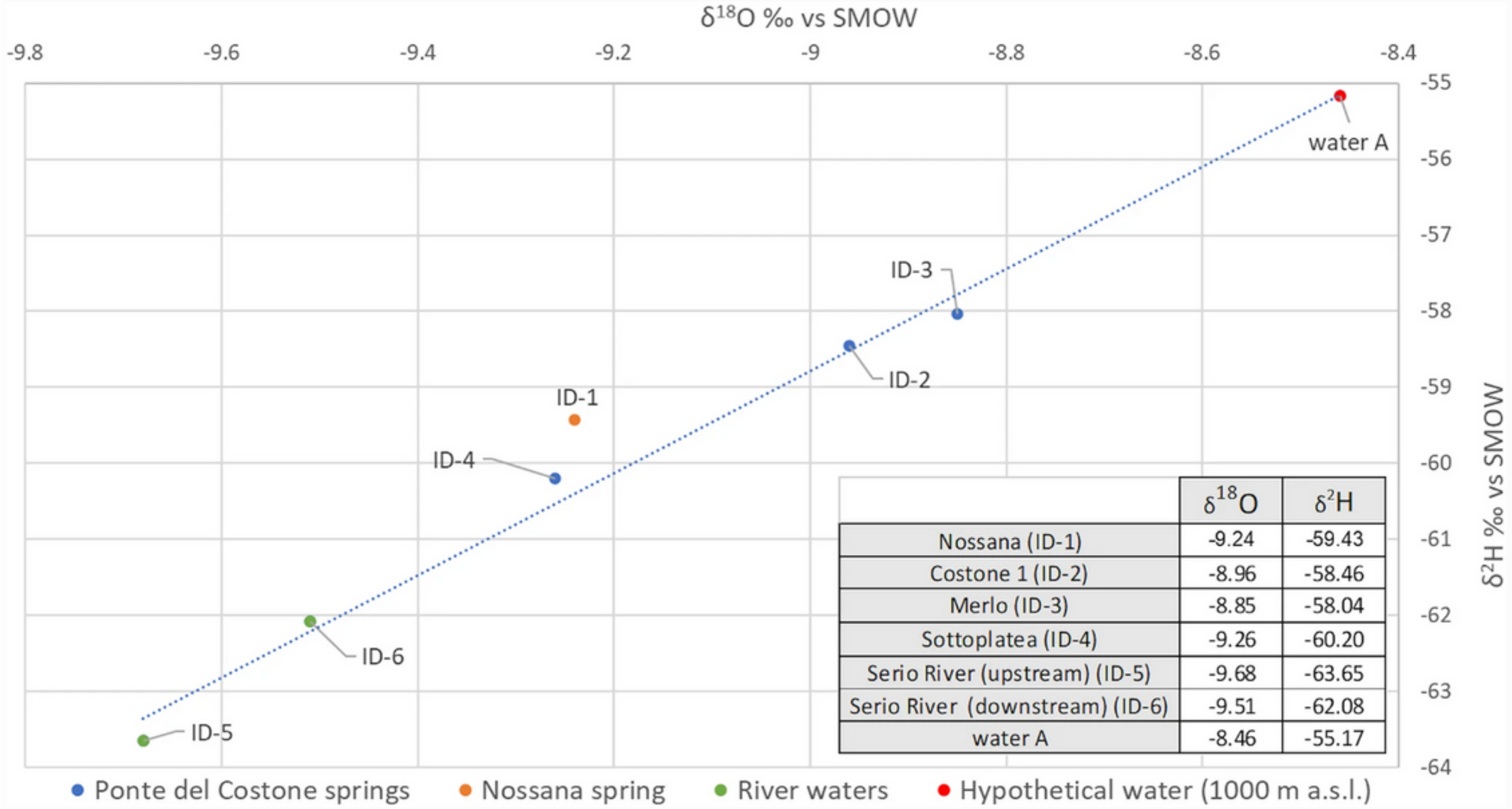
- After performing a weighted average, the mean elevations of the high vulnerability areas were obtained for the Nossana and Ponte del Costone catchments to be compared with the results of isotopic correlation.

Validation map process

Applying the weighted average for the TPS and IDW interpolation methods, the values are within the range of elevation estimated by isotopic correlation (±106 m).

