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The exploitation of the middle Valseriana springs (northern Italy):

current situation, studies undertaken, and next challenges.

Sustain Valencia 2022
Achieving Sustainable Groundwater Management: Promising Directions and Unresolved Challenges

Valencia · October 6-8, 2022

UNIVERSITÀ DEGLI STUDI DI MILANO
DIPARTIMENTO DI SCIENZE DELLA TERRA "ARDITO DESIO"

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

All data used in these investigations were collected during the **2018-2019 biennium** with a special focus on the Nossana and Ponte del Costone springs.

GOALS

- Evaluate the current qualitative-quantitative status of Valseriana spring waters
- Assess the possible threats to water quality (identification of vulnerable areas)
- Quantify possible threats to water availability due to climate change.

OUTPUT

- 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

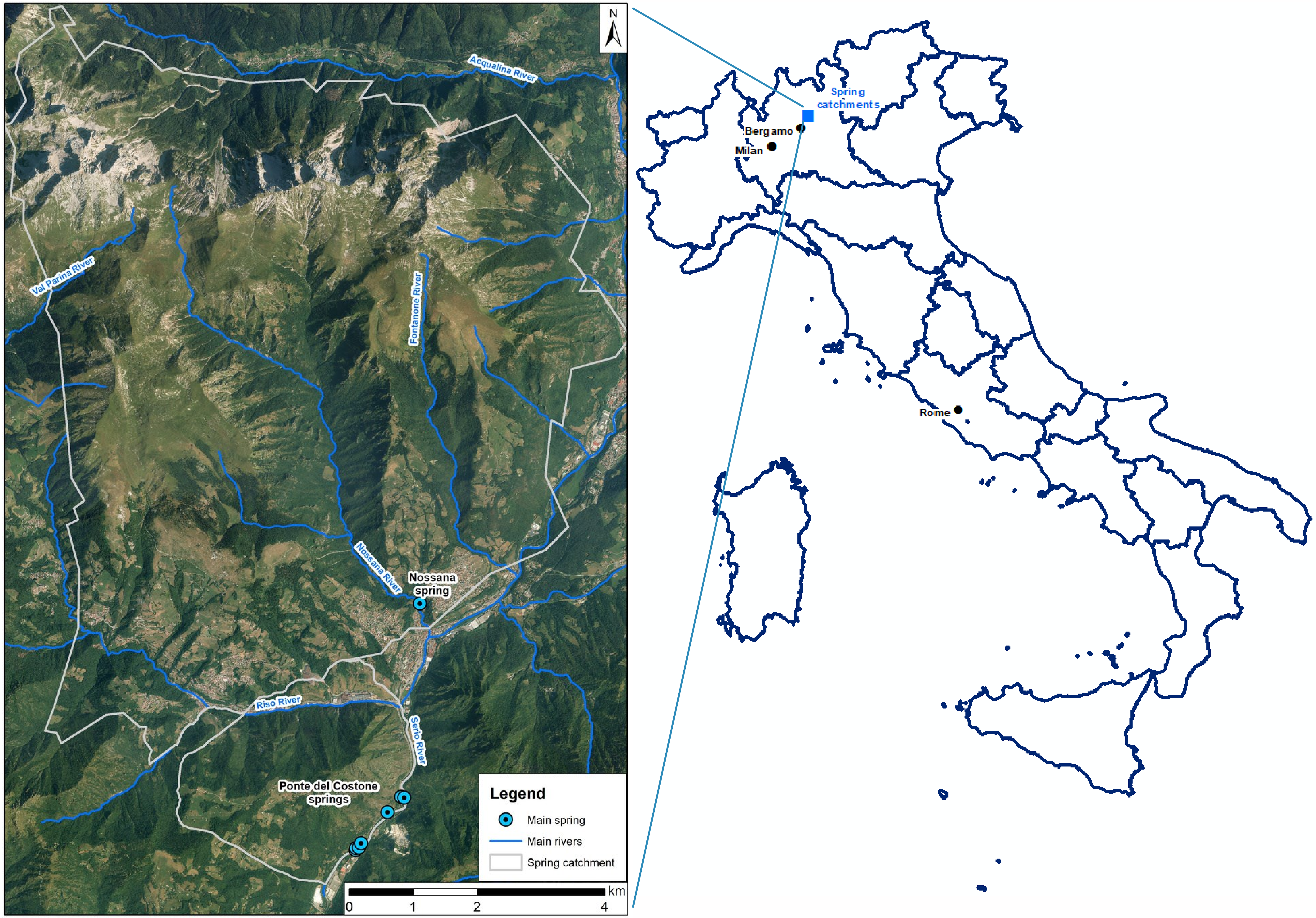
Study Area

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

- **Nossana** catchment: **80 km²**

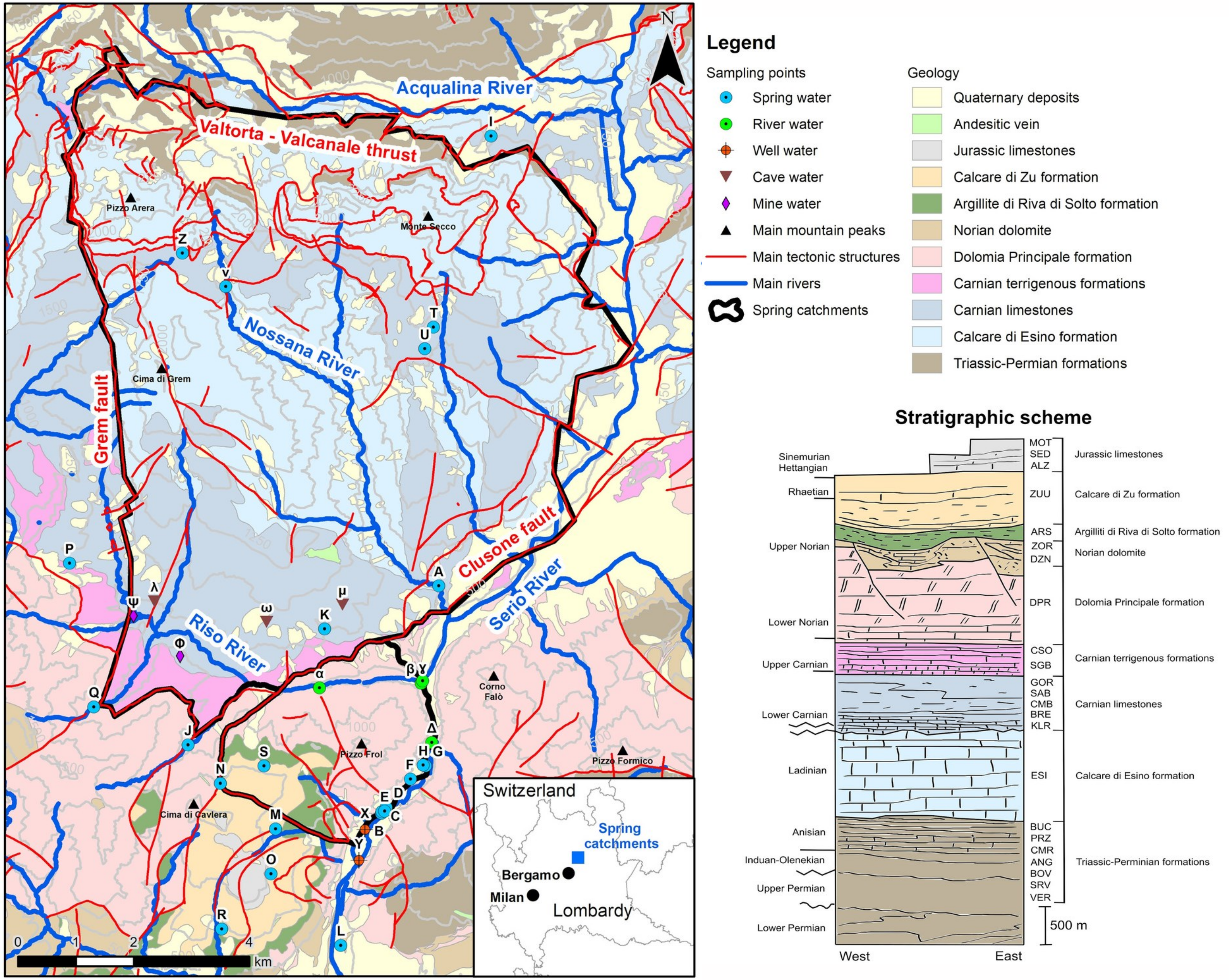
- **Ponte del Costone** catchment: **10 km²**

