

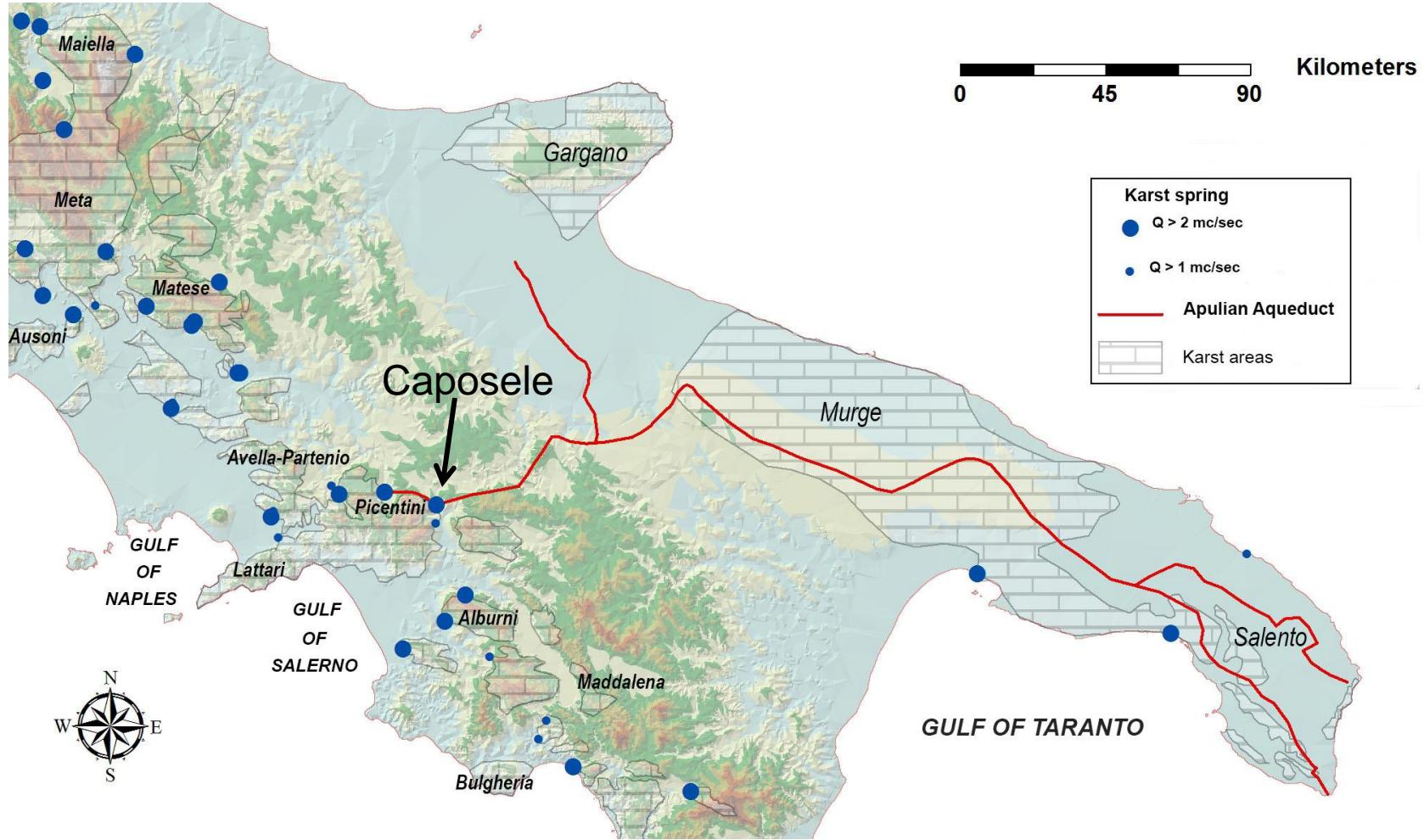
Aspetti idrologici ed idrogeologici della sorgente Sanità di Caposele, alimentante l'Acquedotto Pugliese

Hydrological and hydrogeological features of the Sanità spring of Caposele, Southern Italy, which feeds the Pugliese aqueduct

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in collaborazione con Acquedotto Pugliese S.p.A.

Caposele spring and Pugliese aqueduct



Pugliese aqueduct:

total length: more than 400 km
main gravity-channel (244 km long) up to Villa Castelli
93 bridges and 105 tunnels
Pavoncelli tunnel, 15.3 km
Murge tunnel, 16 km

Caposele spring:

elevation: 417 m a.s.l.
mean discharge $\approx 4 \text{ m}^3/\text{sec}$

Main historical points before the tapping

1868, Camillo Rosalba (engineer of the Public Works Office)



1901, first studies and surveys in the area of Sanità springs (supported by a financing of the central state, one million lire).

1902, the consortium “Acquedotto Pugliese” (State and other local authorities) was formed, with full powers on the construction and future management.

1906, begin the excavation of the tunnel crossing (Pavoncelli) and subsequently those of the main channel up to Villa Castelli.

Main historical points of the tapping

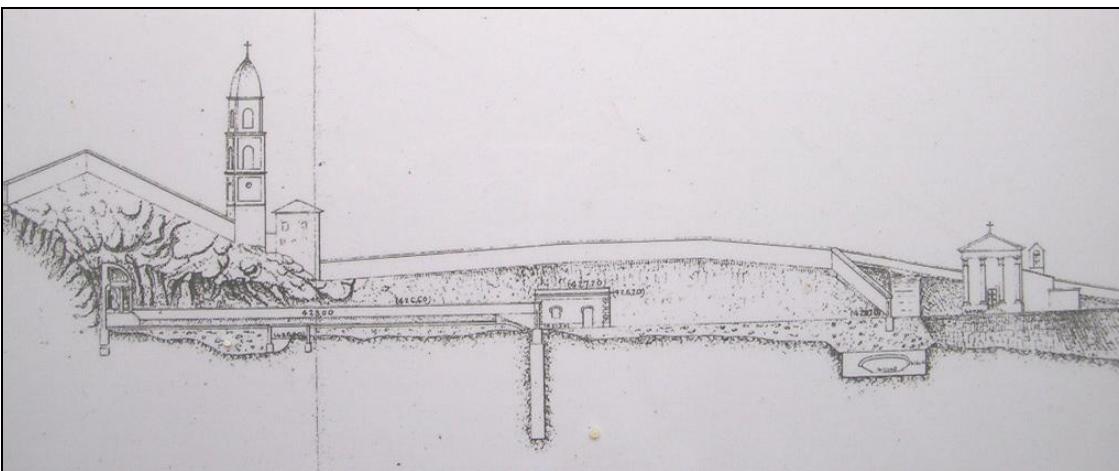
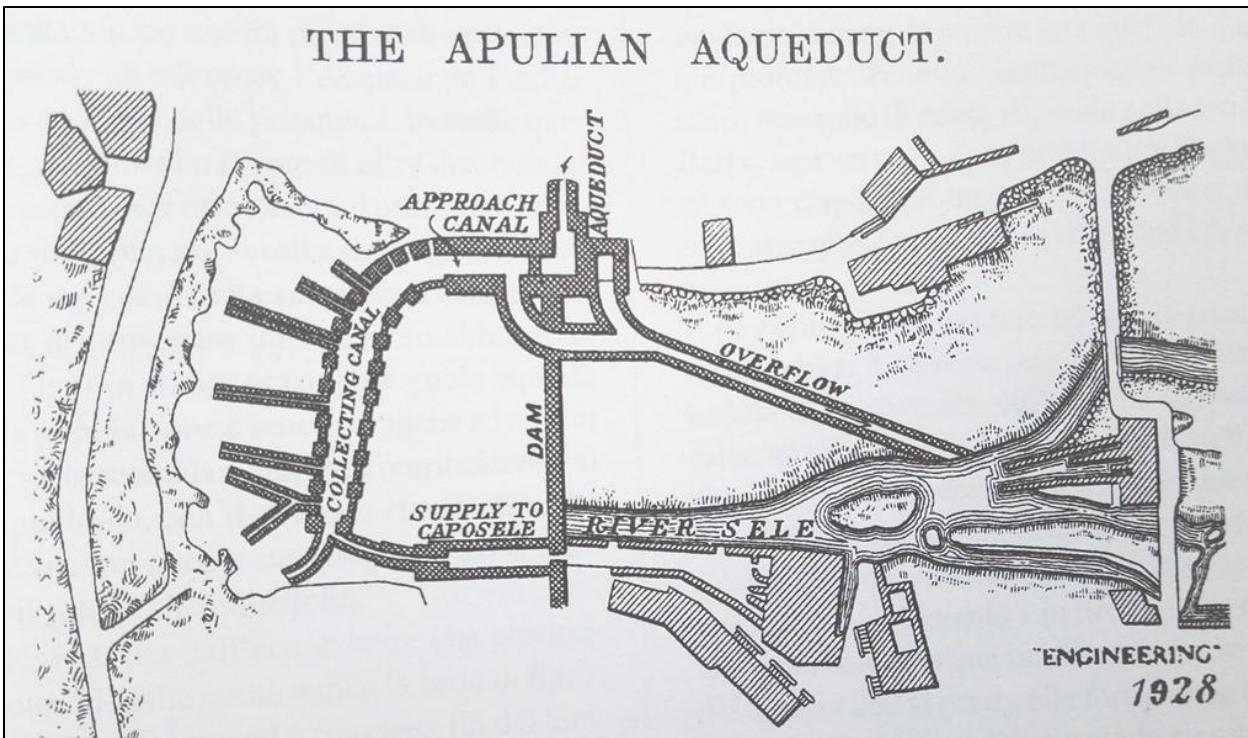


1915, arrival of spring water in Bari

1918, Brindisi

1927, Lecce

Main features of the tapping zone



Caposele spring view

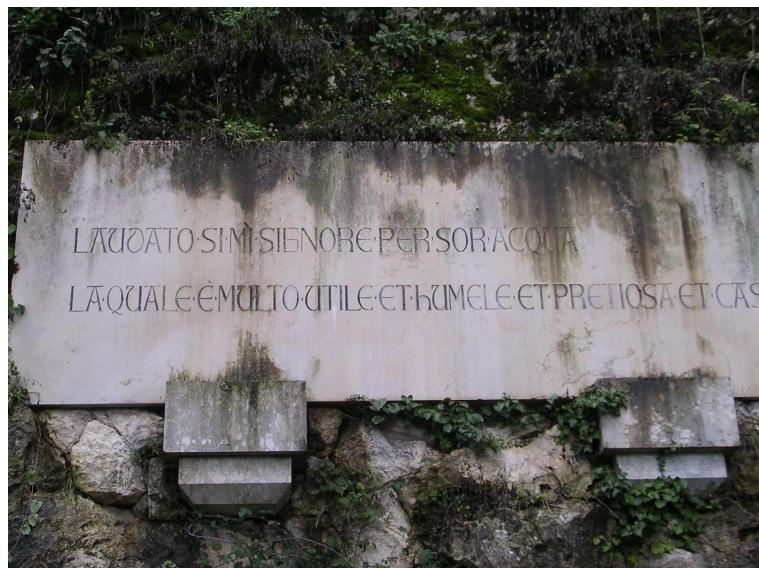
Main channel in the tapping area



Caposele spring view

Beginning of the last century (≈1900)