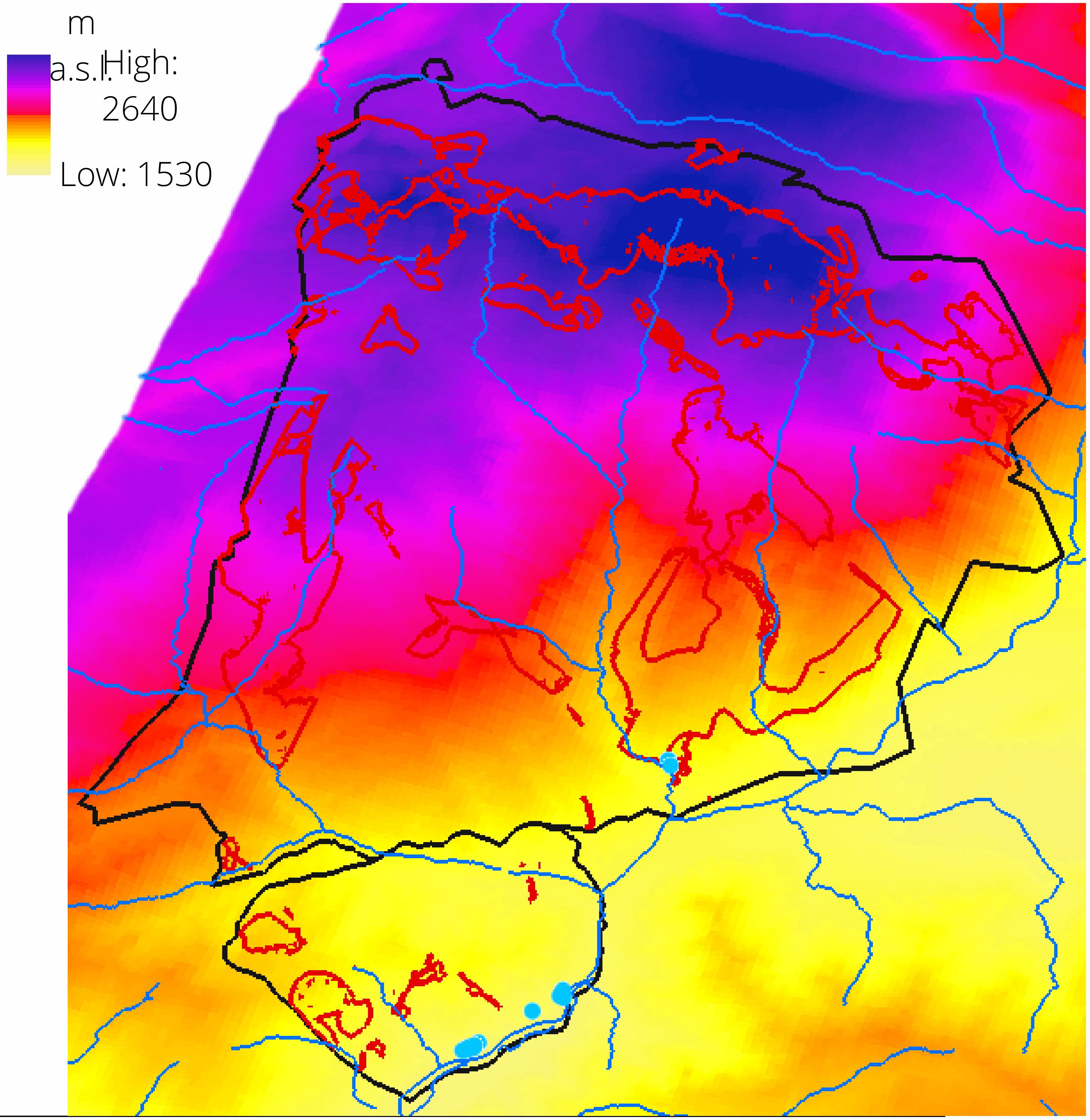
Catchment (m a.s.l.)	TPS	IDW	isotopic correlation
Nossana	1670	1856	1776
Ponte del Costone	923	923	1561

water A → δ18O value of a hypothetical recharge water A at the 1000 m elevation by exploiting local isotopic correlation



	$\delta^{18}O$	$\delta^{2}H$
Nossana (ID-1)	-9.24	-59.43
Costone 1 (ID-2)	-8.96	-58.46
Merlo (ID-3)	-8.85	-58.04
Sottoplatea (ID-4)	-9.26	-60.20
Serio River (upstream) (ID-5)	-9.68	-63.65
Serio River (downstream) (ID-6)	-9.51	-62.08
water A	-8.46	-55.17

The demonstration of this mixing encourages the hypothesis of the validation of the map, given the excellent result obtained for the Nossana catchment.



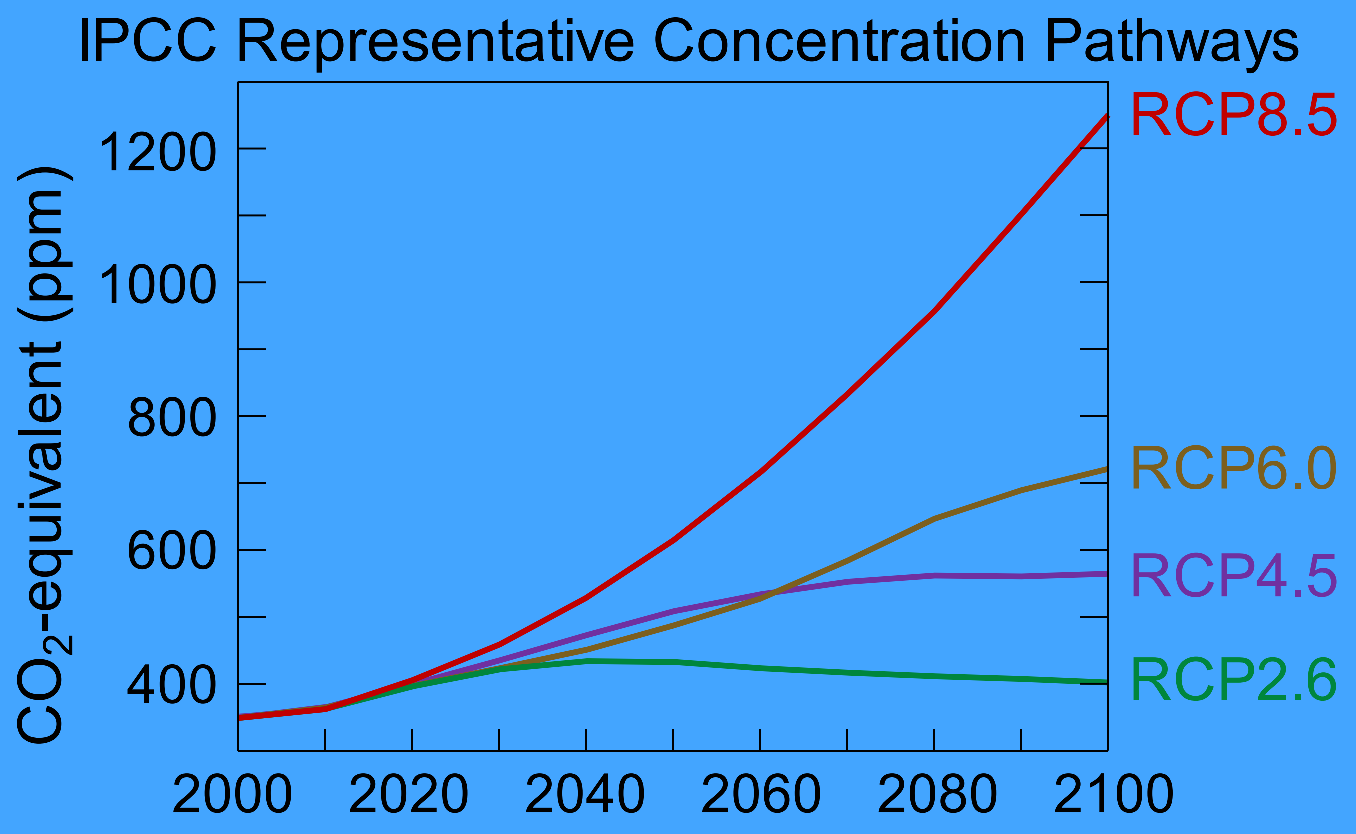
- The **COPA+K** approach **allowed determining more precise areas** compared to COP (most vulnerable areas from 35.6% to 23.6%);
- **COPA+K** method **underlined the different responses** of the two considered water systems (percentage difference from 5.2% for COP to 17.5% for COPA+K approach);
- **The COPA+K vulnerability map was validated** by correlating δ18O values and precipitation altitude through a local isotopic correlation from reference data;
- A **commingling** of the **Ponte del Costone springs** with the waters of the **Serio river** has been **demonstrated**;
- The **COPA+K** has been shown to be an **excellent method for** the entire karst environment of the **Pre-Alpine belt** due to its easy applicability --> **NO lot of data and NO considerable computational effort.**