- **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

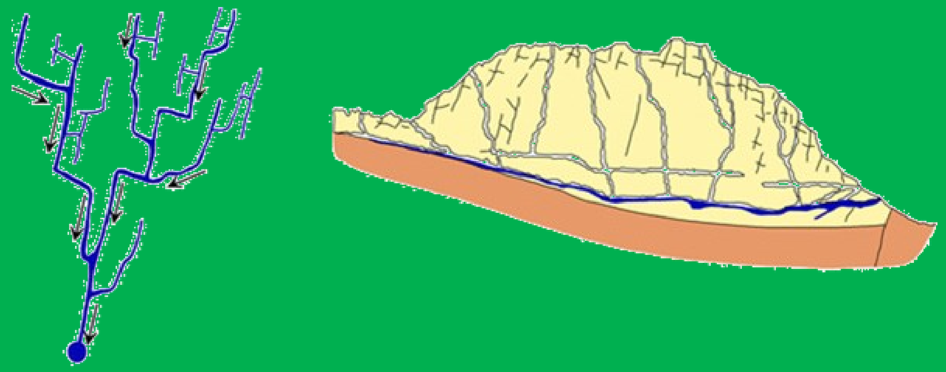
- The whole environment is dominated by **calcareous-dolomitic carbonate series**
- The **Nossana** aquifer is set in the **Calcare di Esino formation** (Ladin - Carnic age)
- The water system of **Ponte del Costone** is formed by 13 springs distributed in about 1 km along the Serio river and it has 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

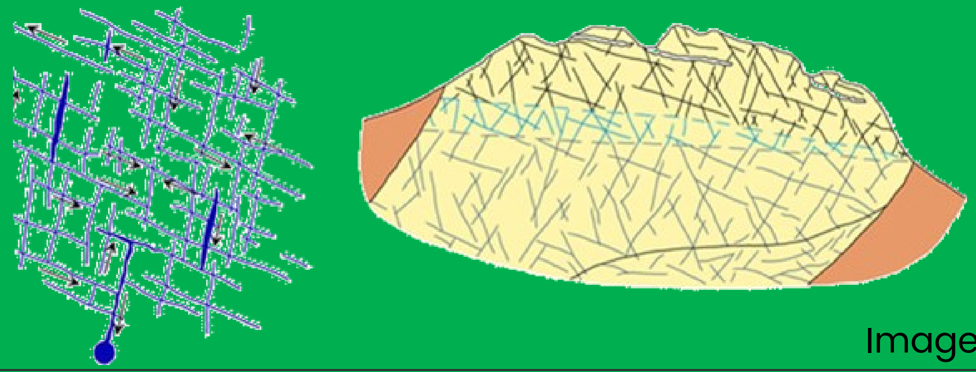
Nossana spring

- 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}

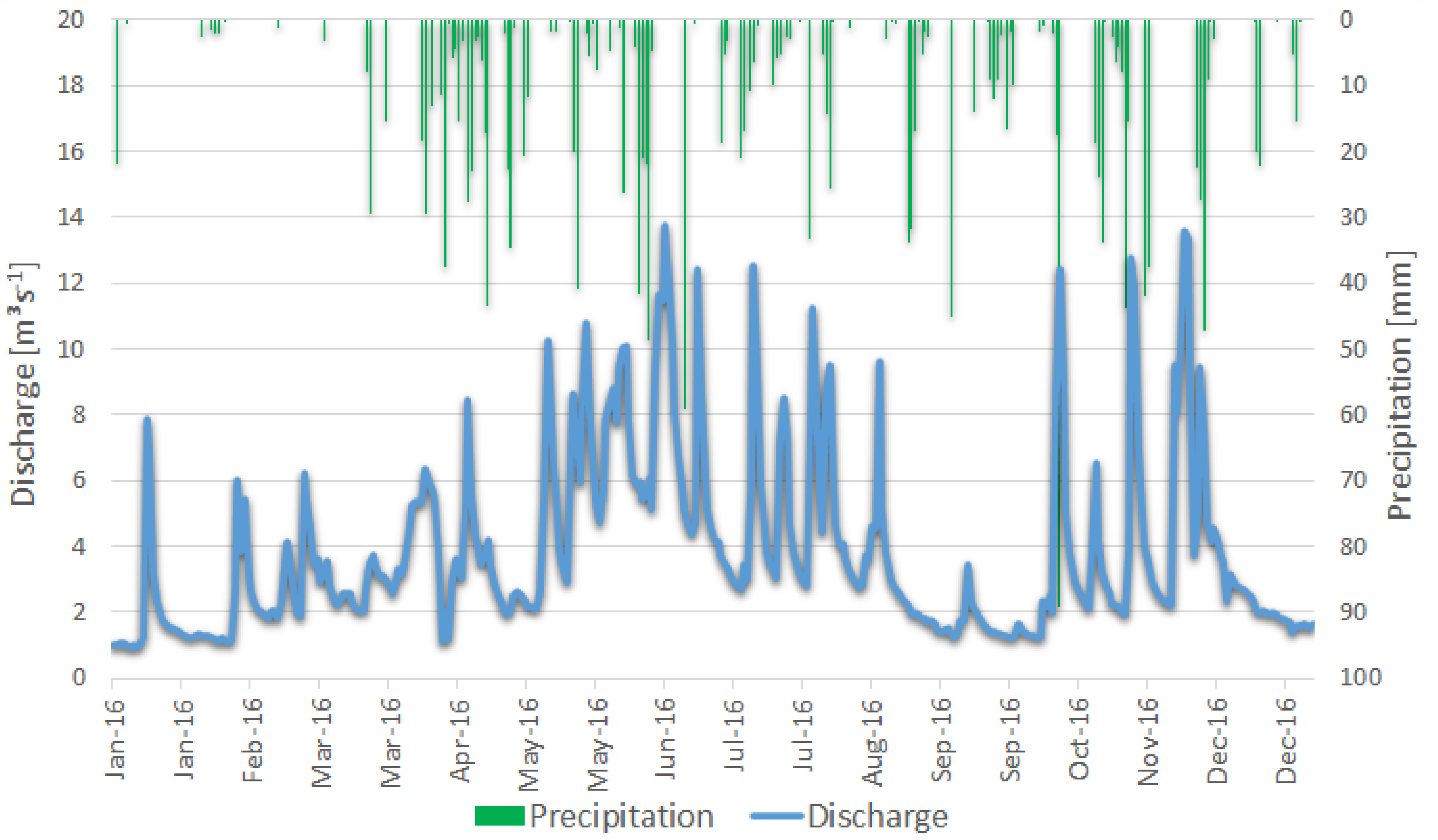


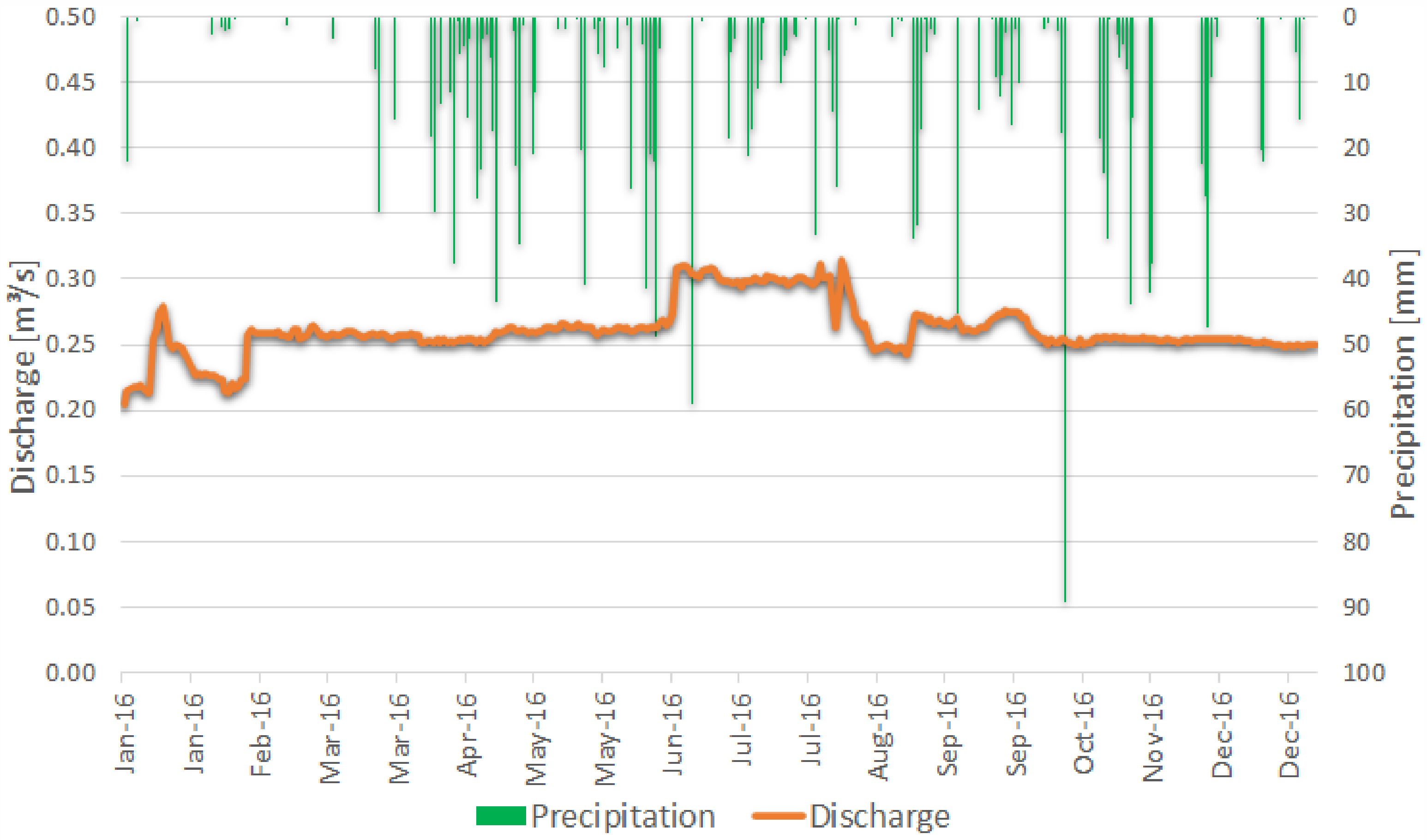
Ponte del Costone springs

- The Ponte del Costone cumulative discharge 0.15 - 0.45 m^3s^{-1}
- System with dispersive circulation
- Three main groups distribuited along Serio river: Galleria del Costone, Merlo, and Bosco (from South to North)