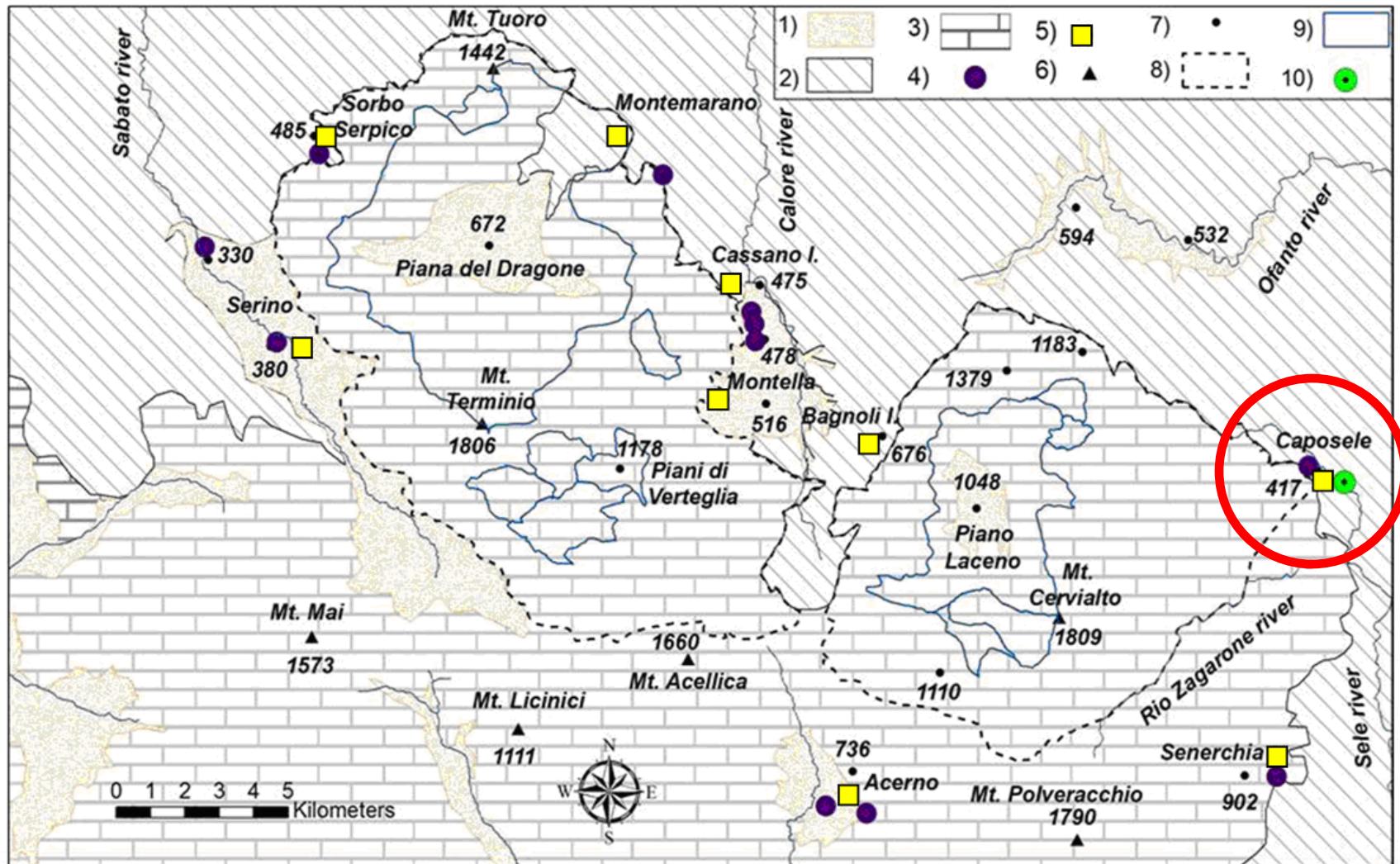




Caposele spring view
currently

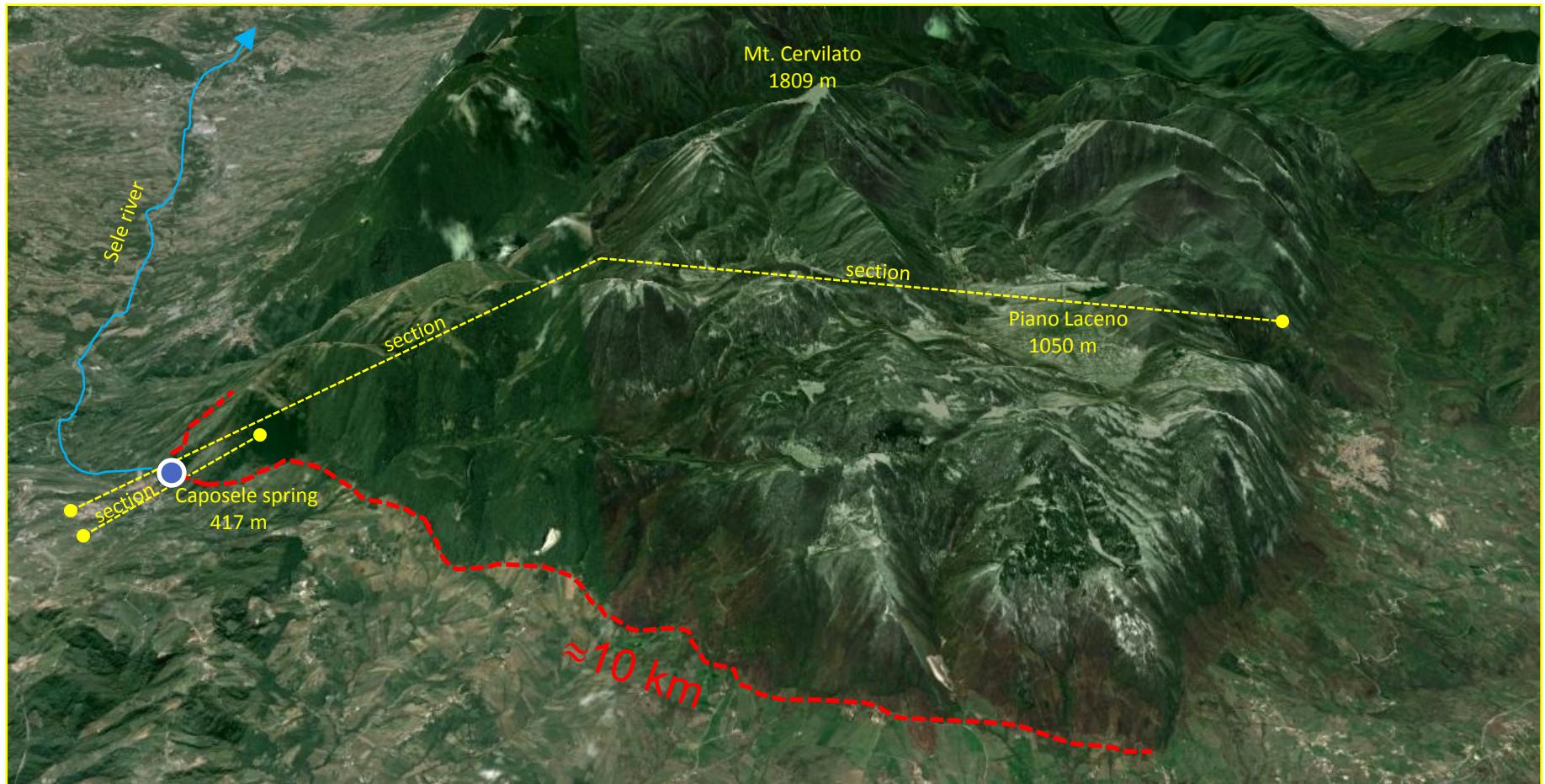


Hydrogeological sketch of north-eastern sector of Mt. Picentini

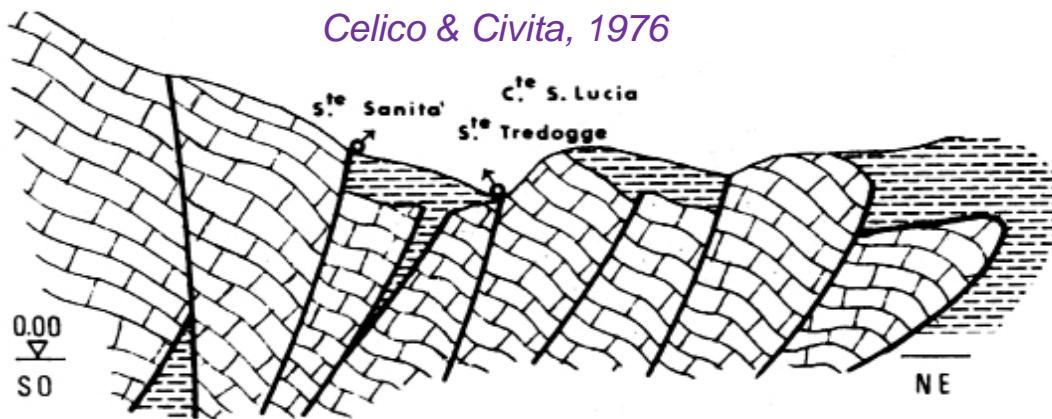


- 1) Continental mantle (Quaternary); 2) argillaceous complex and flysch sequences (Paleogene–Miocene); 3) calcareous-dolomite series (Jurassic–Miocene); 4) main karst spring; 5) village; 6) mountain peak; 7) elevation (m a.s.l.); 8) Spring catchment ; 9) endorheic area; 10) river gauge.