Projections of **Future Discharges** under Climate Change

- Quantification of the expected changes in precipitation and temperature in the study area (reference period 1998-2017)
- Calibration and validation of a hydrological lumped-parameter model based on observed data
- Recognition of possible limits in the future utilization of the spring as a drinking supply (2021-2100)

- Daily discharge of Nossana spring from 1998 to 2017 (UniAcque S.p.A);
- Daily precipitation and temperature from 1998 to 2017 (ARPA Lombardia);
- Temperature and precipitation data from 9 RCMs runs including 3 IPCC different scenarios based on greenhouse gasses emission*.

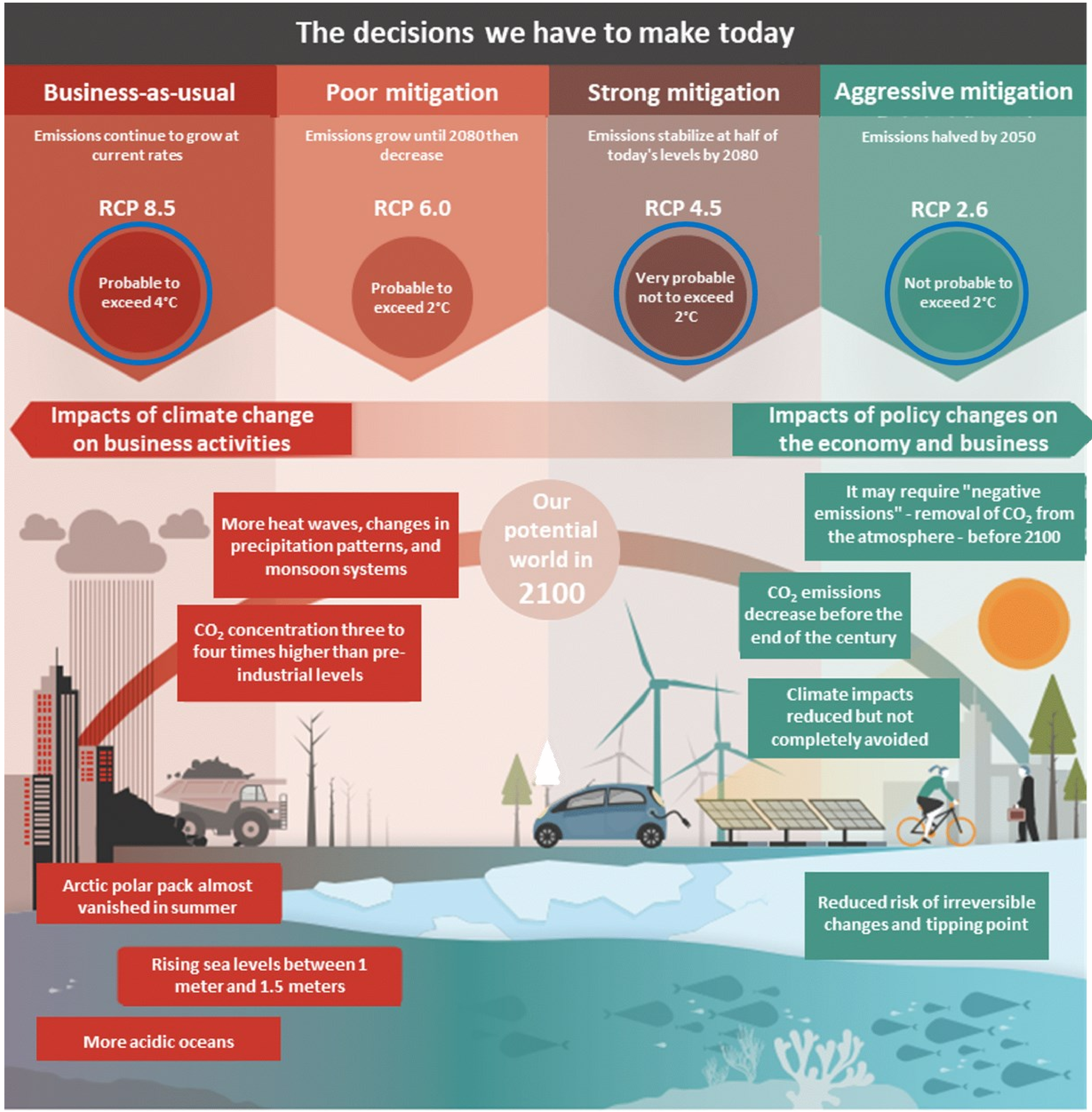
*Coordinated Regional Climate Downscaling Experiment (CORDEX) - www.euro-cordex.net



*fifth IPCC Assessment Report

Considered scenarios

From AR5 – IPPC, 2014.