Images from Vigna & Banzato, 2015





Water chemical-physical monitoring

1 - Sampling Campaign (May 2018 - July 2019)

34 sampling sampling points

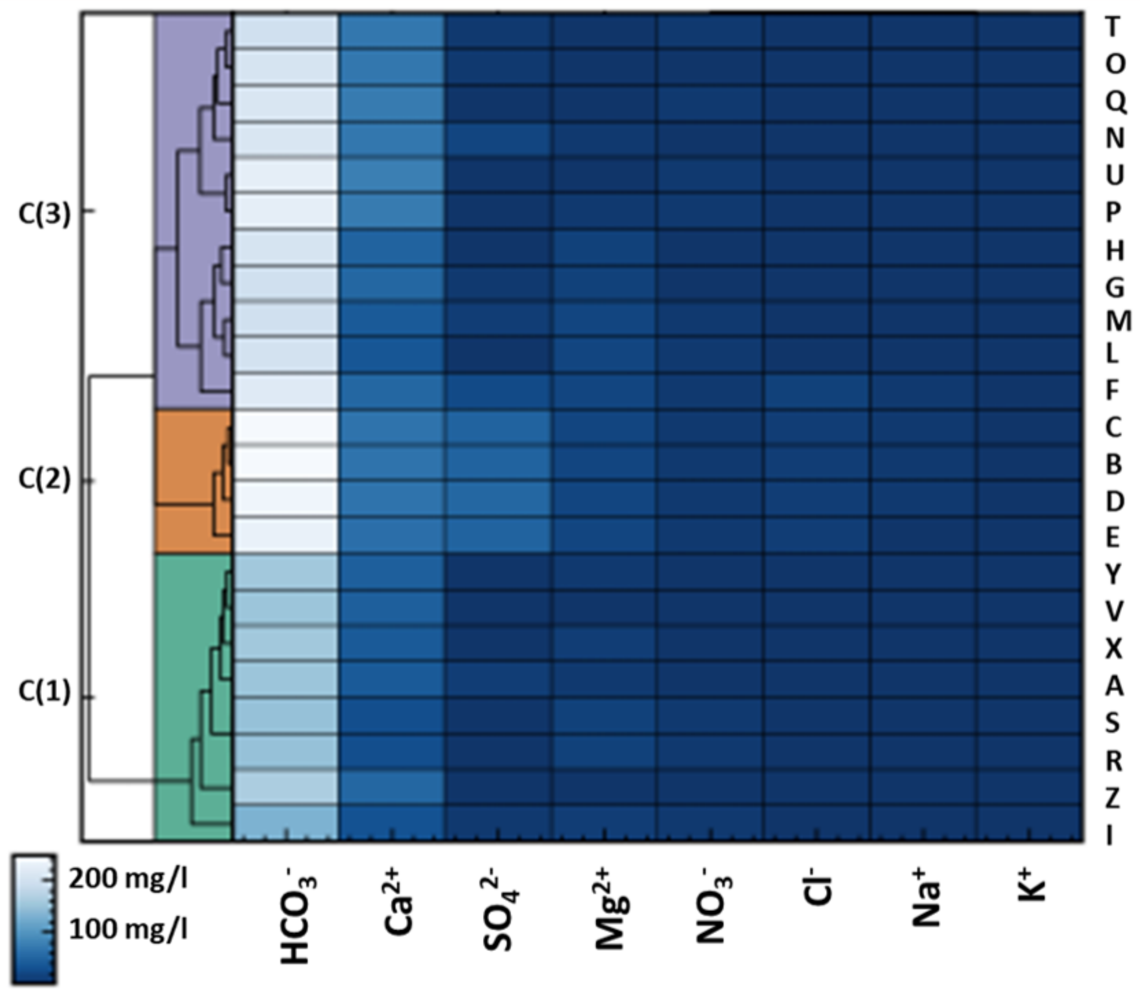
2 - Hydrochemical And Isotopic Analysis

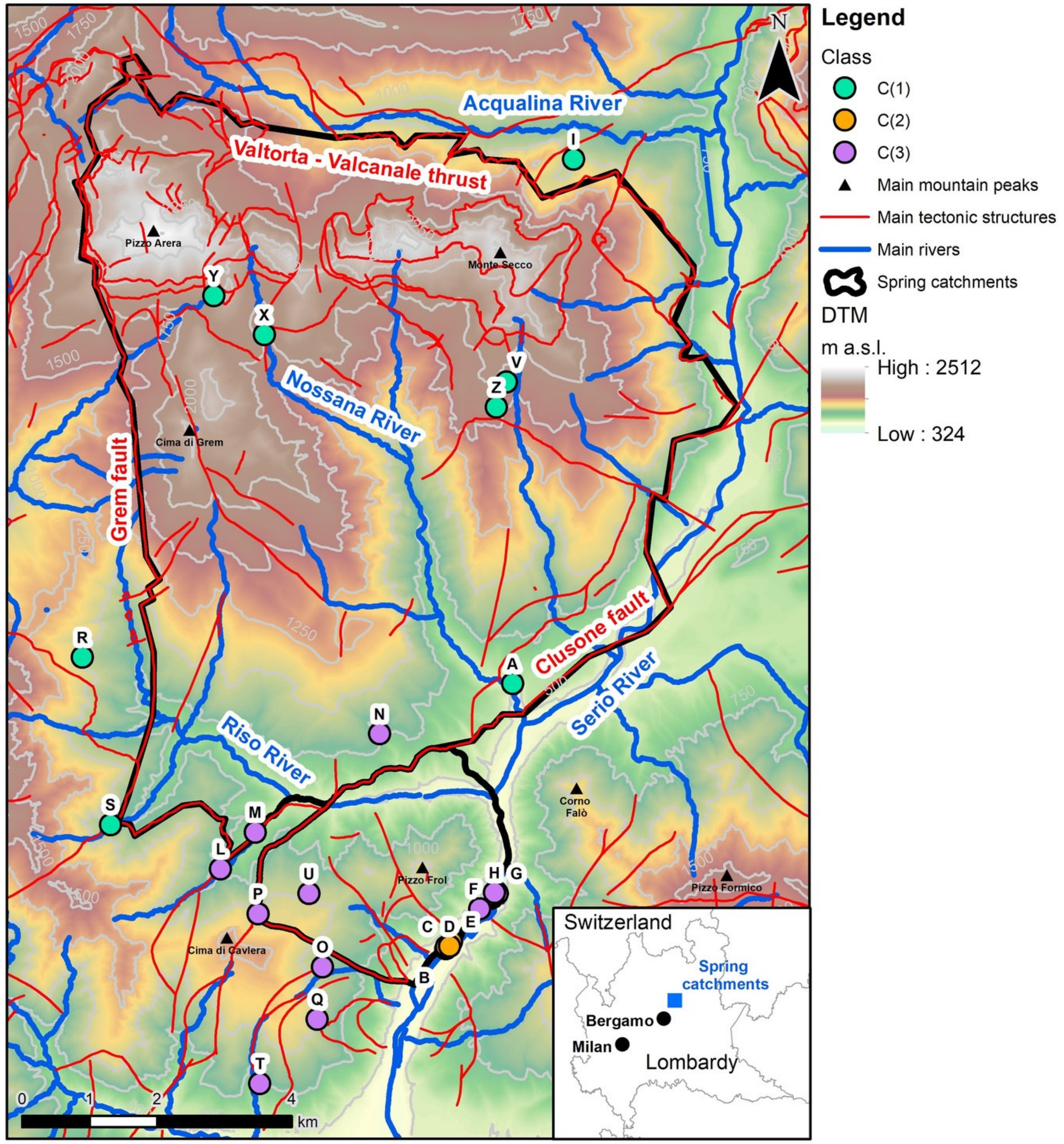
Chemical analyses, Stable isotopes analyses (^{18}O, ^{2}H, and ^{13}C), and the $^{3}H/^{3}He$ dating analyses