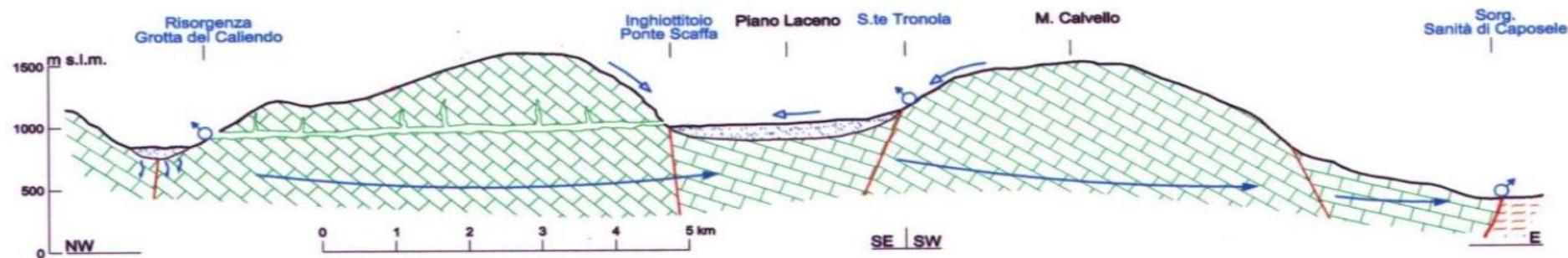
3D view of the Cervialto massif



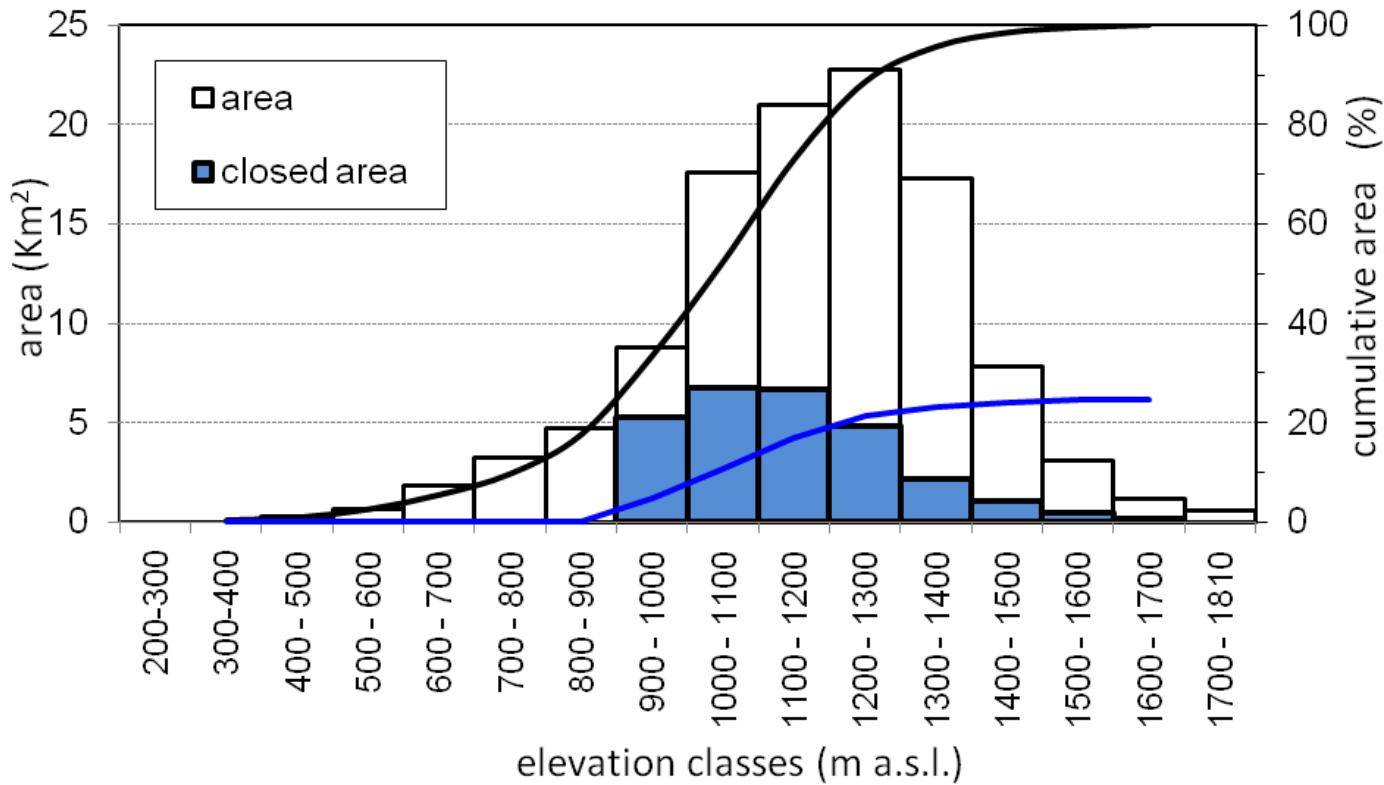
Hydrogeological cross-section



Aquino et al., 2005



Class elevation distribution *hydrogeological spring catchment, 110 km²*

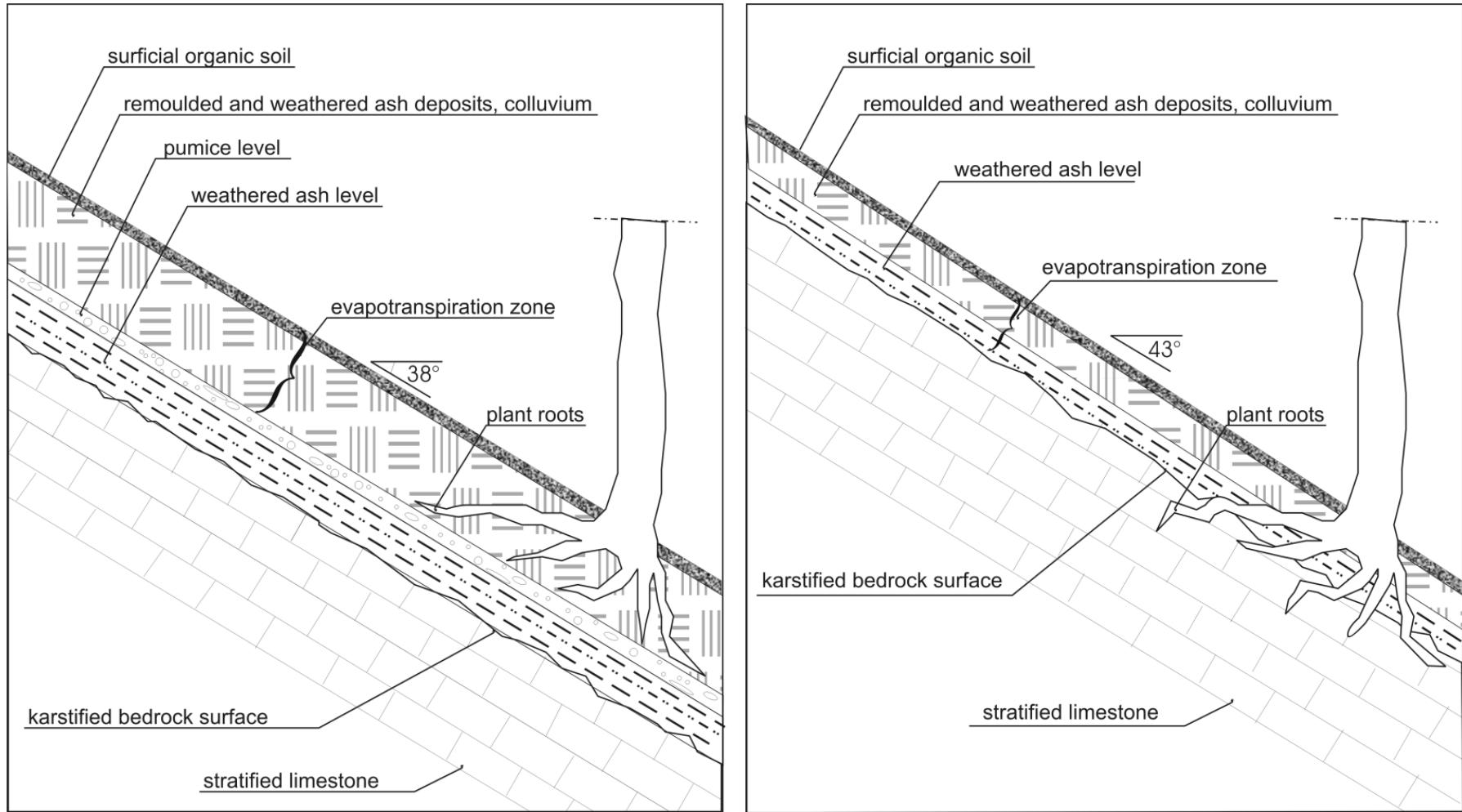


elevation mean: 1173 m

spring elevation : 417 m

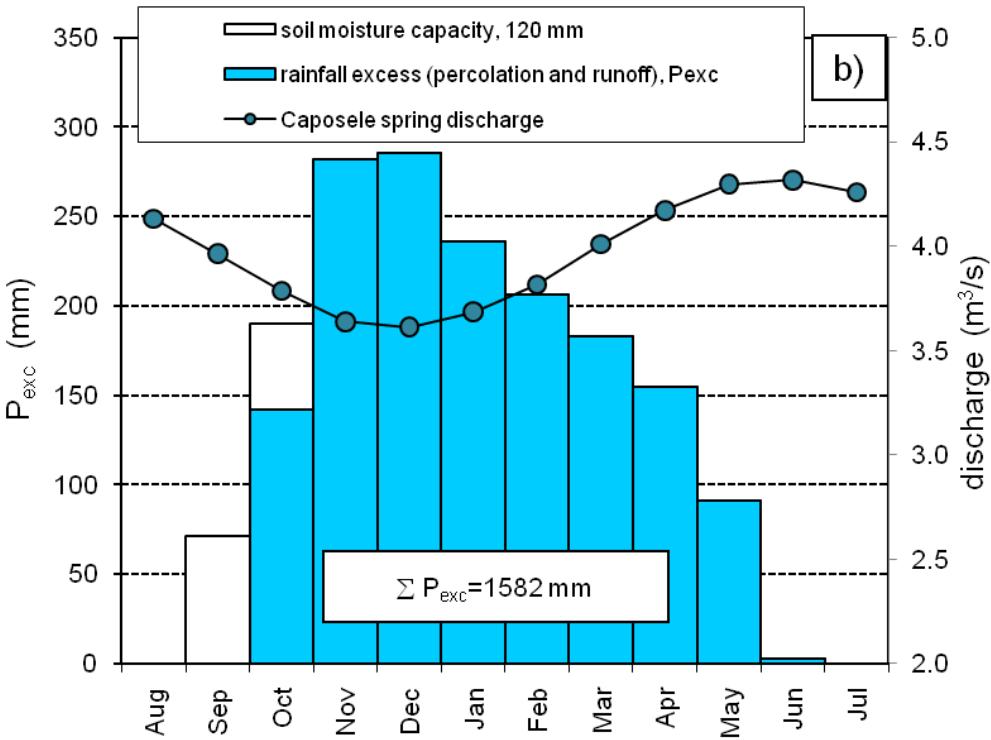
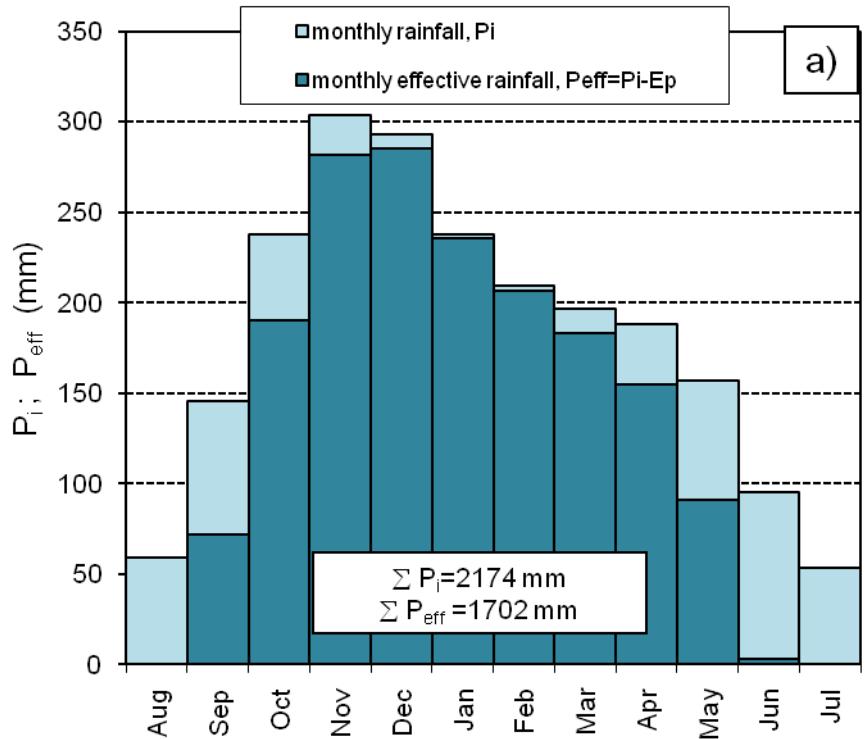
rock thickness (mean) above the spring: 756 m