The decisions we have to make today

Business-as-usual	Poor mitigation	Strong mitigation	Aggressive mitigation
Emissions continue to grow at current rates	Emissions grow until 2080 then decrease	Emissions stabilize at half of today's levels by 2080	Emissions halved by 2050
RCP 8.5	RCP 6.0	RCP 4.5	RCP 2.6
Probable to exceed 4°C	Probable to exceed 2°C	Very probable not to exceed 2°C	Not probable to exceed 2°C

Impacts of climate change on business activities

More heat waves, changes in precipitation patterns, and monsoon systems

CO_2 concentration three to four times higher than pre-industrial levels

Arctic polar pack almost vanished in summer

Rising sea levels between 1 meter and 1.5 meters

More acidic oceans

Our potential world in 2100

Impacts of policy changes on the economy and business

It may require "negative emissions" - removal of CO_2 from the atmosphere - before 2100

CO_2 emissions decrease before the end of the century

Climate impacts reduced but not completely avoided

Reduced risk of irreversible changes and tipping point

For this research, scenarios related to RCP 2.6 (low), RCP 4.5 (medium), and RCP 8.5 (high degree of greenhouse gas emissions) were considered.

The IPCC (Intergovernmental Panel on Climate Change) analyzed 4 potential future scenarios that depend on policy-makers' decisions to reduce greenhouse gas emissions.

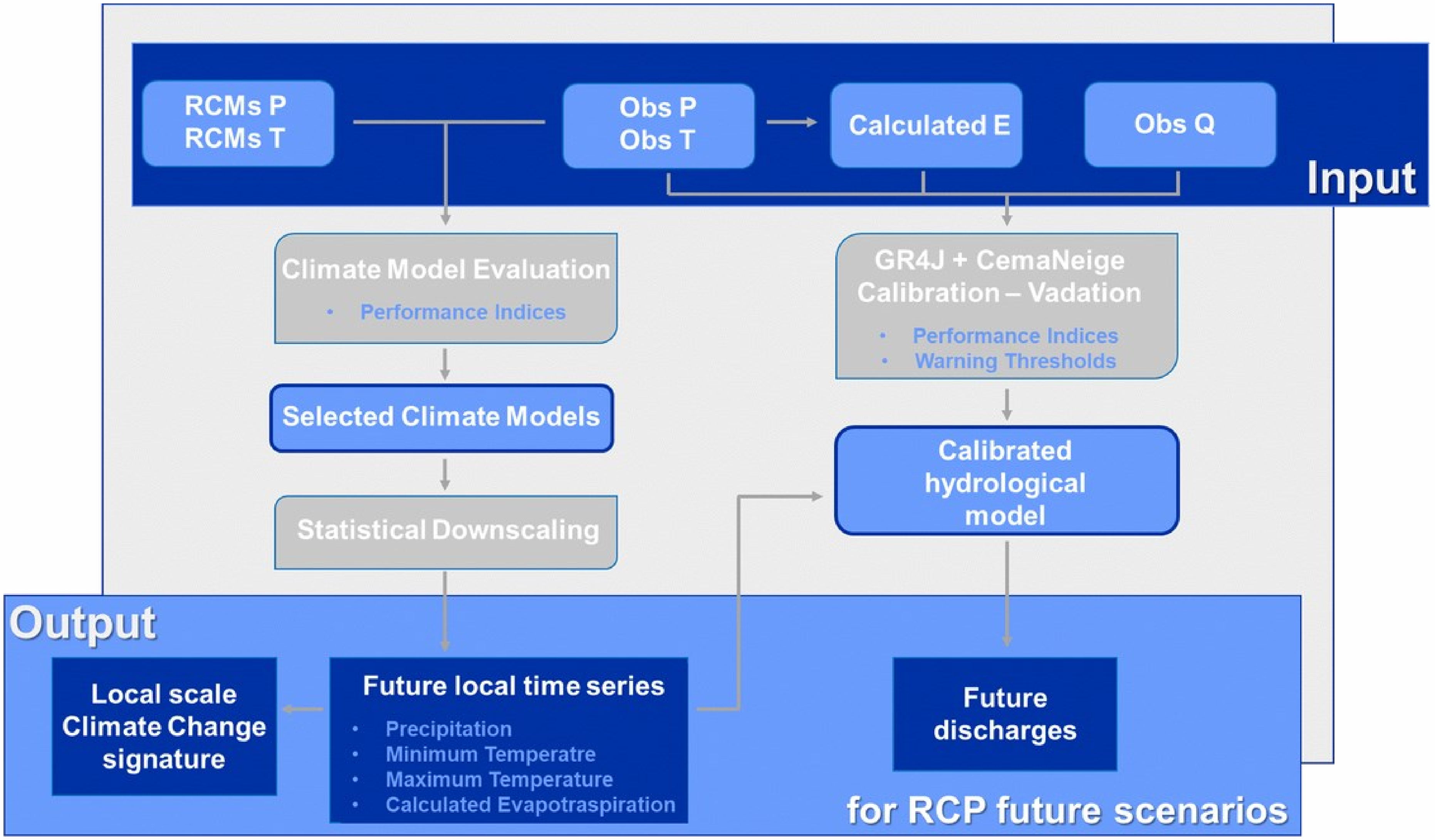
Method

RCP 2.6 --> 3 models
RCP 4.5 --> 3 models
RCP 8.5 --> 3 models

p1 2021-2040
p2 2041-2060
p3 2061-2080
p4 2081-2100

Warning threholds:
Q 1.32 mc/s for winter
Q 1.52 mc/s for summer

Reference period 1998-2017



RCMs P
RCMs T

Obs P
Obs T

Calculated E

Obs Q

Input

Climate Model Evaluation
- Performance Indices

GR4J + CemaNeige
Calibration – Vadation
- Performance Indices
- Warning Thresholds

Selected Climate Models

Calibrated hydrological model

Statistical Downscaling

Output

Local scale Climate Change signature

Future local time series
- Precipitation
- Minimum Temperatre
- Maximum Temperature
- Calculated Evapotraspiration