3 - Hydrochemical Characterization

Hierarchical Cluster analysis was performed considering major cations and anions

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



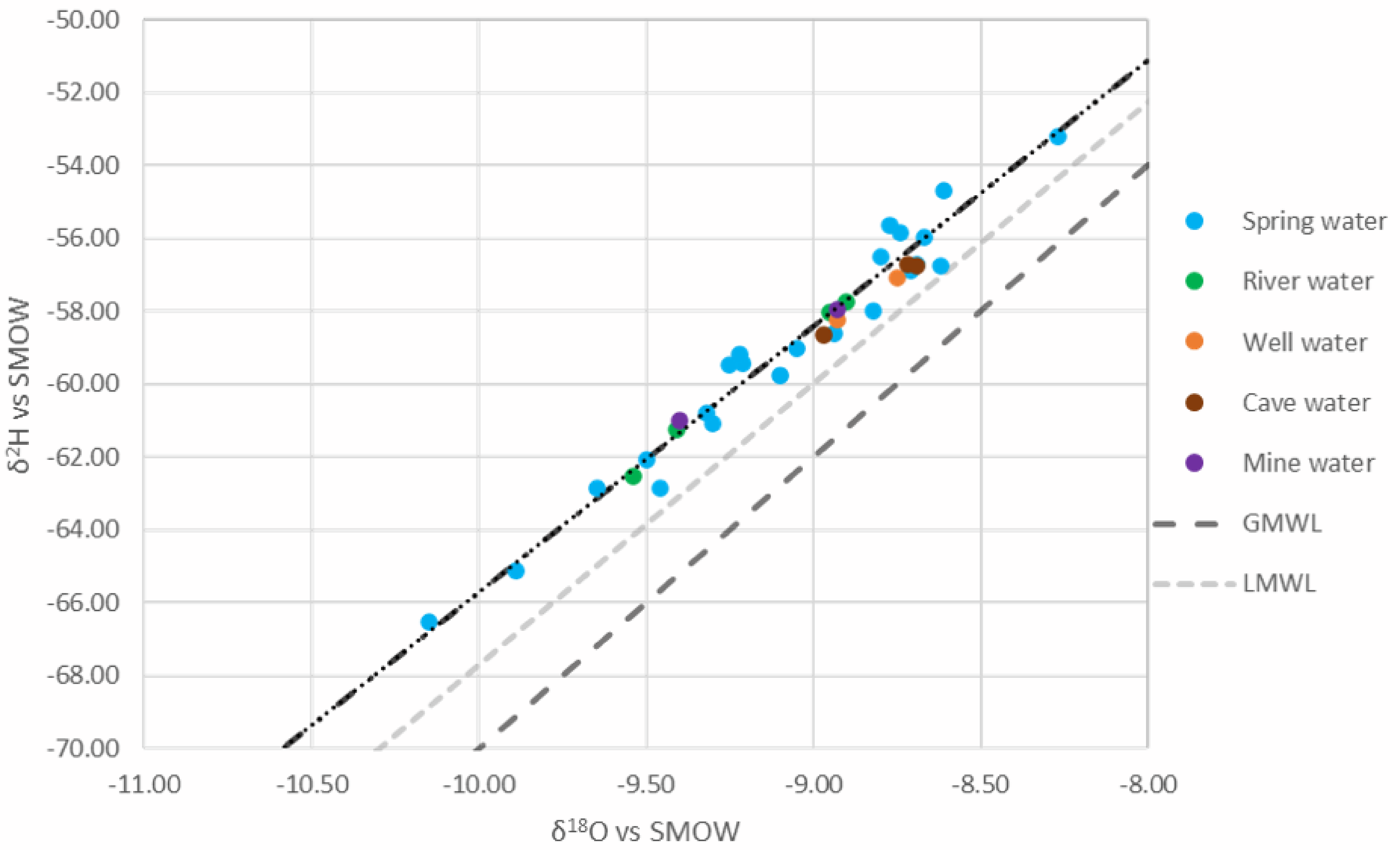


Isotopic features and
Resident time estimation

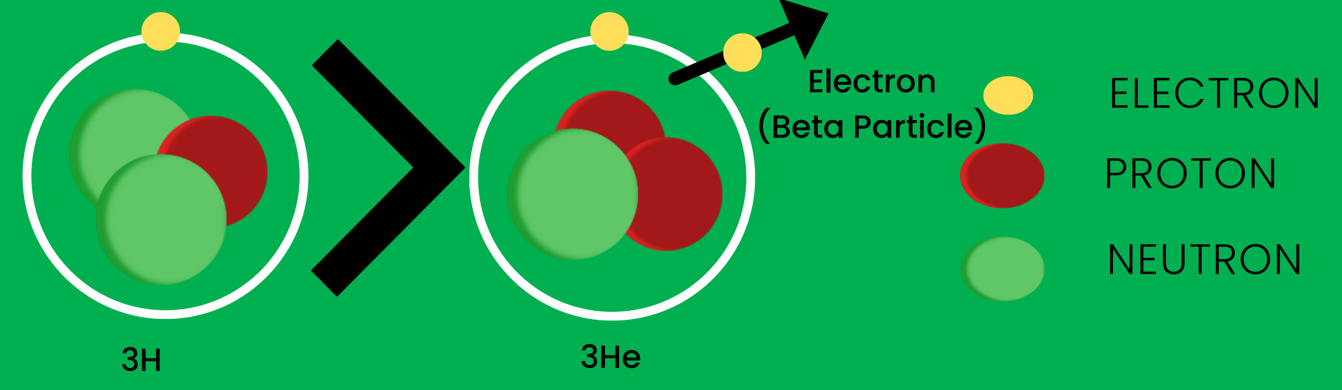
- Study area Meteoric Water Line:

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

- **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

Nossana, July 2019

Vulnerability assessment of **karst aquifers**

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
- Karst network development
- Meteorological data
- Isotopic data