Schematic soil-profile of Campania slopes

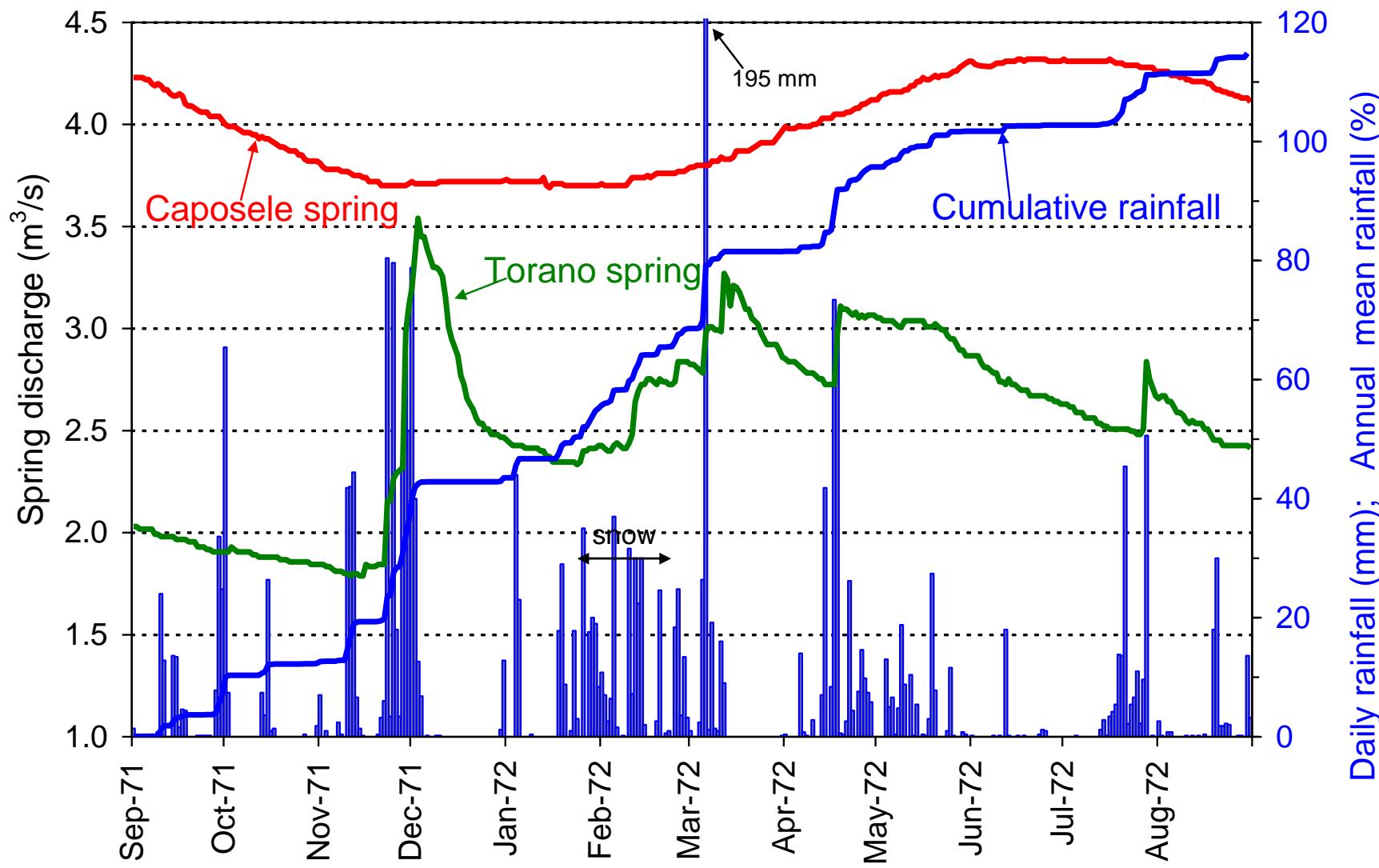


Main climatic features: long-term mean monthly values

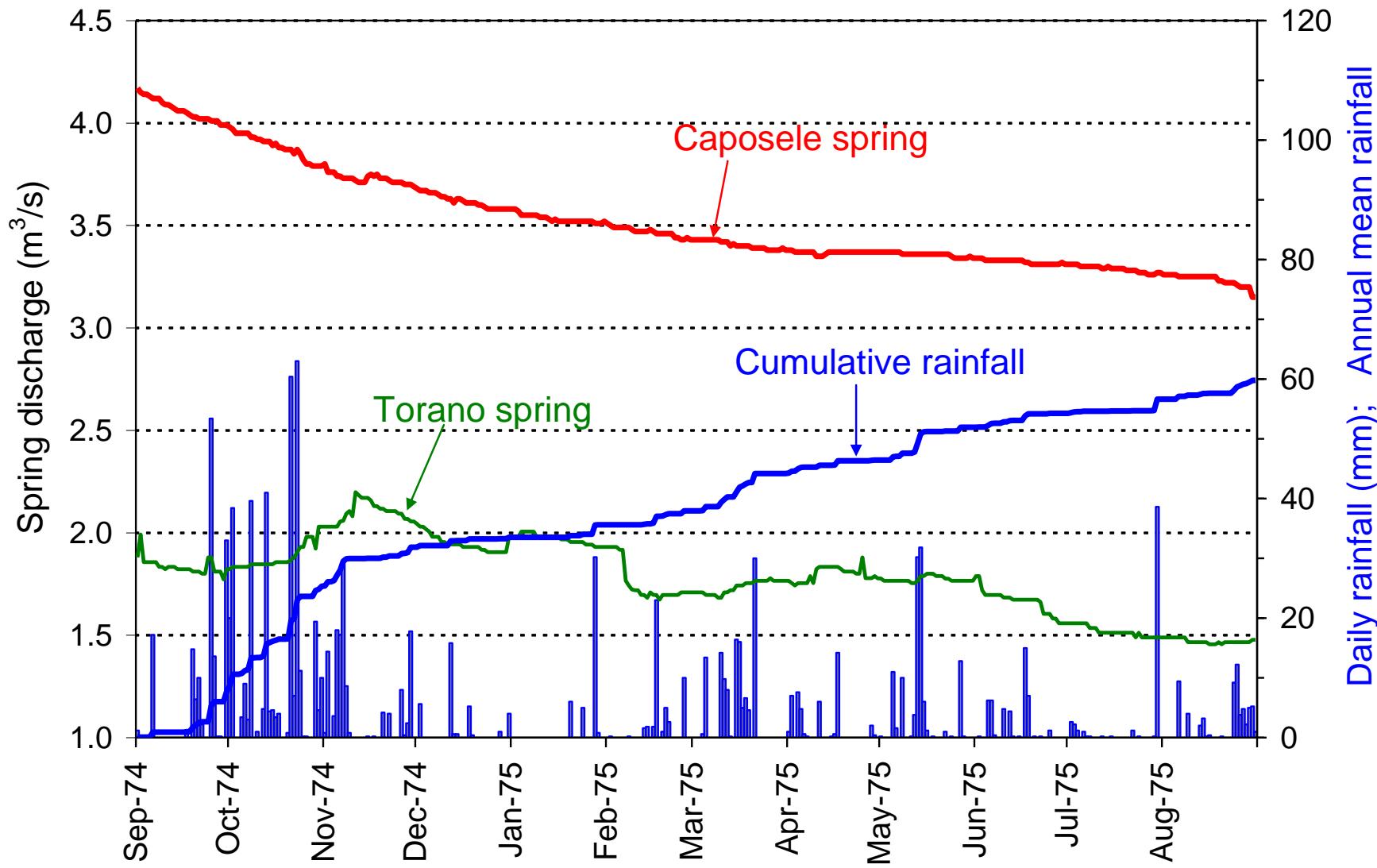
Thornthwaite balance, Montevergine, 1270 m a.s.l.



Daily values during a wet year

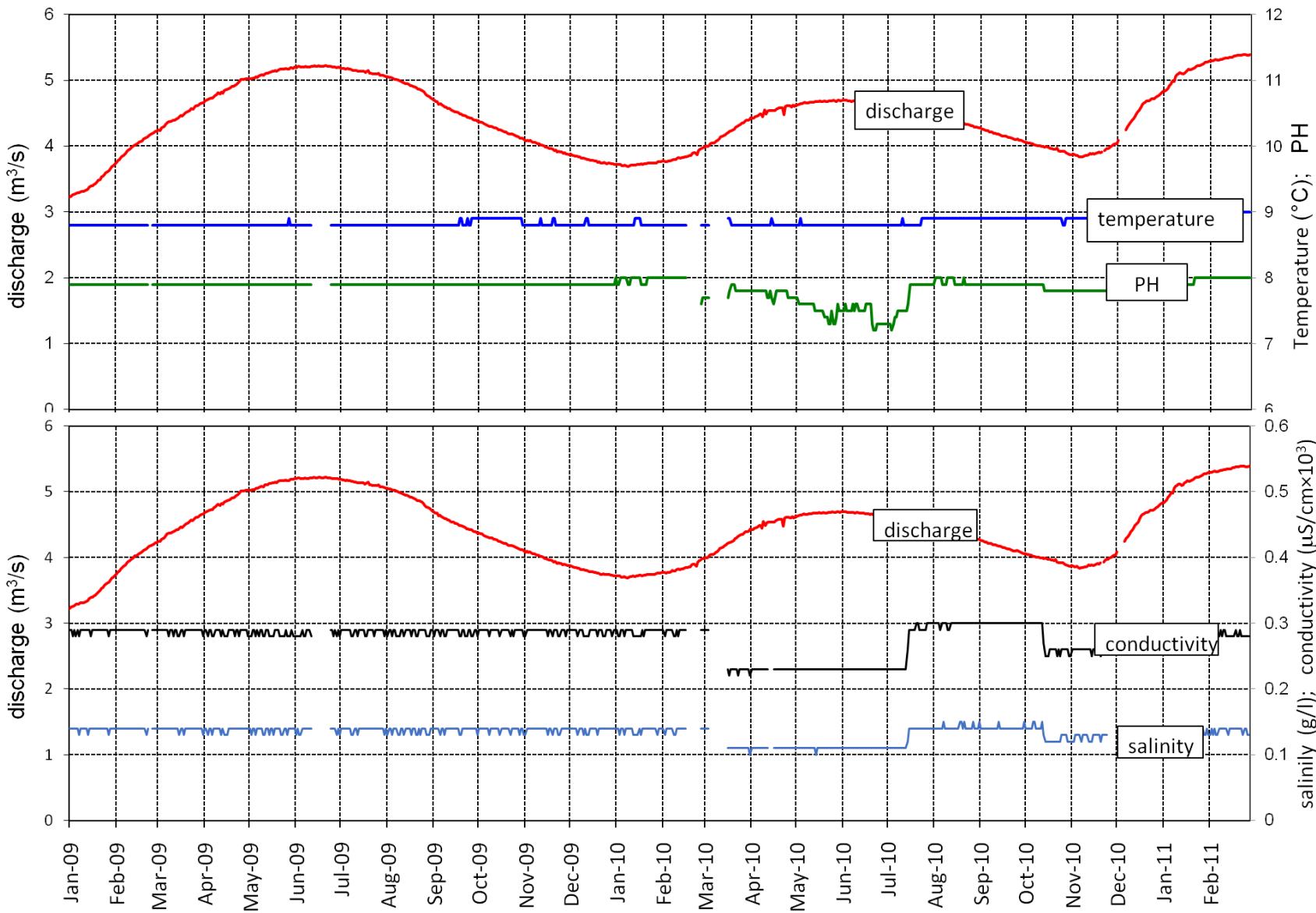


Daily values during a dry year



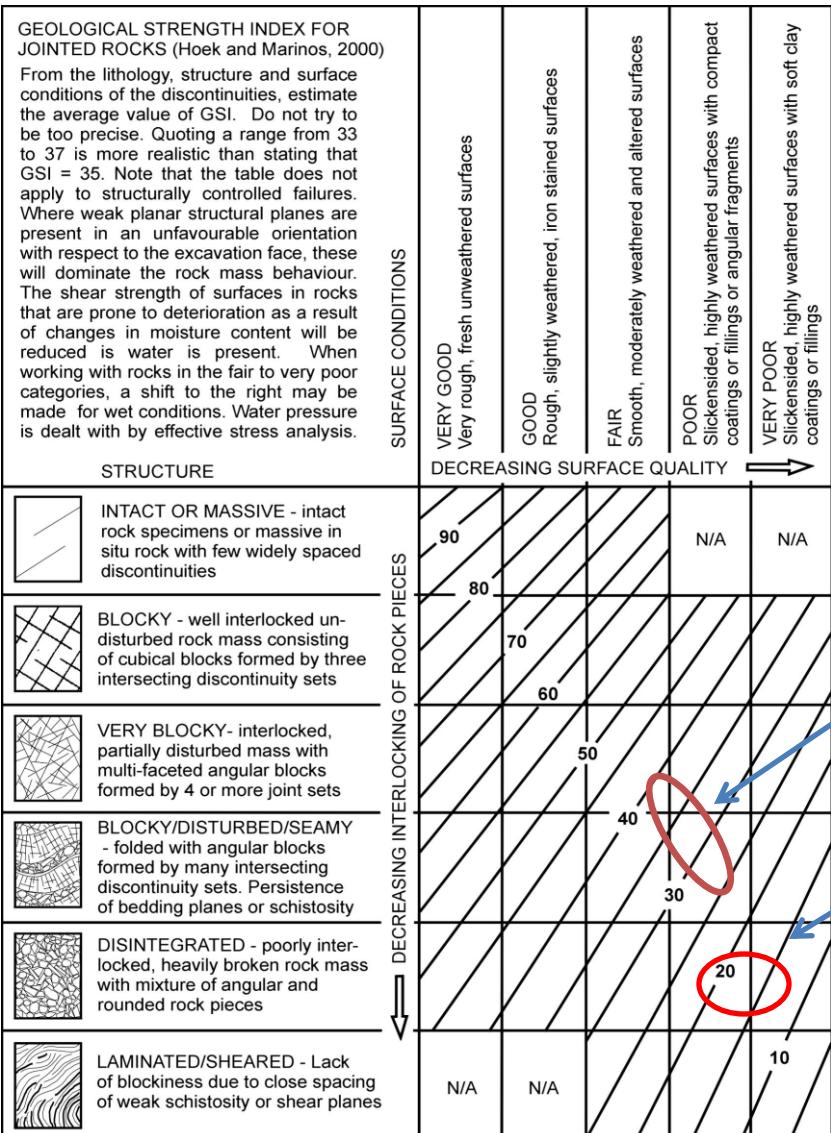
Physical and chemical characteristics of springwater