Future discharges

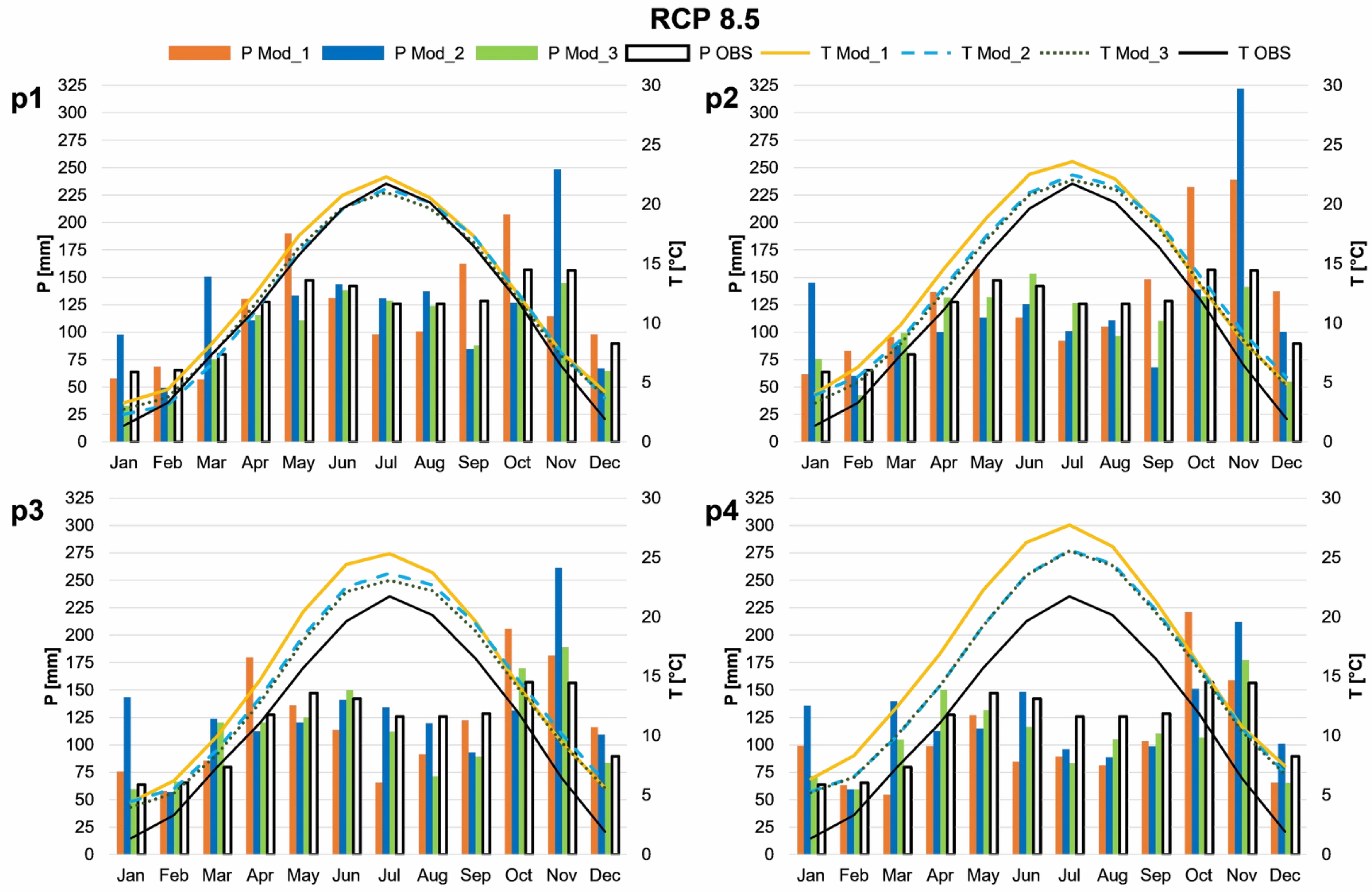
for RCP future scenarios

	Precipitation			Tmin			Tmax		
Model	NSE	MAE (mm)	%MAE	NSE	MAE (°C)	%MAE	NSE	MAE (°C)	%MAE
Mod_1 RCP 2.6	0.79	12.35	10.71	0.96	1.10	17.69	0.97	1.18	7.09
Mod_1 RCP 4.5	0.66	14.97	12.97	0.97	1.00	17.19	0.97	1.08	6.48
Mod_1 RCP 8.5	0.76	12.71	11.20	0.97	1.00	15.96	0.98	0.90	5.43
Mod_2 RCP 2.6	0.31	19.81	17.16	0.97	0.90	14.20	0.97	0.99	5.95
Mod_2 RCP 4.5	0.52	17.44	15.12	0.97	1.00	16.13	0.96	1.27	7.65
Mod_2 RCP 8.5	0.31	22.90	19.85	0.97	0.90	15.42	0.96	1.28	7.66
Mod_3 RCP 2.6	0.23	20.53	17.79	0.97	1.00	15.96	0.96	1.19	7.14
Mod_3 RCP 4.5	0.37	17.17	14.88	0.98	0.80	12.79	0.97	0.99	5.95
Mod_3 RCP 8.5	0.52	17.78	15.41	0.98	0.80	12.69	0.97	0.98	5.88