C CONCENTRATION OF THE 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

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

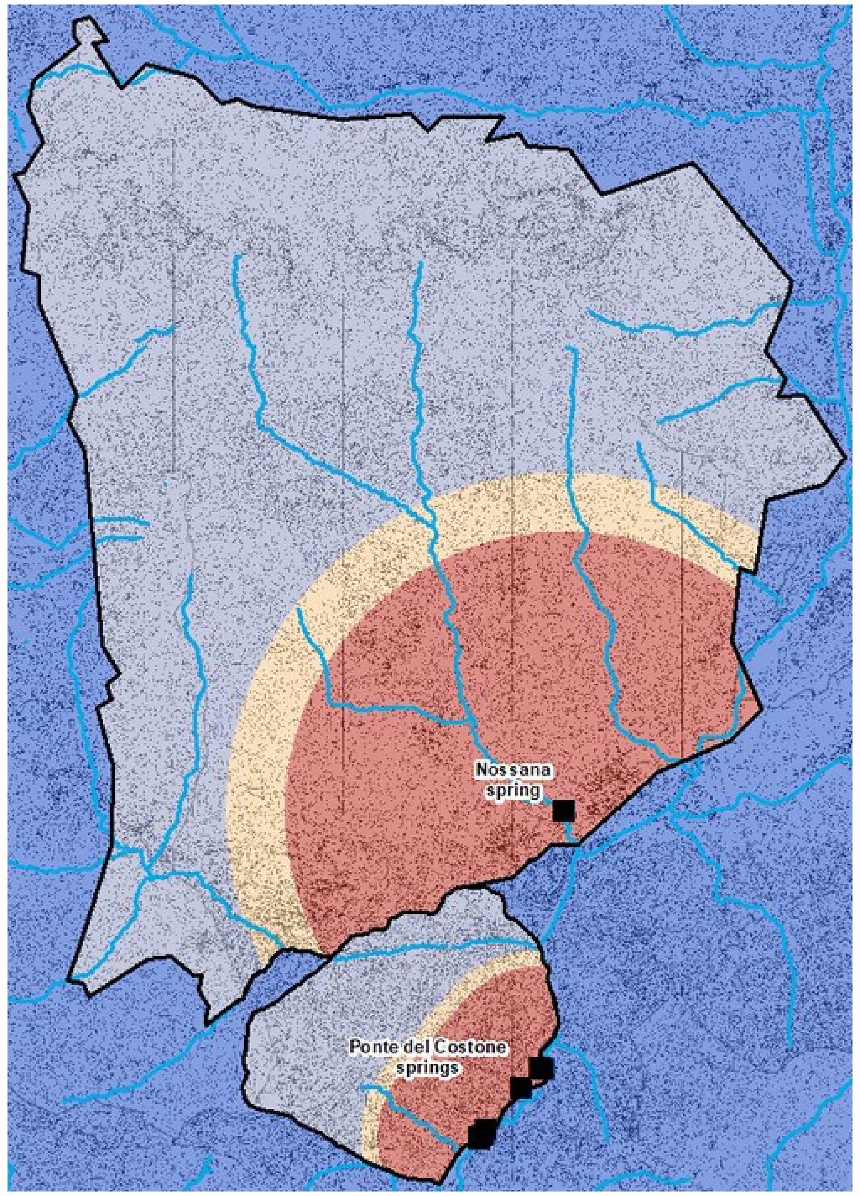
→ **A MAP**

COPA+K index

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

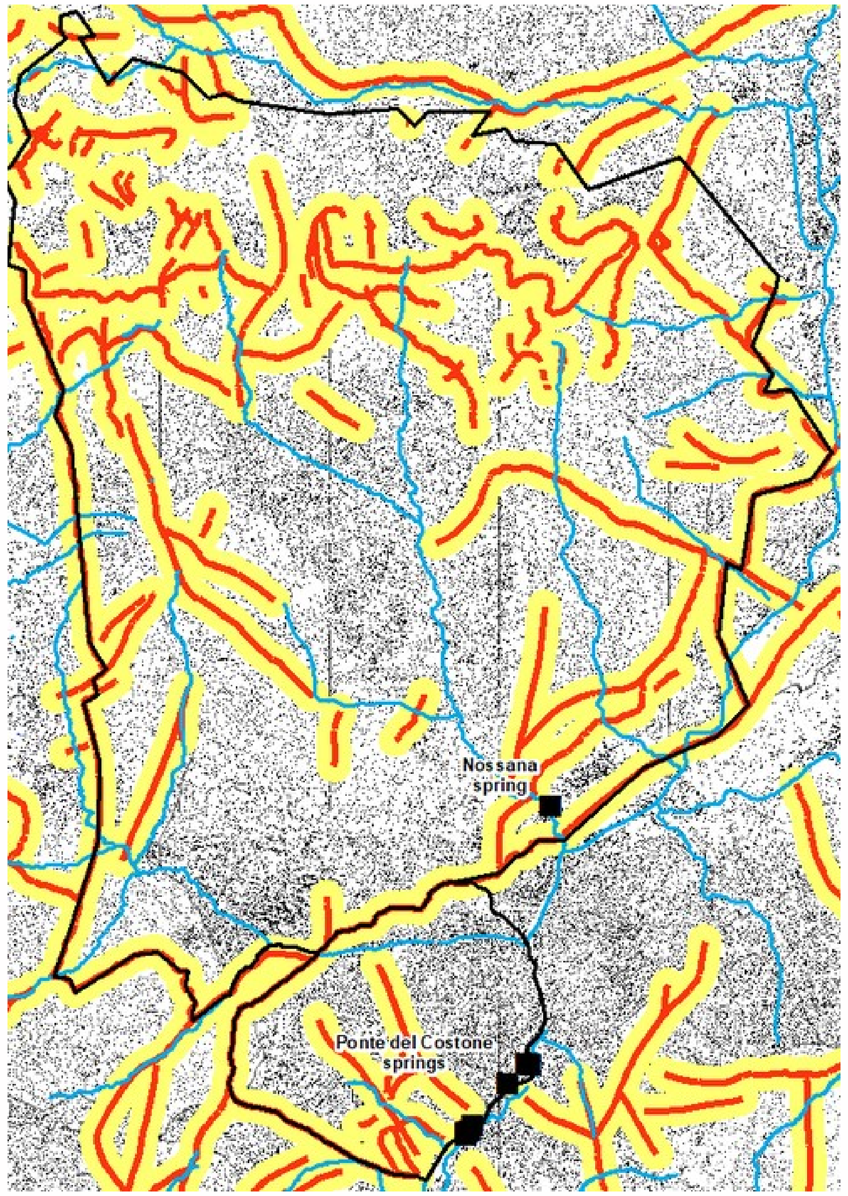
COPA+K INDEX	Reduction of protection
0 – 0.5	Very High
0.5 – 1	High
1 – 2	Moderate
2 – 4	Low
4 – 17	Very Low

→ **COPA+K MAP**



Distances to spring

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



Buffer 200 m around main discontinuities

Results

35.6% to 23.6%

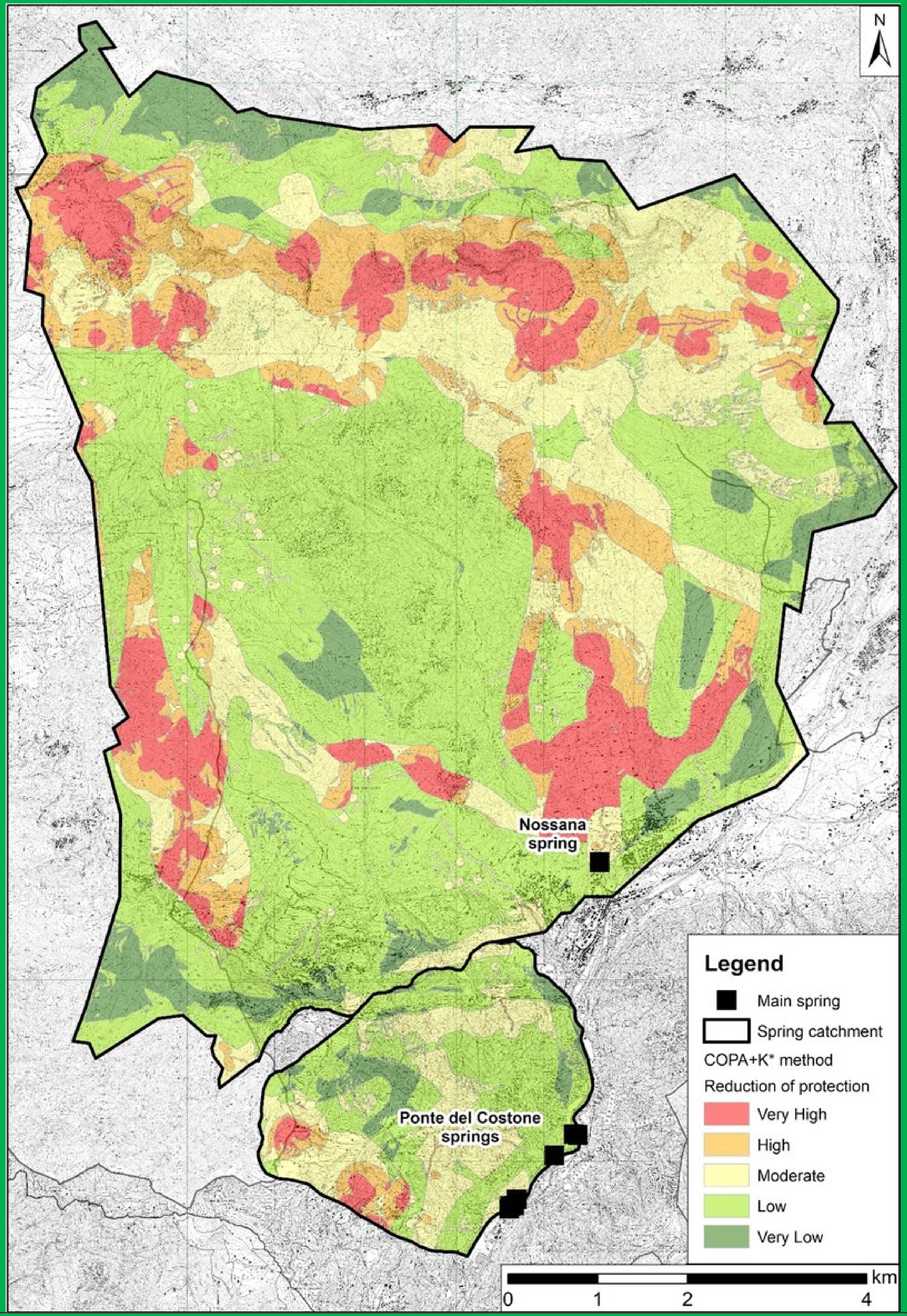
CONSIDERING THE MOST VULNERABLE CLASSES (VH AND H), THE VALUES MOVE FROM 35.6% (COP) TO 23.6% (COPA+K) OVER THE WHOLE STUDY AREA.