1 Jan 2009 – 27 Feb 2011



Factors controlling the shape of the hydrograph

Rock mass conditions, Cervialto rock outcropping



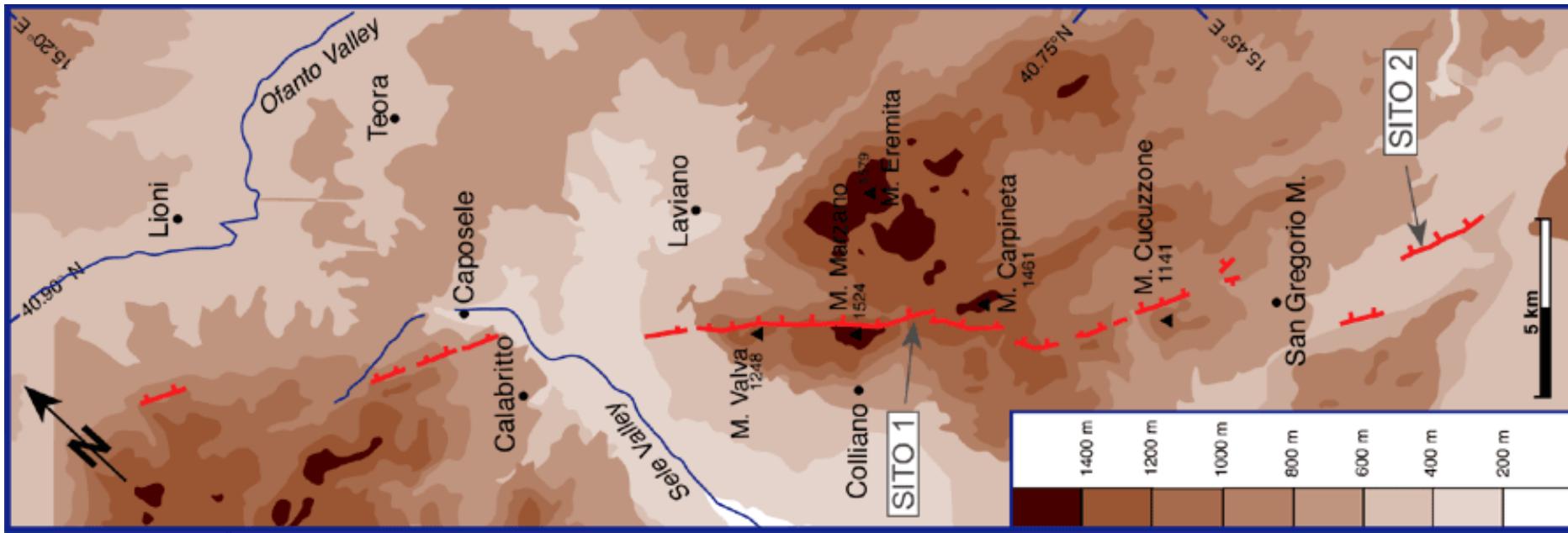
ZONA CINIELLO



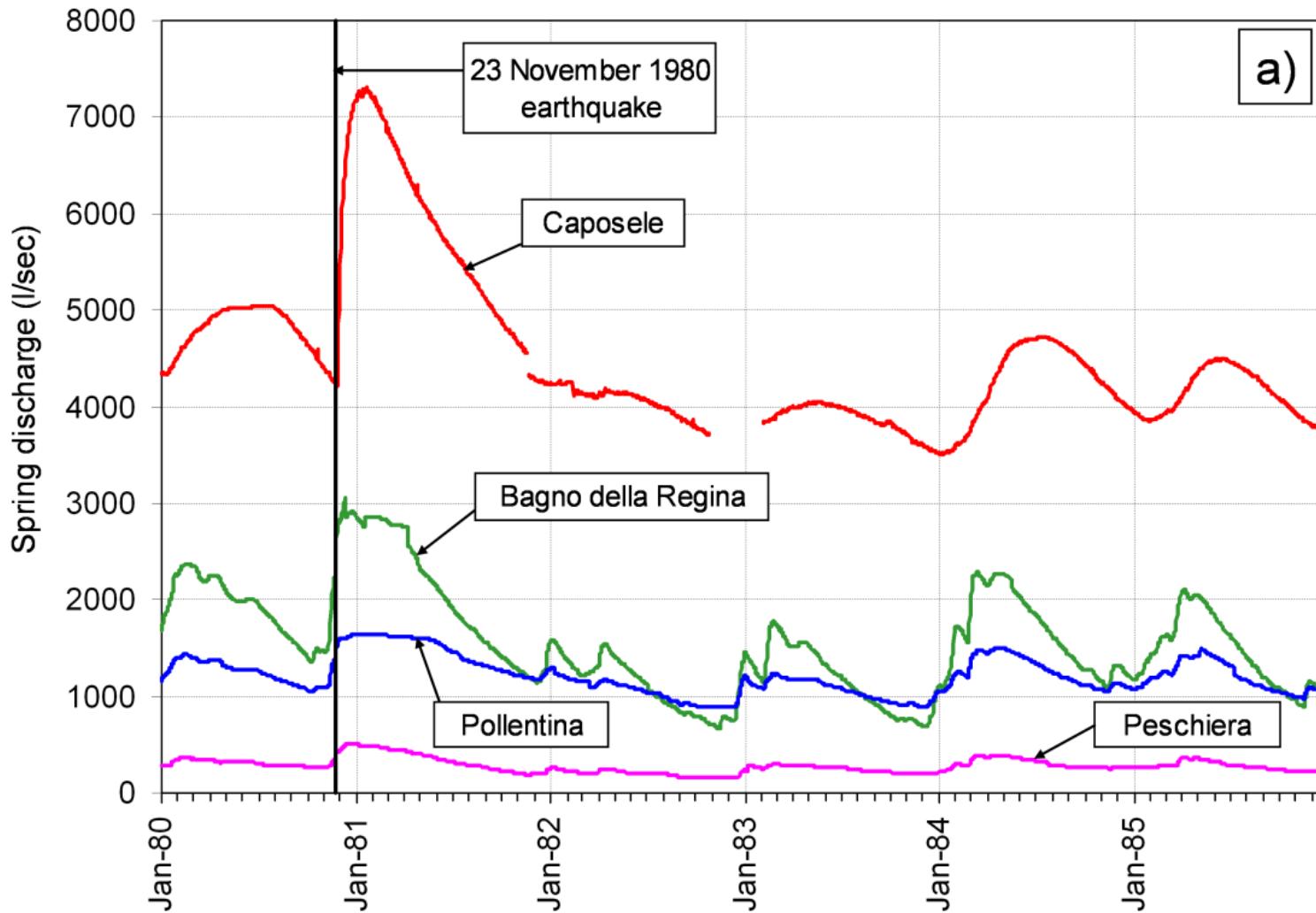
CONTRADA DEL PASTORE

Factors controlling the shape of the hydrograph

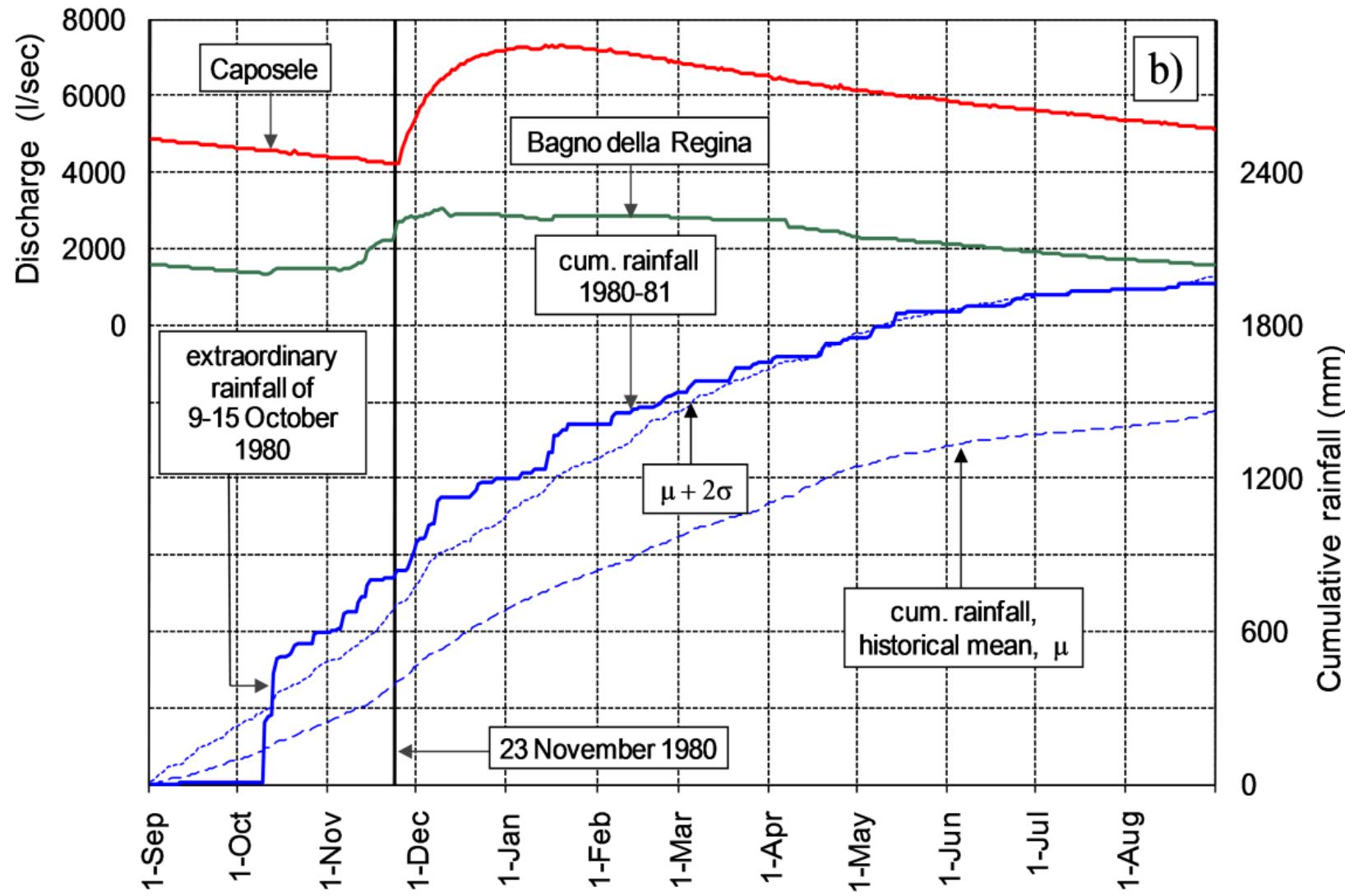
fault scarp induced by 1980 Irpinia earthquake



The effect of 23 November 1980 earthquake (Ms=6.9)

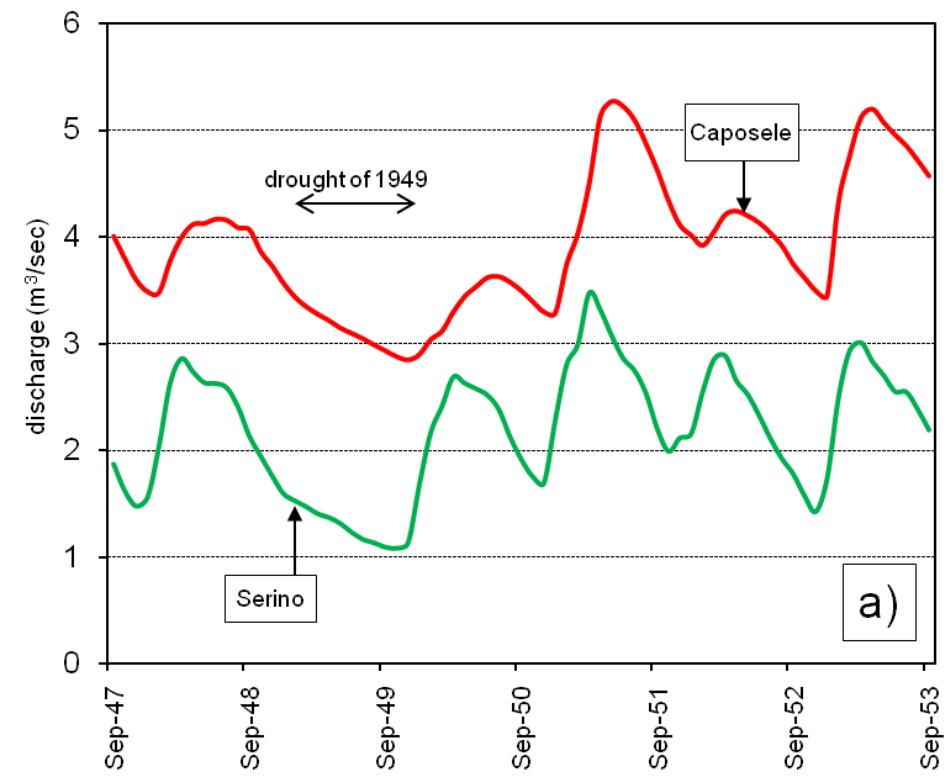


The effect of 23 November 1980 earthquake (Ms=6.9)