Precipitation --> NSE > 0.0; MAE < 20%
Temperature --> NSE > 0.8; MAE < 20%

Step 1 - Climate model evaluation

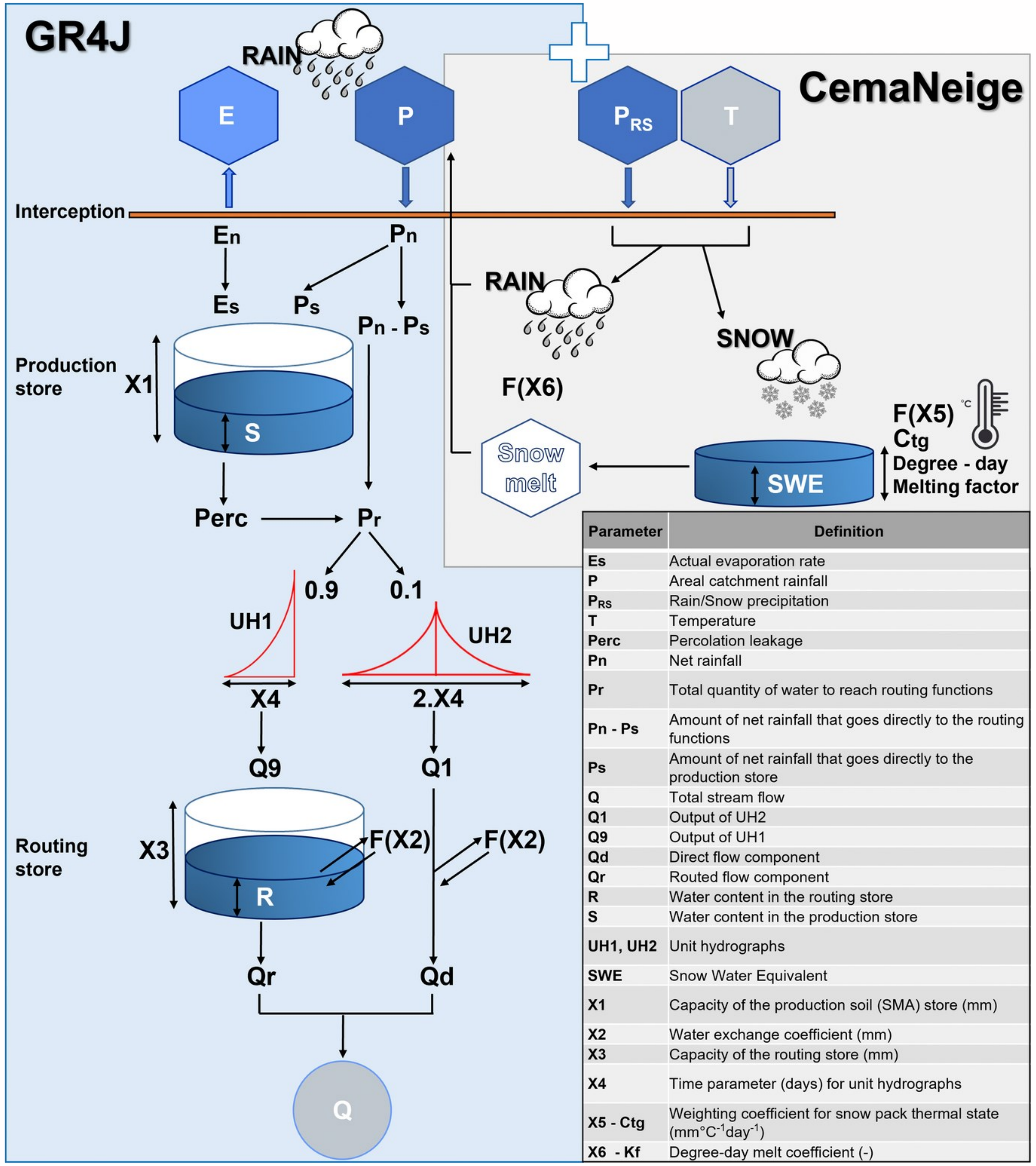
Step 2 – Statistical downscaling



Performed using Change Farctors and Weather simulator (RainSim V3.0 - Burton et al., 2008)

- Not all models agree regarding mean annual precipitation trends in different periods
- General summer precipitation decrease (Jul-Sep) and autumn increase (Oct-Nov) for all periods
- Temperature increases up to ≈ 5 °C (RCP 8.5 – p4)