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

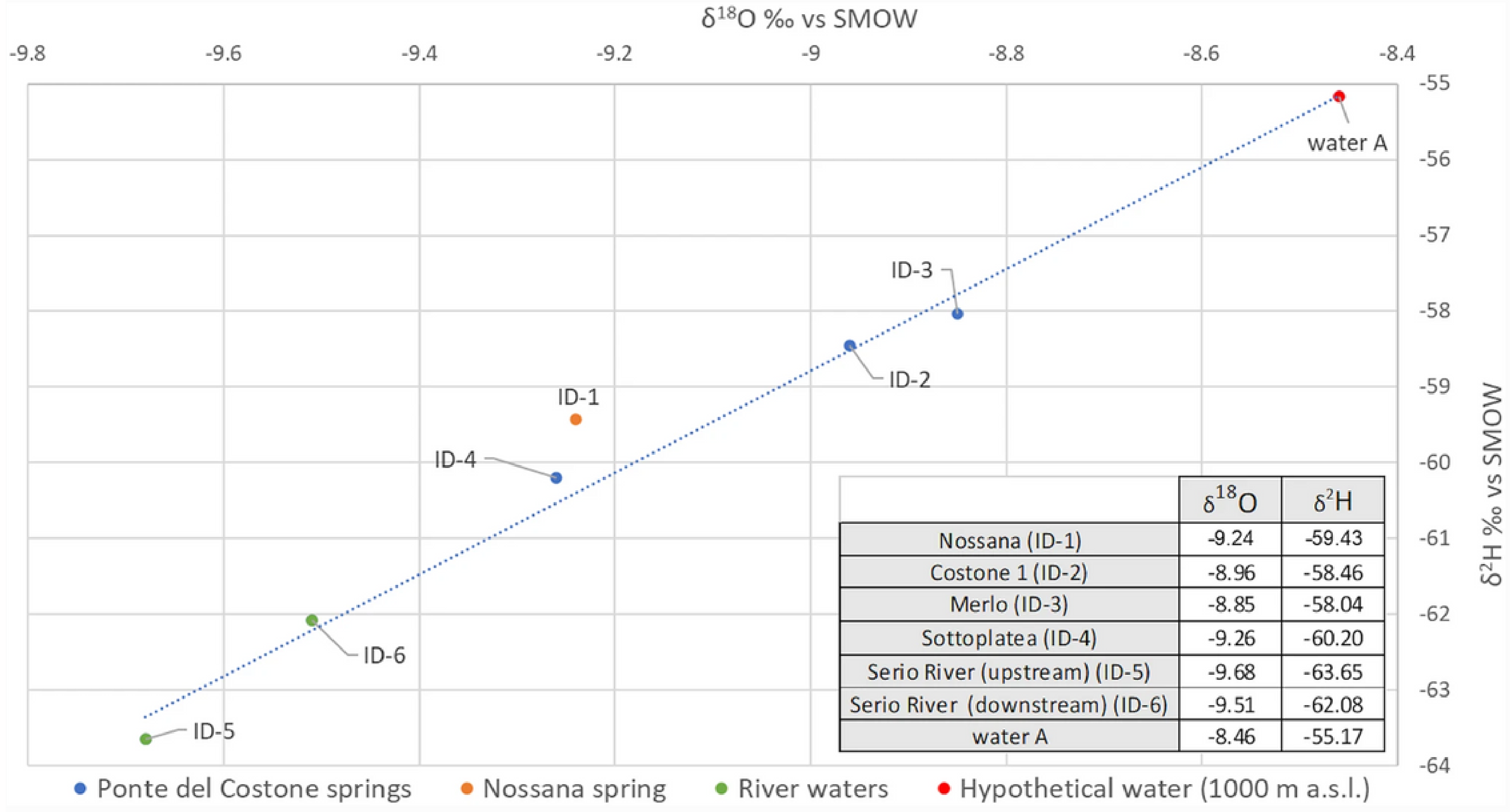


Validation map process

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

Catchment (m a.s.l.)	COP		COPA+K		isotopic correlation
	TPS	IDW	TPS	IDW	
Nossana	1494	1513	1670	1856	1776
Ponte del Costone	736	736	923	923	1561

water A → $\delta^{18}O$ 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

Projections of **Future Discharges** under Climate Change

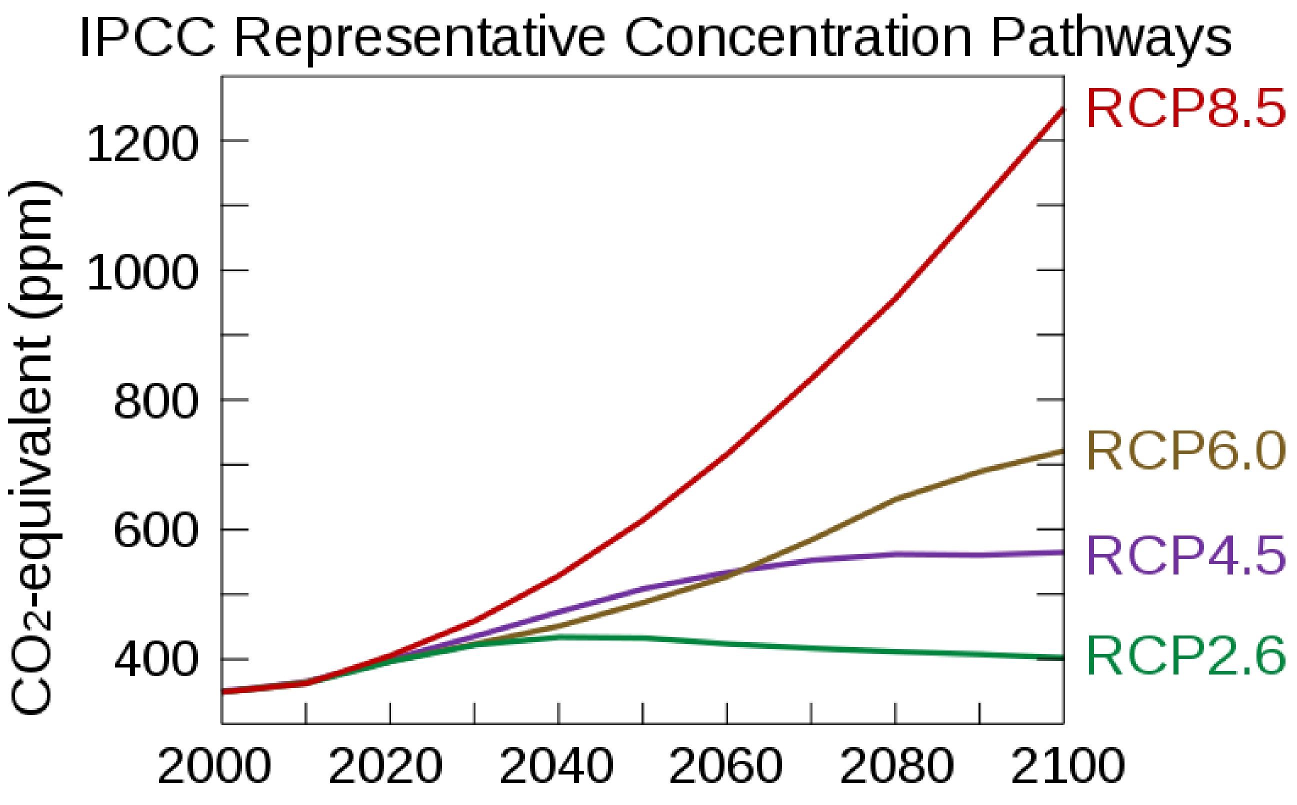
GOALS

- 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)