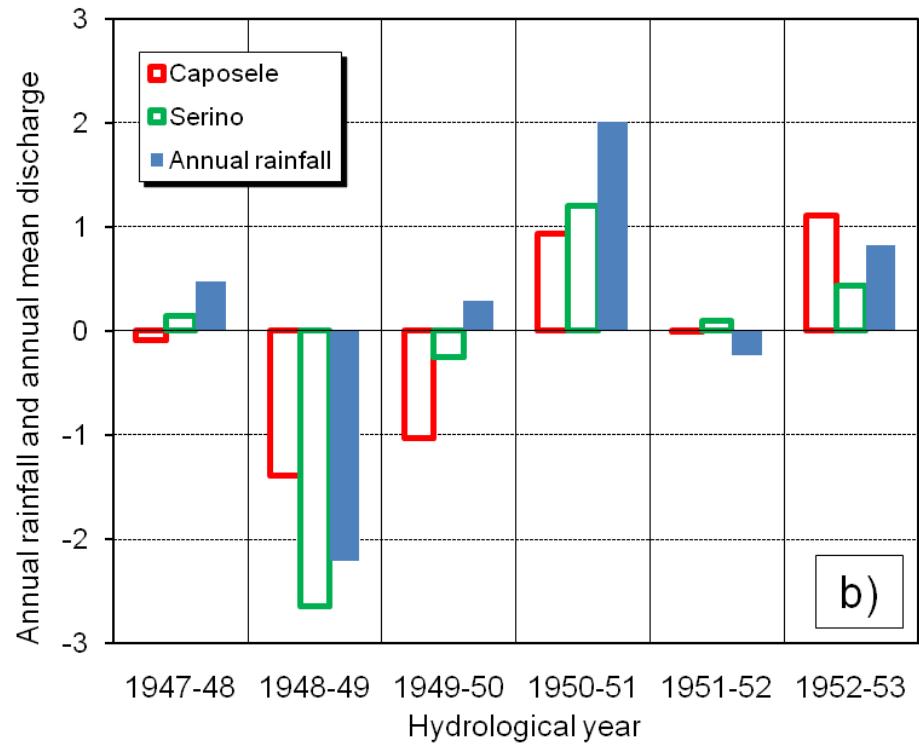


The effect of drought on the following years

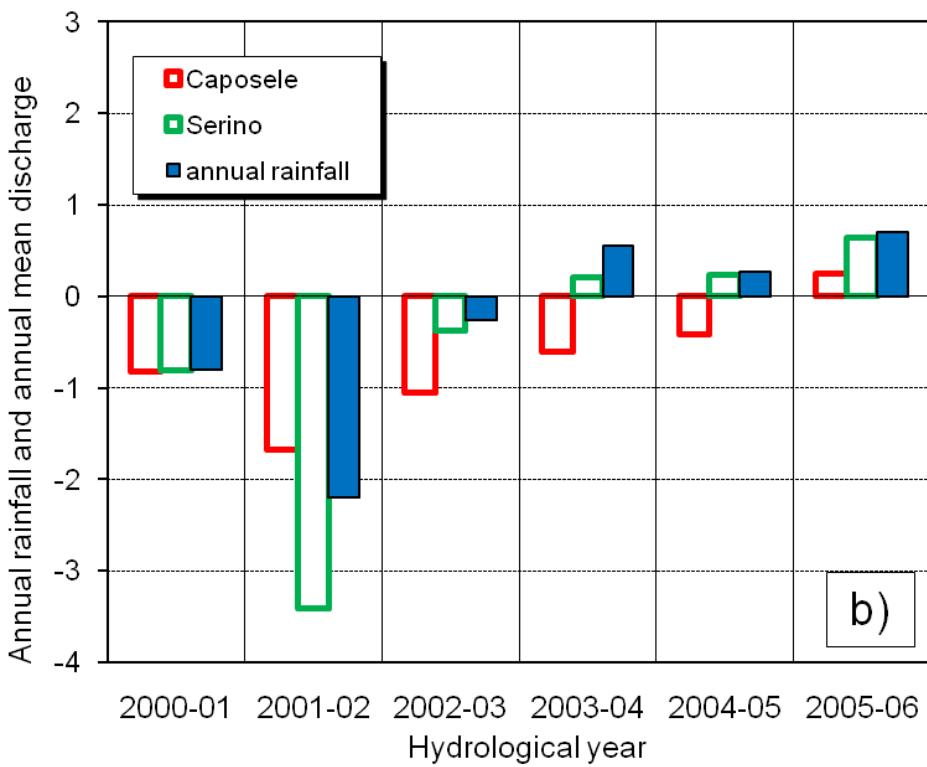
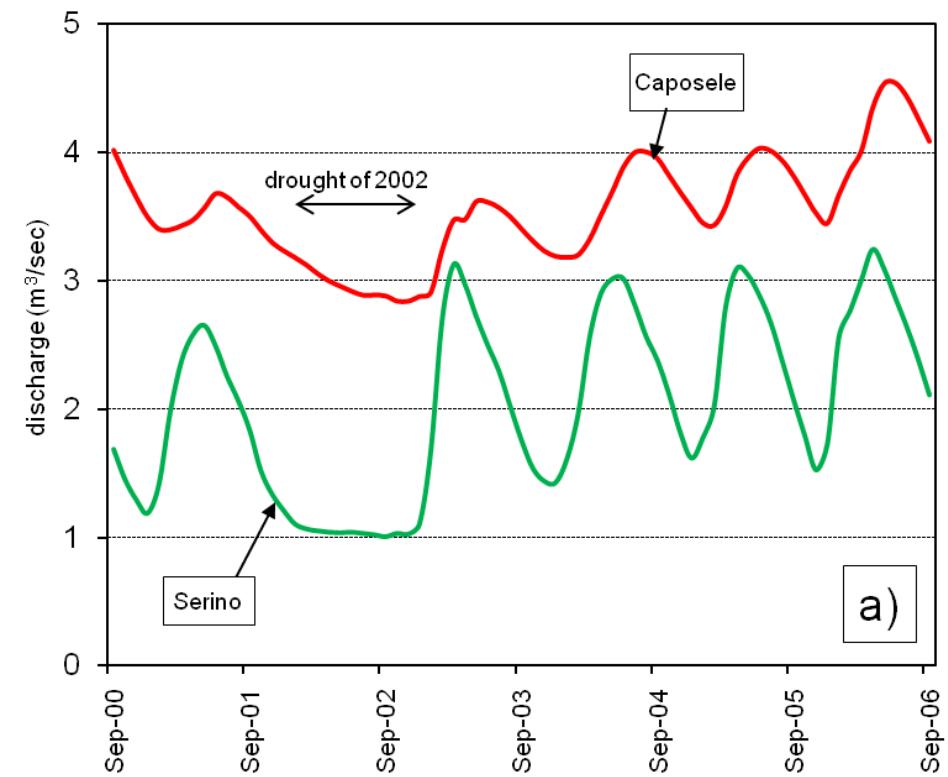
Daily spring discharge



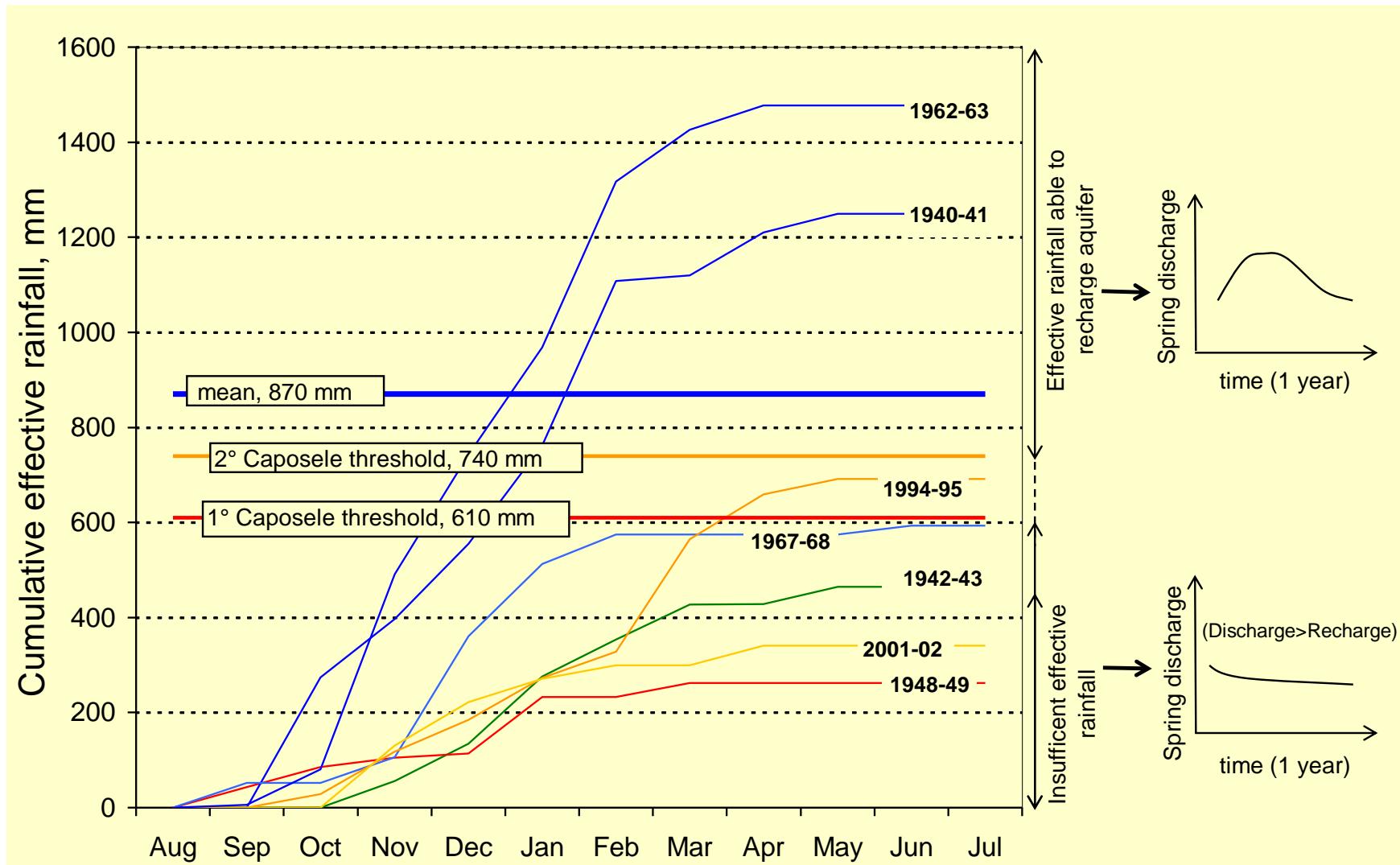
Annual rainfall and annual mean discharge standardised values



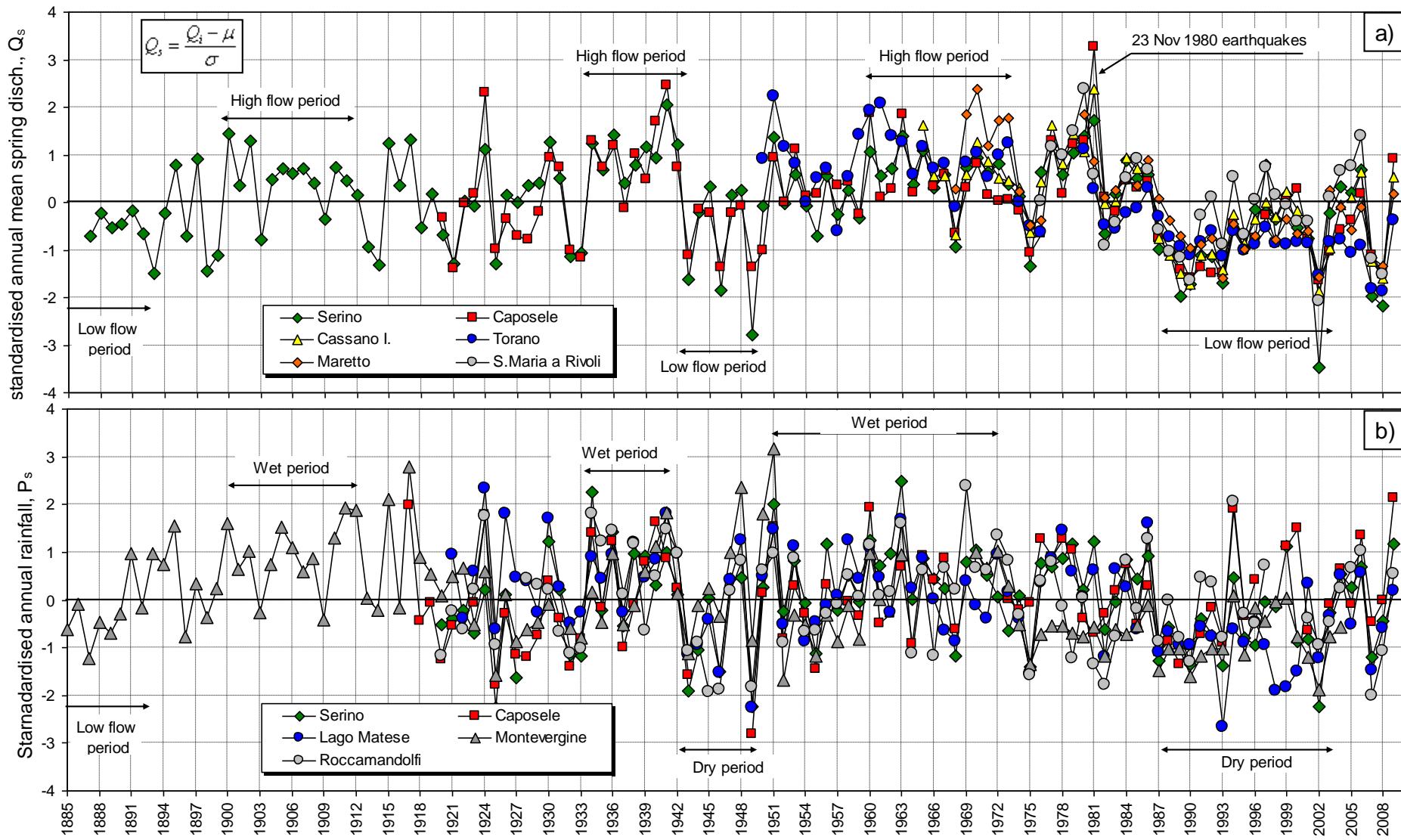
The effect of drought on the following years



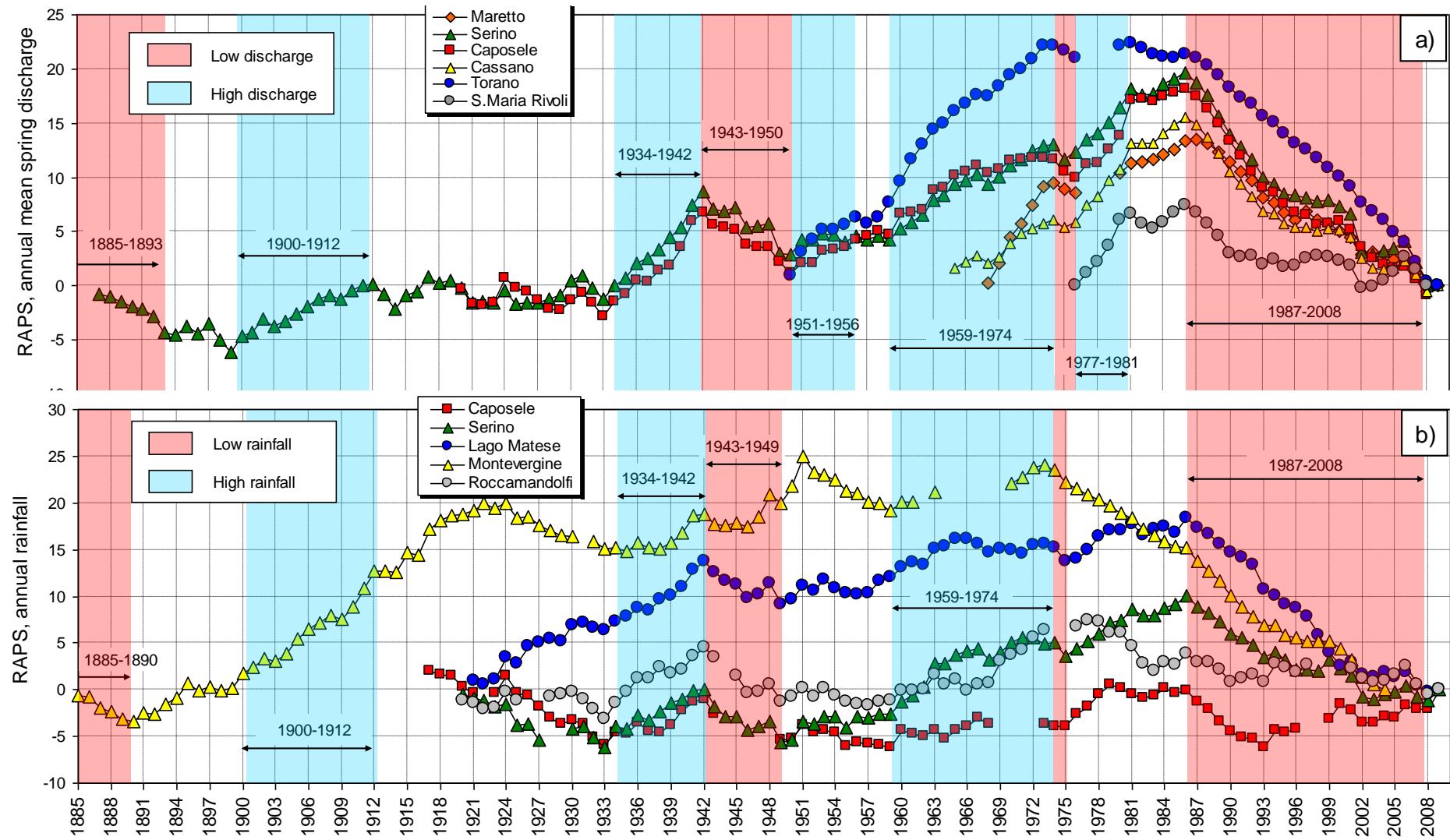
Cumulative rainfall and spring hydrograph shape