Step 3 – Hydrologic Model Calibration



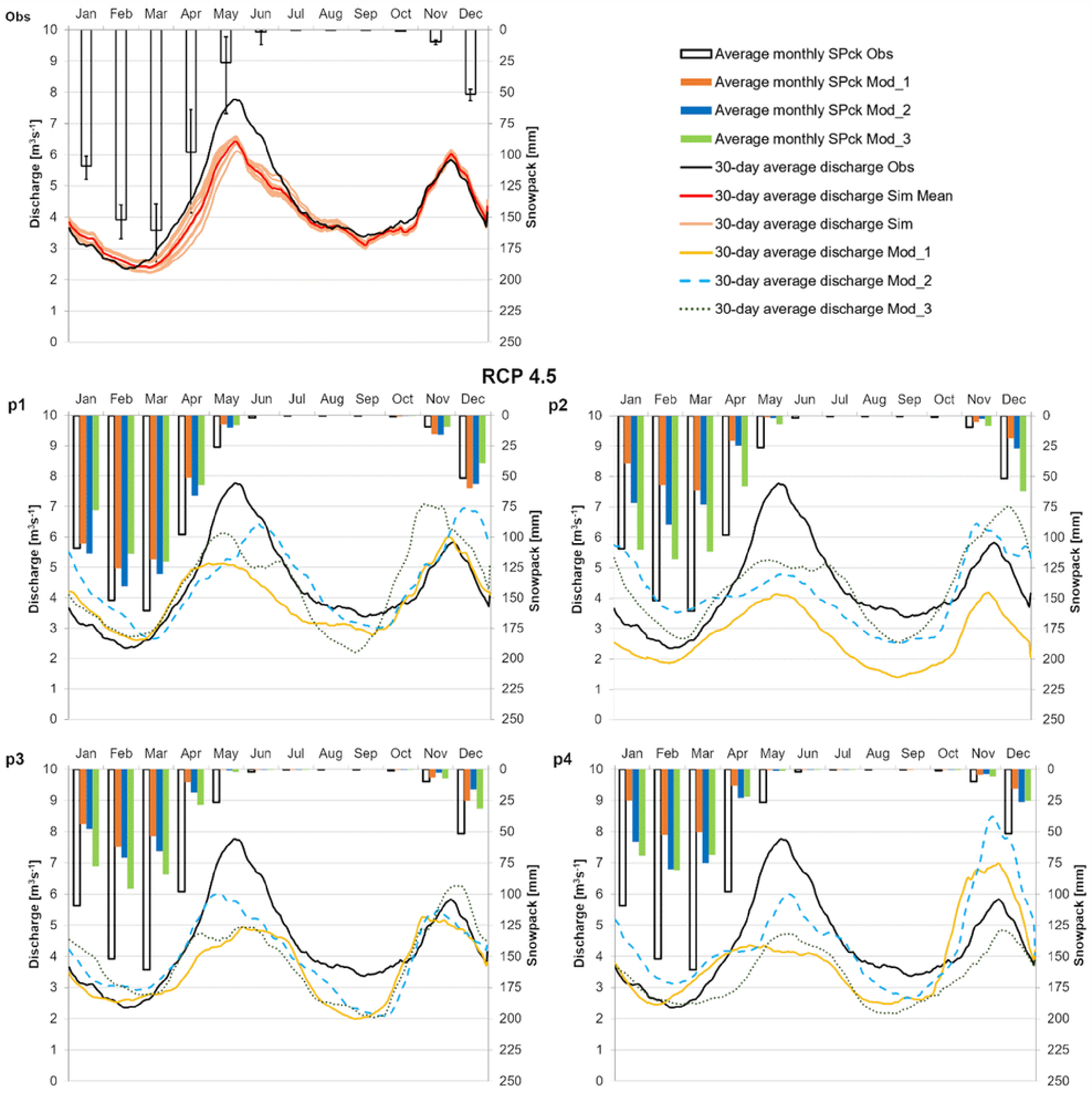
Parameter	Definition
Es	Actual evaporation rate
P	Areal catchment rainfall
P_{RS}	Rain/Snow precipitation
T	Temperature
Perc	Percolation leakage
Pn	Net rainfall
Pr	Total quantity of water to reach routing functions
Pn - Ps	Amount of net rainfall that goes directly to the routing functions
Ps	Amount of net rainfall that goes directly to the production store
Q	Total stream flow
Q1	Output of UH2
Q9	Output of UH1
Qd	Direct flow component
Qr	Routed flow component
R	Water content in the routing store
S	Water content in the production store
UH1, UH2	Unit hydrographs
SWE	Snow Water Equivalent
X1	Capacity of the production soil (SMA) store (mm)
X2	Water exchange coefficient (mm)
X3	Capacity of the routing store (mm)
X4	Time parameter (days) for unit hydrographs
X5 - Ctg	Weighting coefficient for snow pack thermal state (mm°C^{-1}day^{-1})
X6 - Kf	Degree-day melt coefficient (-)

Daily rainfall-runoff performed with **GR4J model** (Génie Rural Journalier with 4 parameters - Perrin et al., 2003), extended with the **CemaNeige snow accounting routine** (Valéry et al., 2014)

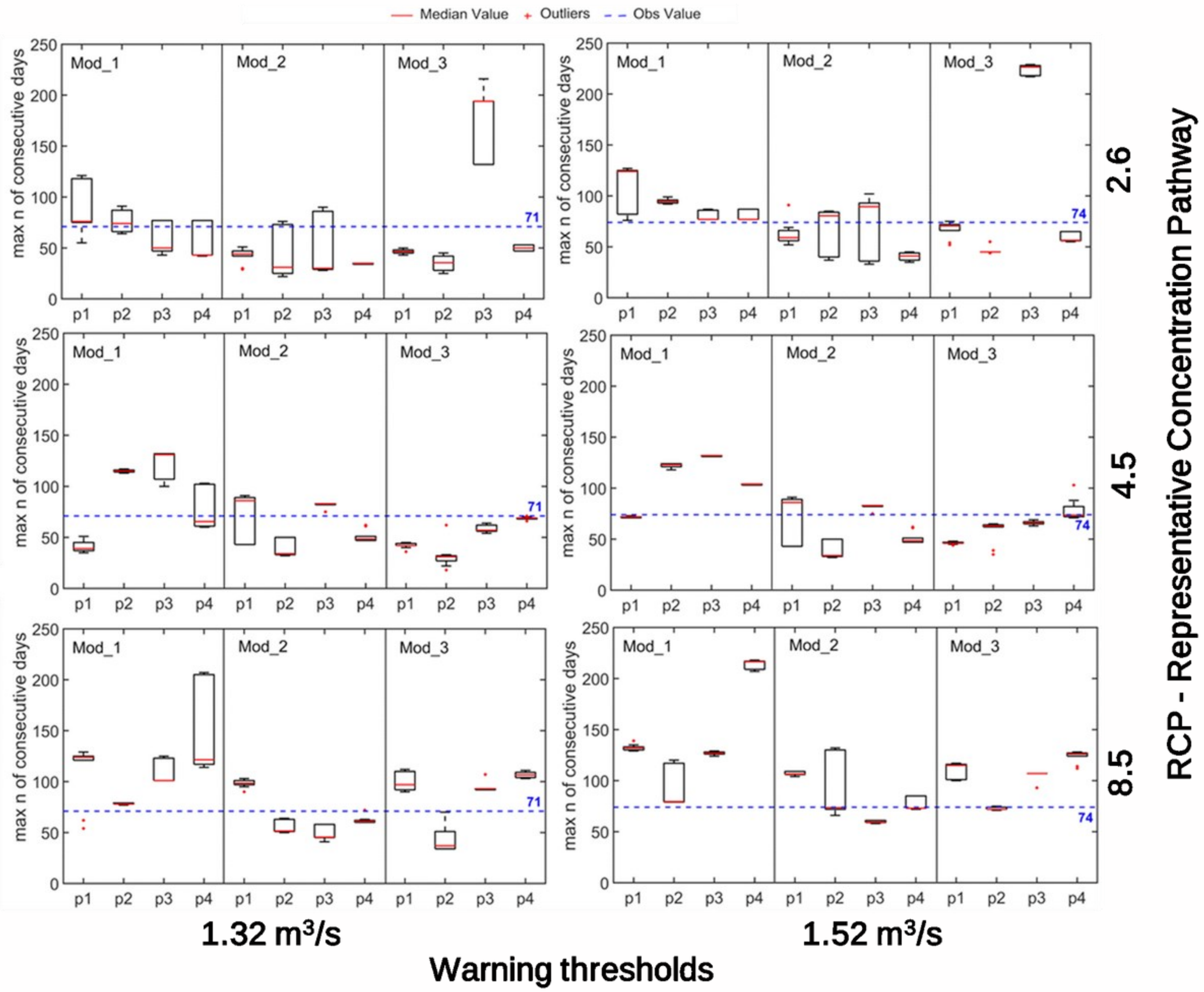
Random generation of **10,000 model parameter sets**
Model spin-up: 1998-1999
Calibration: 2000-2008
Validation: 2009-2017
Criteria 1: KGE > 0.70; lNSE > 0.5
Criteria 2: number of days and consecutive with discharge below warning thresholds