DATA

- 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

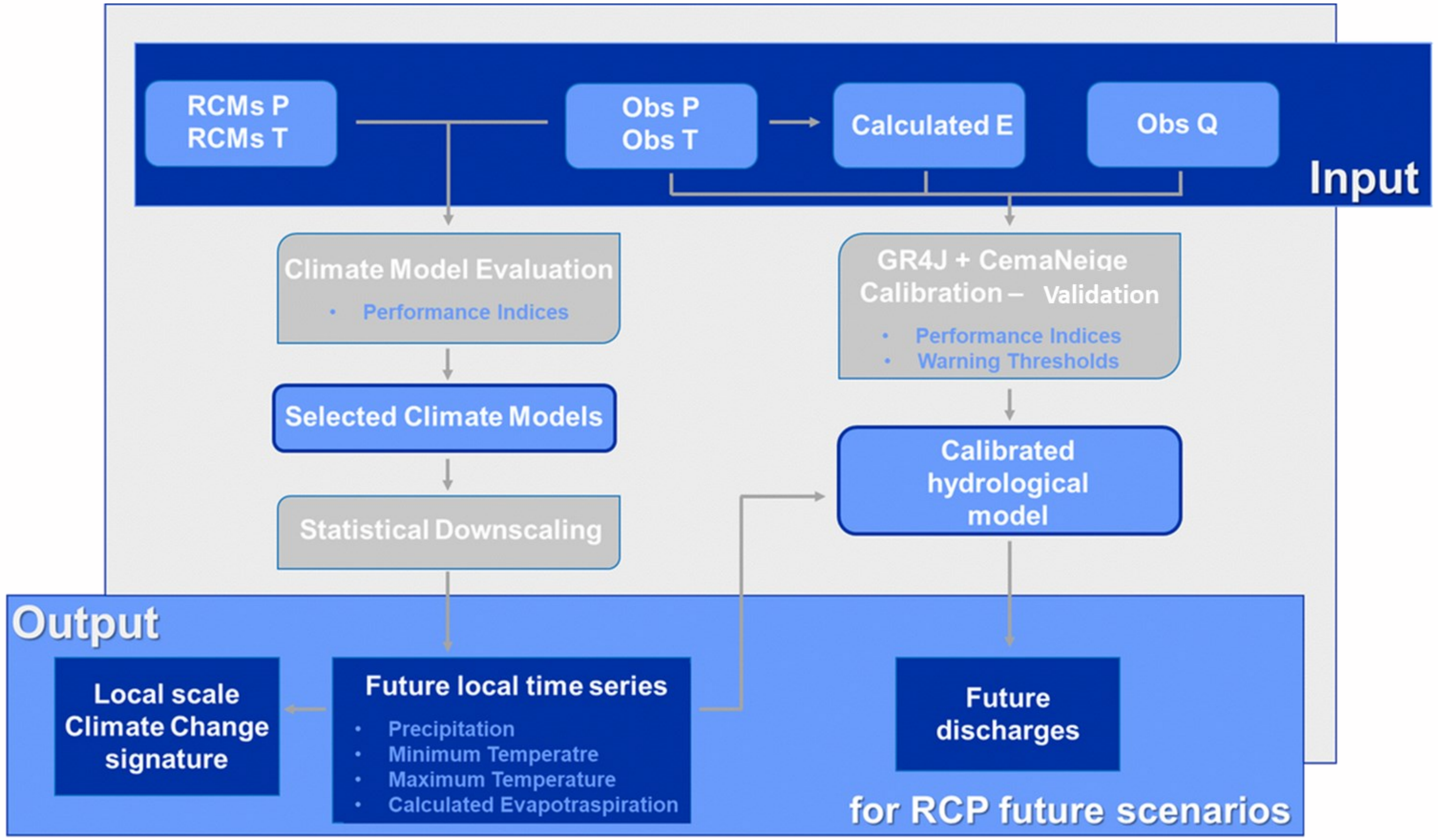
Method

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



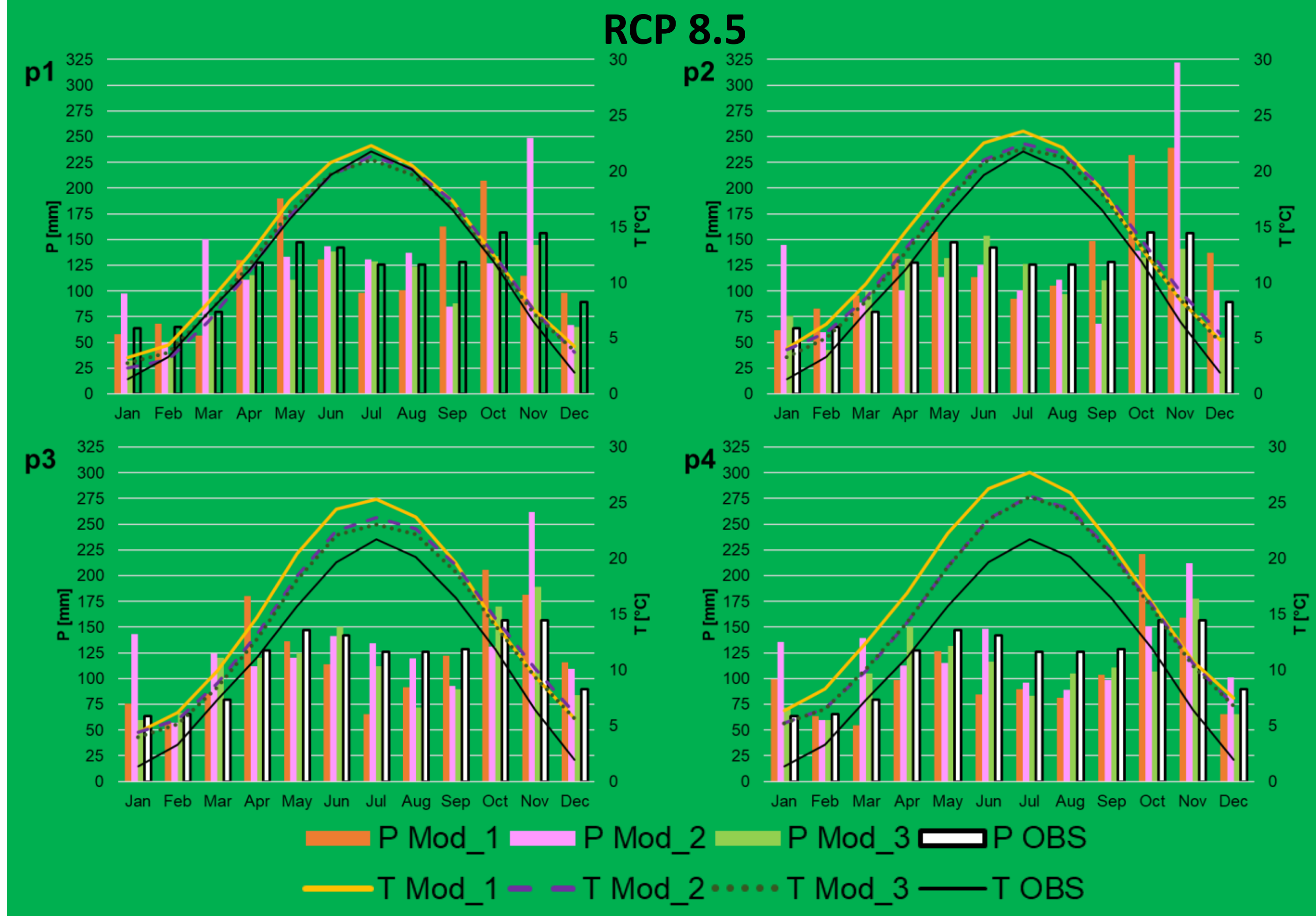
Step 1 - Climate model evaluation

Model	Precipitation NSE	Precipitation MAE (mm)	Precipitation %MAE	Tmin NSE	Tmin MAE (°C)	Tmin %MAE	Tmax NSE	Tmax MAE (°C)	Tmax %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%

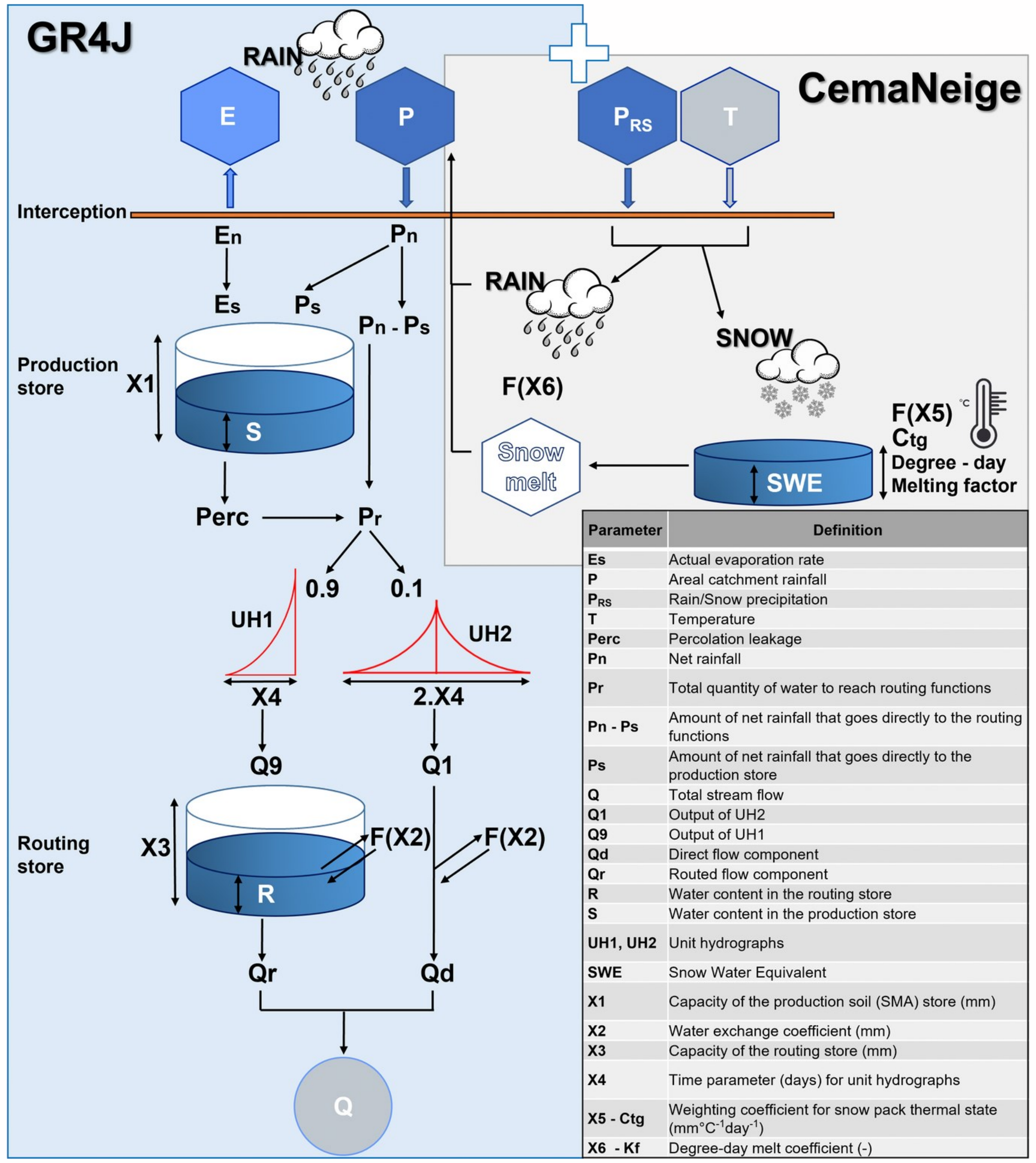
Step 2 - Statistical downscaling

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 ºC (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 (-)