Trend and fluctuation of spring discharges and rainfall

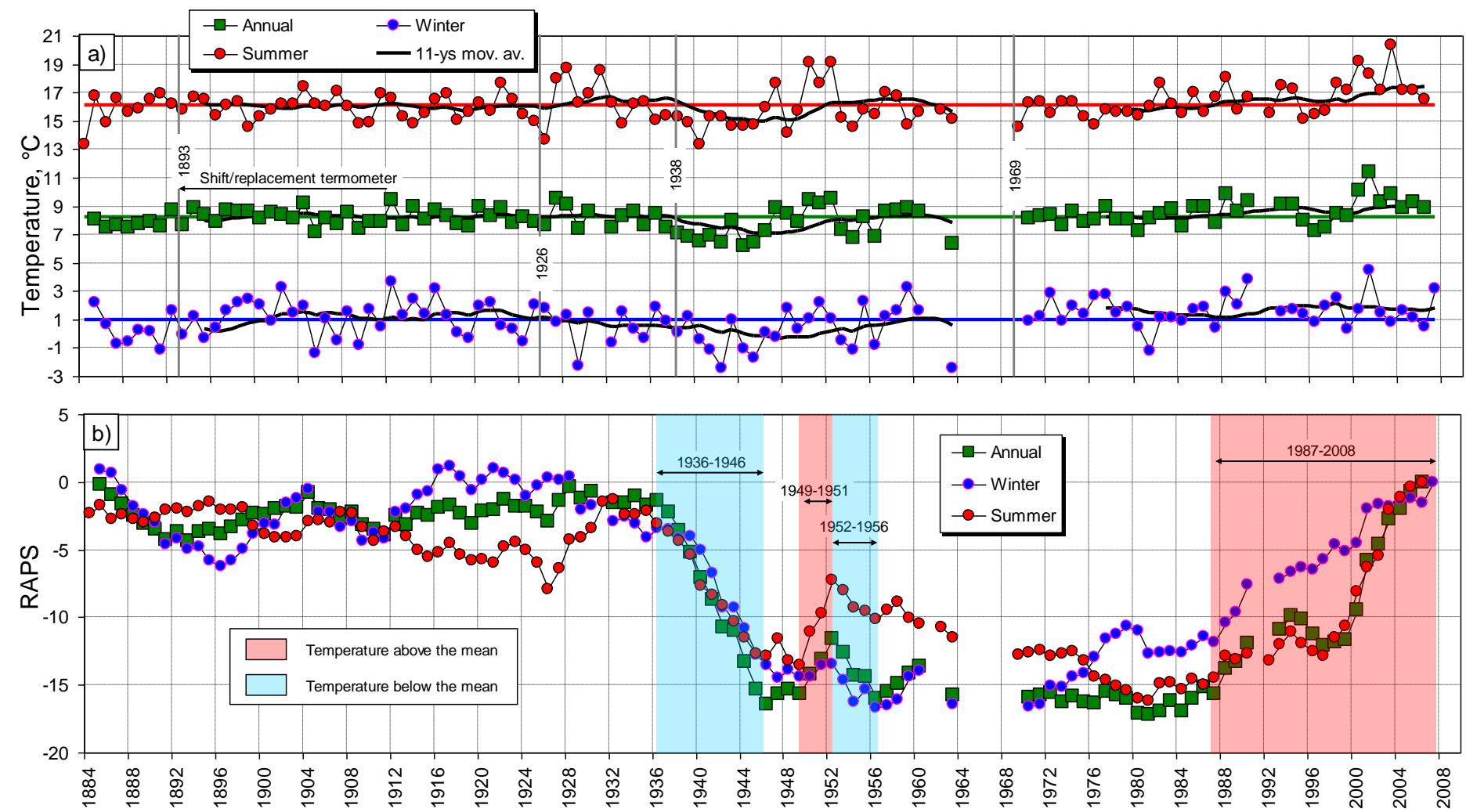


RAPS of time series (discharge and rainfall)

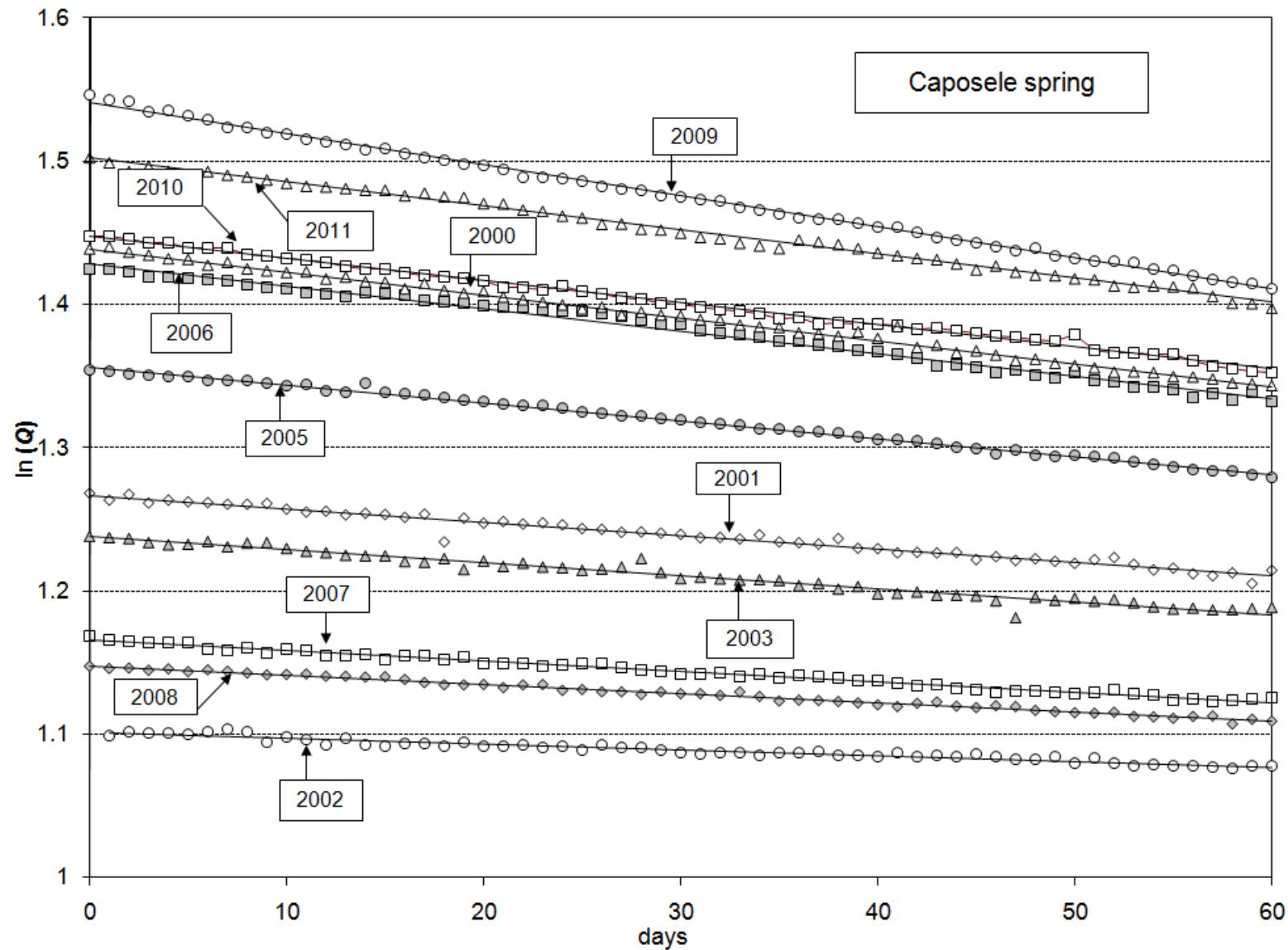


Temperature trend, Montevergine station, 1270 m a.s.l.

Period 1884 - 2008

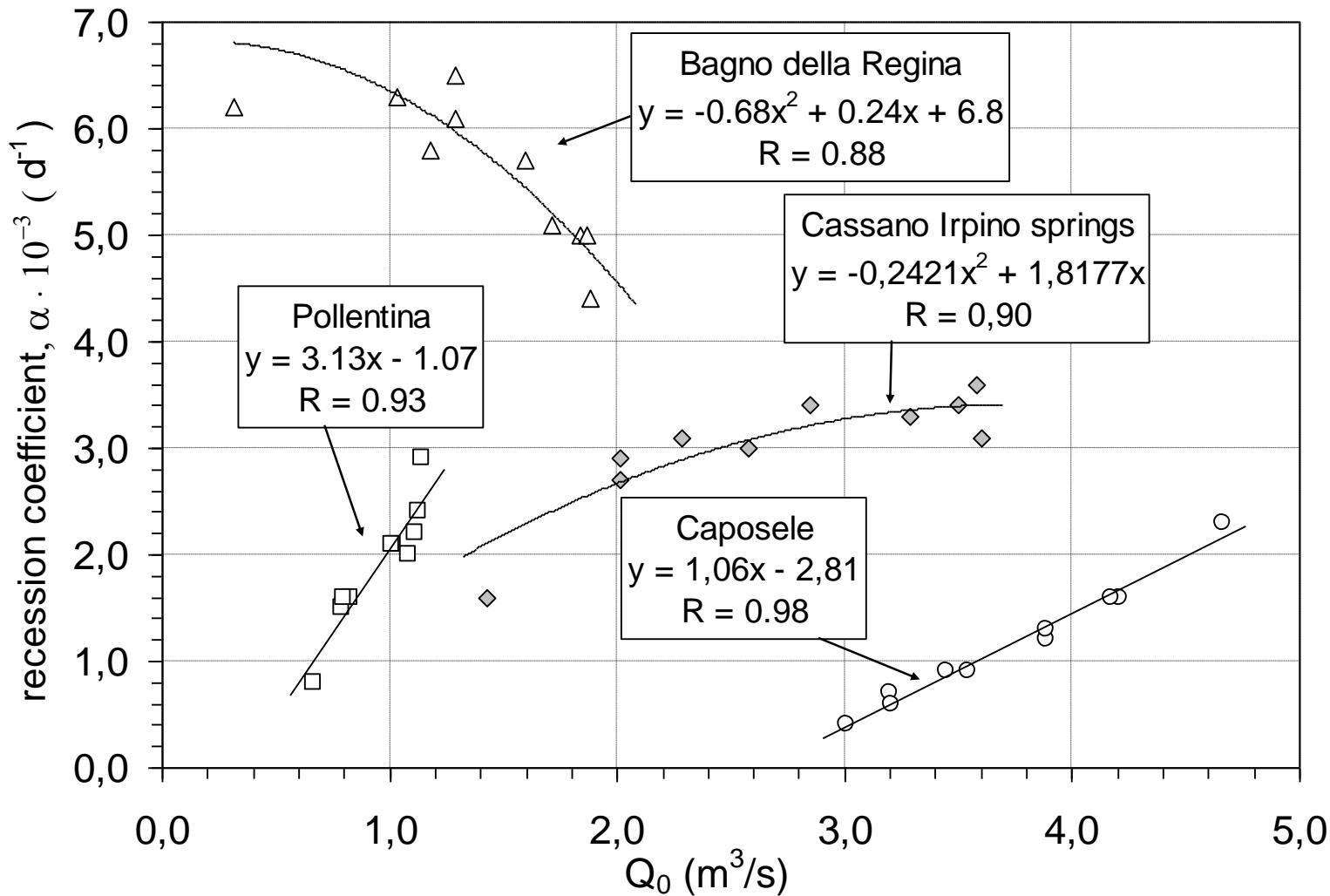


Aquifer behavior during dry periods (recession)