- 10 parameter sets
- Underestimation number of days below warning thresholds
- Maximum number of days below the warning threshold best indicator

Step 4 – Future discharges



- Longest period below the 1.32 m3/s warning threshold 36 extra days
- Longest period below the 1.52 m3/s warning threshold 64 extra days.



- Variation of recharge periods
- Variation of annual cycle trend
- Decrease in mean discharge

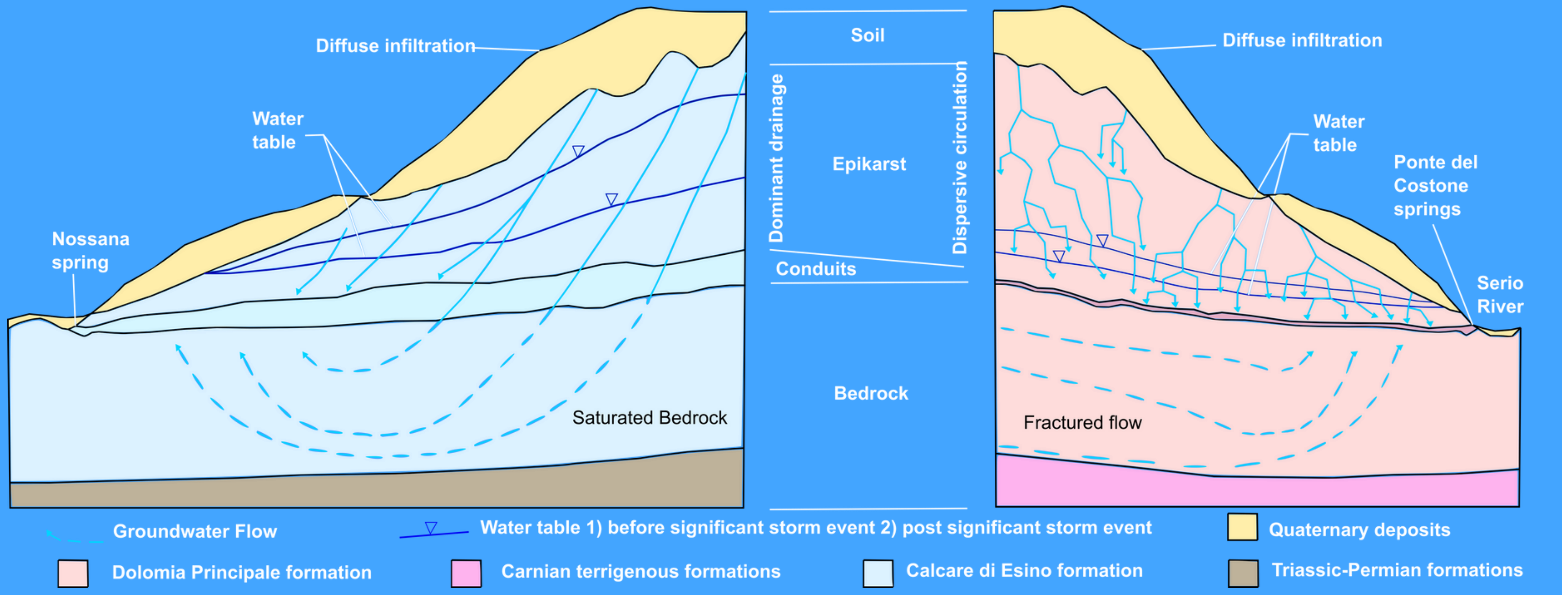
- Mean temperature will likely increase throughout the rest of the XXI century, from 0.7 °C in 2021–2040 (RCP4.5, Mod_2) to 5.8 °C in 2081–2100 (RCP8.5, Mod_1)
- No clear trend for precipitation, changes in mean annual rainfall varies between -18.5% (2041–2060, RCP4.5, Mod_2) and 15.1% (2041–2060, RCP8.5, Mod_2)
- Pronounced decrease of precipitation is expected in the summer period after 2060
- Mean discharges are generally projected to decrease in comparison to observed flow
- After 2060, the length of the periods with discharge lower than the warning thresholds is expected to increase. These periods could last up to 64 days (86%) longer than in 1998–2017

Additional water resources might be needed to satisfy the population water demand in the Nossana Spring area, especially after 2060

Take home message

Nossana and Ponte del Costone can be simplified with **hierarchical models** (Asante et al., 2018, White, 2002):

- Piston effect controlled by the amount of precipitation
- Diffuse infiltration in very different timing due to the different response to karst dissolution of the encasing rocks



The applied studies in the Valsieriana has demonstrated the importance of groundwater monitoring and characterization in order to gain a deeper understanding of the internal dynamics of water systems.

The future perspectives are to:

- repeat the use of these techniques to detect the actual qualitative-quantitative variations in the water resource
- Start investigating new additional water resources to meet water demand after 2060, as demonstrated by hydrological modeling.
- expand the investigation to neighboring catchments to understand the real potential of all spring water resources in the region

Thank you for attention!

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