Model spin-up: 1998-1999

Calibration: 2000-2008

Validation: 2009-2017

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)

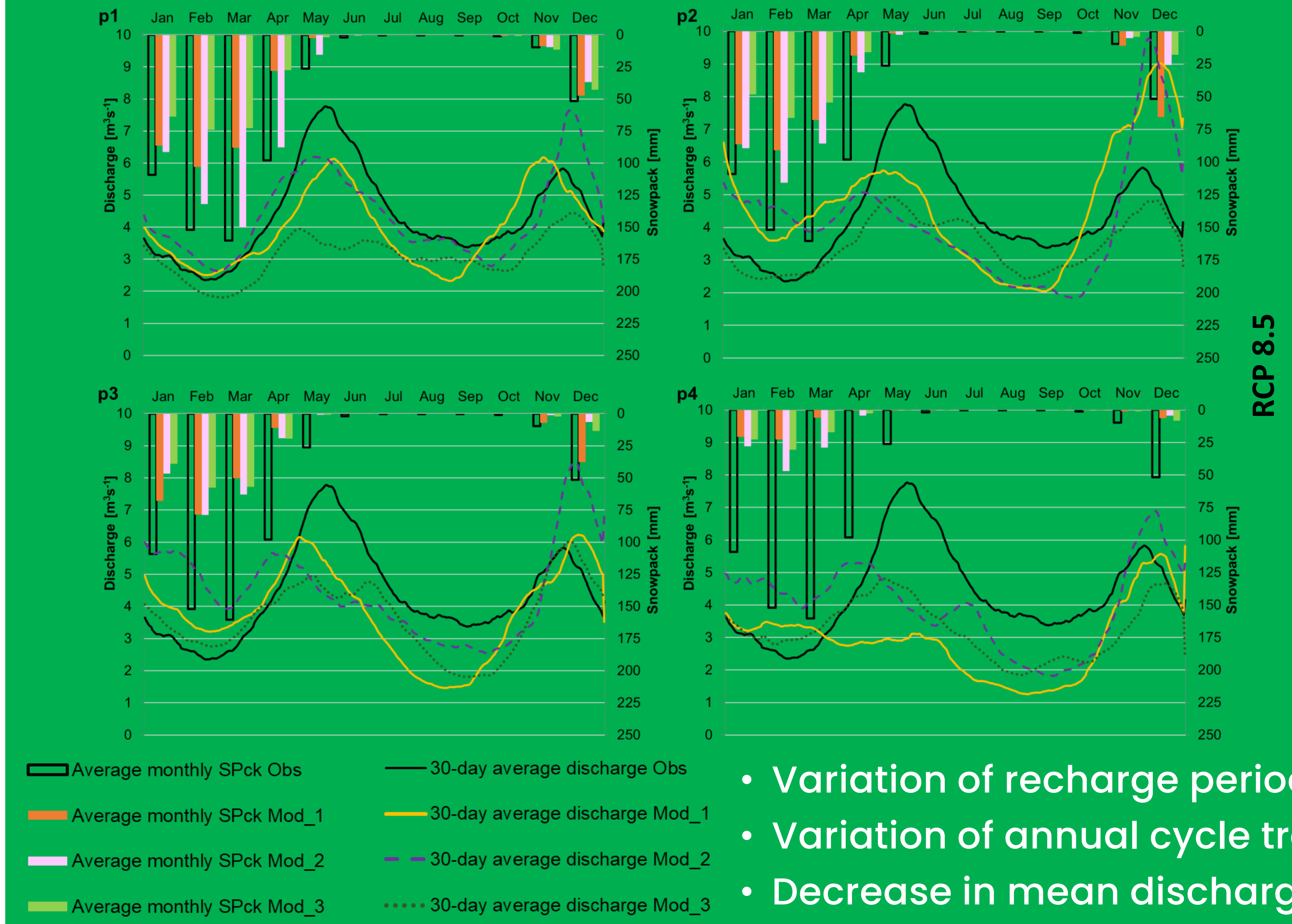
Random generation of **10,000 model parameter sets**

Criteria 1: KGE > 0.70; INSE > 0.5

Criteria 2: number of days and consecutive with discharge below warning thresholds

Step 4 - Future discharges

- Longest period below the 1.32 m^3/s warning threshold 36 extra days
- Longest period below the 1.52 m^3/s warning threshold 64 extra days.



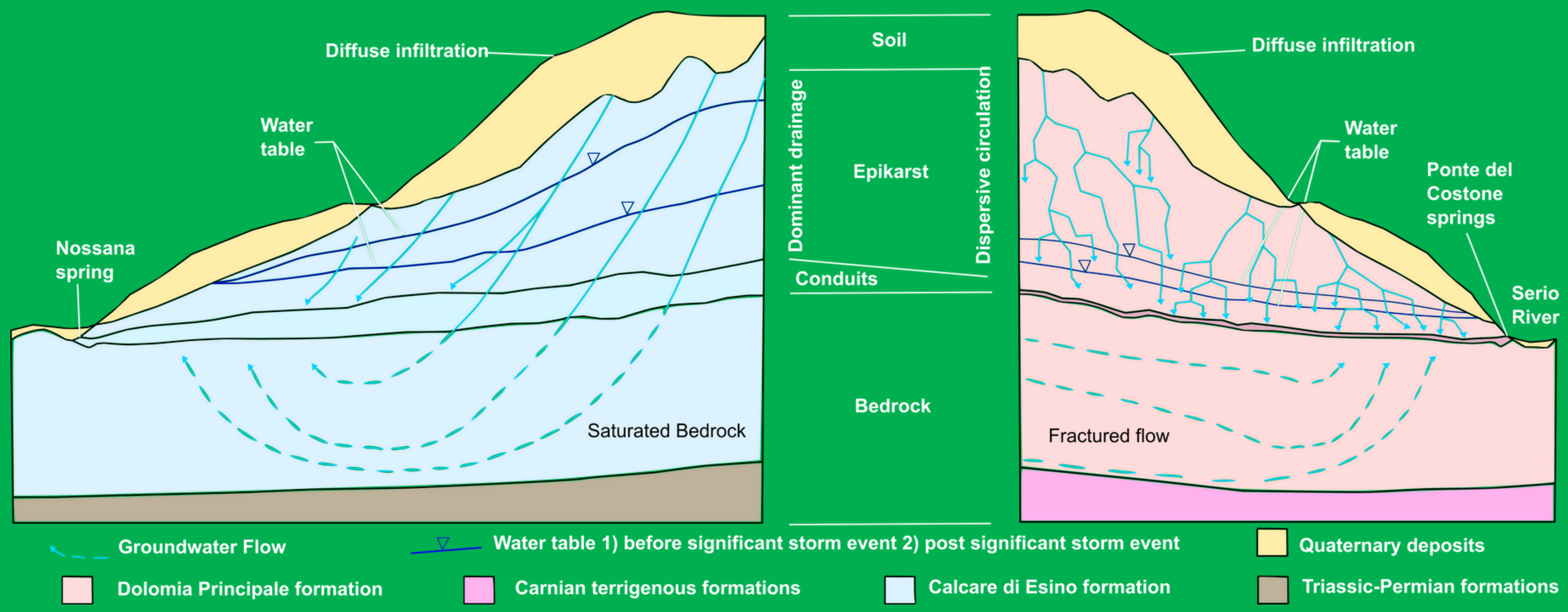
- Variation of recharge periods
- Variation of annual cycle trend
- Decrease in mean discharge

- Temperatures will likely increase between 0.7 and 5.8°C. Pronounced decreases of precipitation and discharge are expected in the summer period after 2060.
- After 2060, the length of the periods with discharge lower than the warning thresholds is expected to increase.

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 work has enabled the company to:

- Ensure the good qualitative-quantitative status of the resource;
- Identify vulnerable areas to preserve the water.
- Have advantage in terms of time to start investigating new additional water resources to meet water demand after 2060, as demonstrated by hydrological modeling.

→ Request to 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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