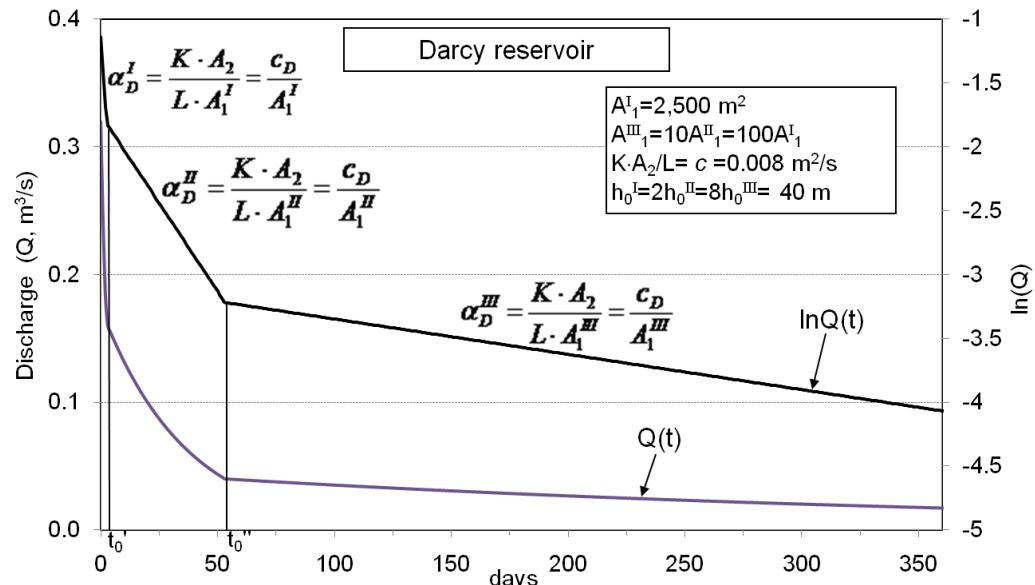
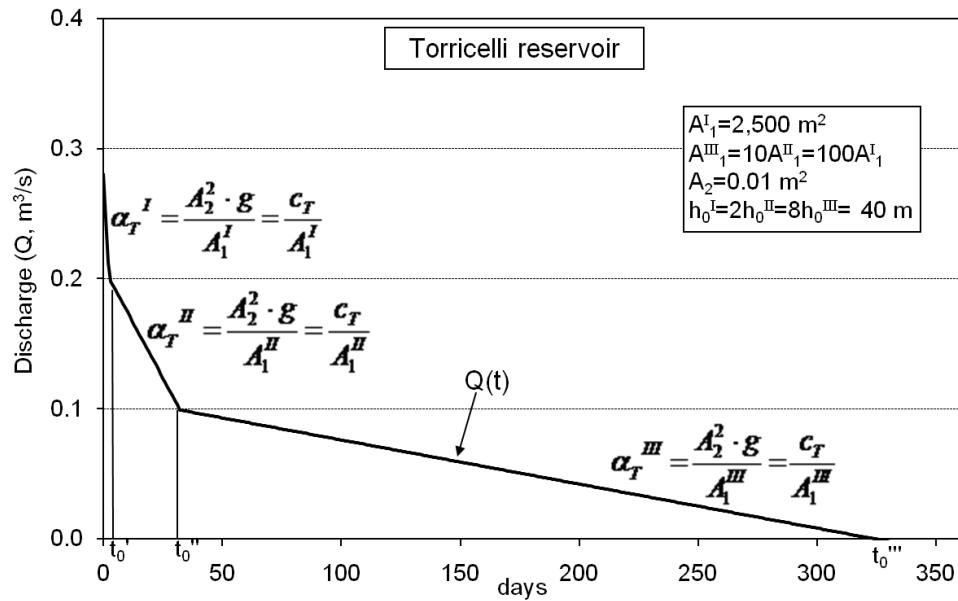
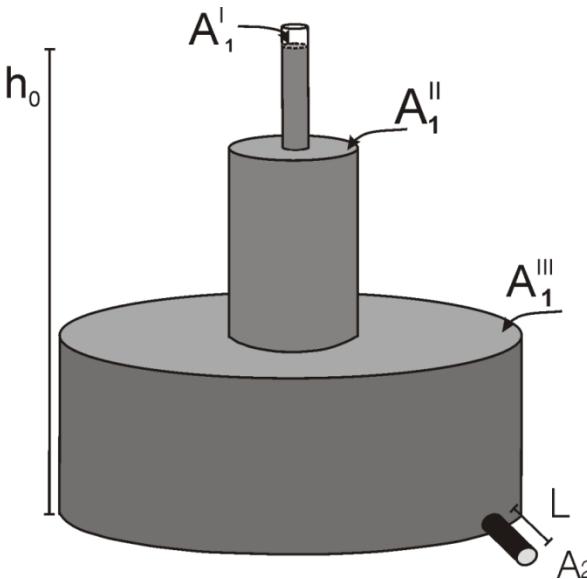


Aquifer behavior during dry periods (recession)

dependence of the recession coefficient on Q_0



Drainage of a composite cylindrical tank-reservoir

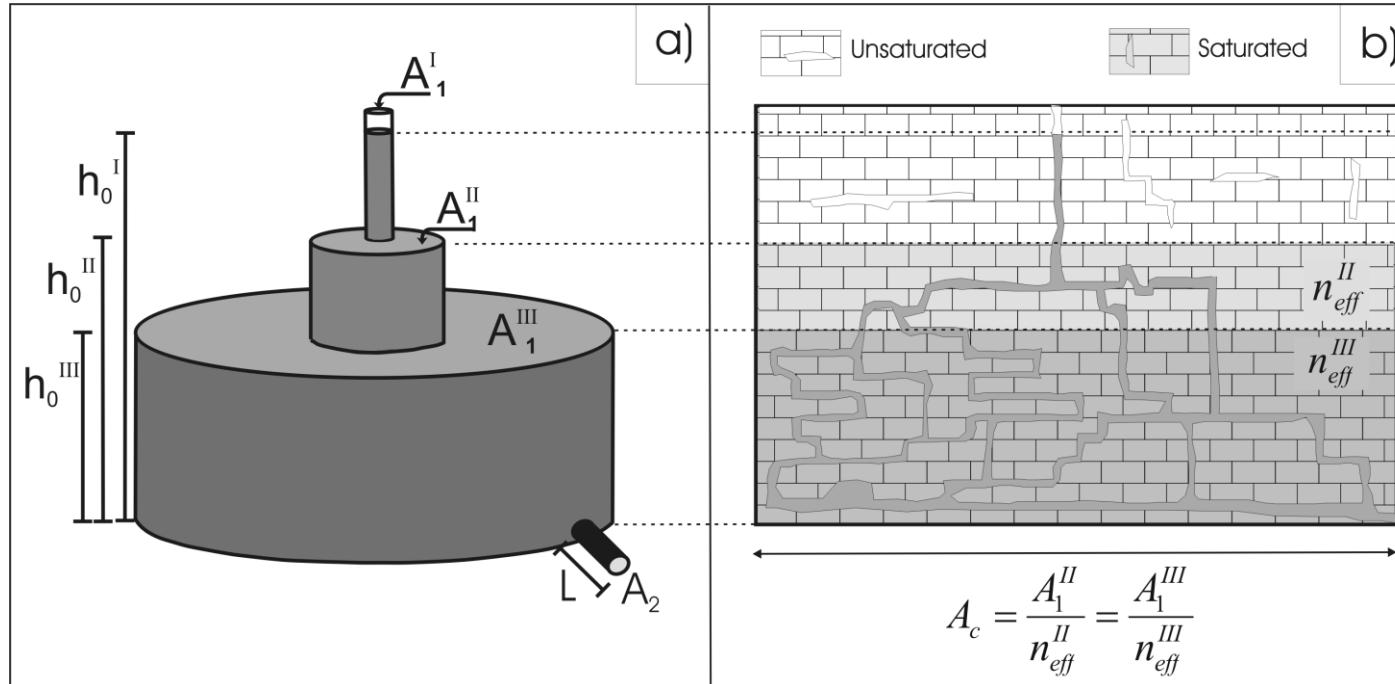


Independent of the model used, the following relationship can be deduced:

$$\frac{\alpha^I}{\alpha^{II}} = \frac{A_1^{II}}{A_1^I}$$

$$\frac{\alpha^{II}}{\alpha^{III}} = \frac{A_1^{III}}{A_1^{II}}$$

From the composite tank-reservoir to karst aquifers



composite tank-reservoir



$$\frac{\alpha^{(II)}}{\alpha^{(III)}} = \frac{A_1^{(III)}}{A_1^{(II)}}$$

Torricelli law



Darcy/Poiseuille law

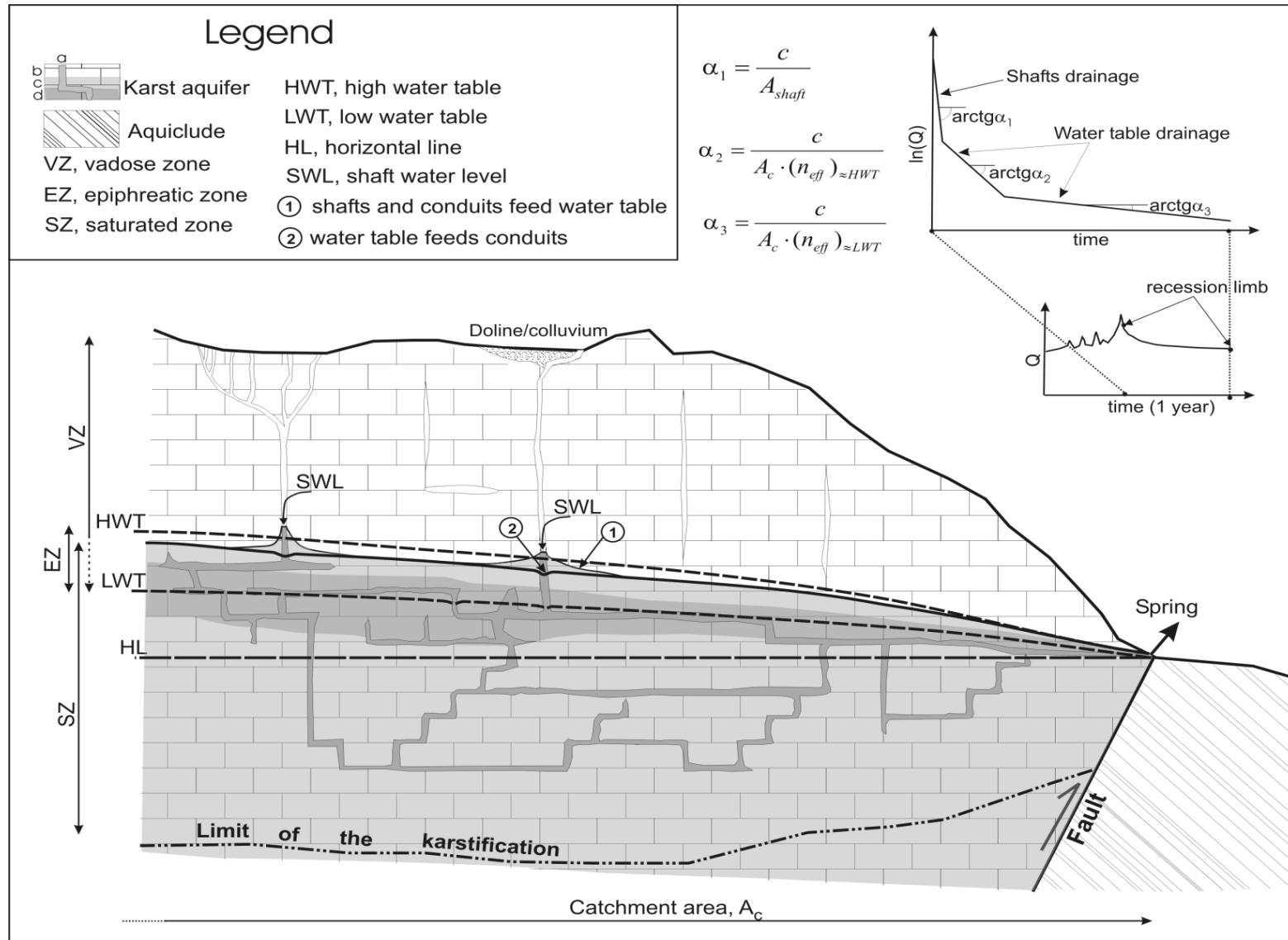
karst aquifer

$$\frac{\alpha^{(II)}}{\alpha^{(III)}} = \frac{A_c \cdot n_{eff}^{(III)}}{A_c \cdot n_{eff}^{(II)}} = \frac{n_{eff}^{(III)}}{n_{eff}^{(II)}}$$

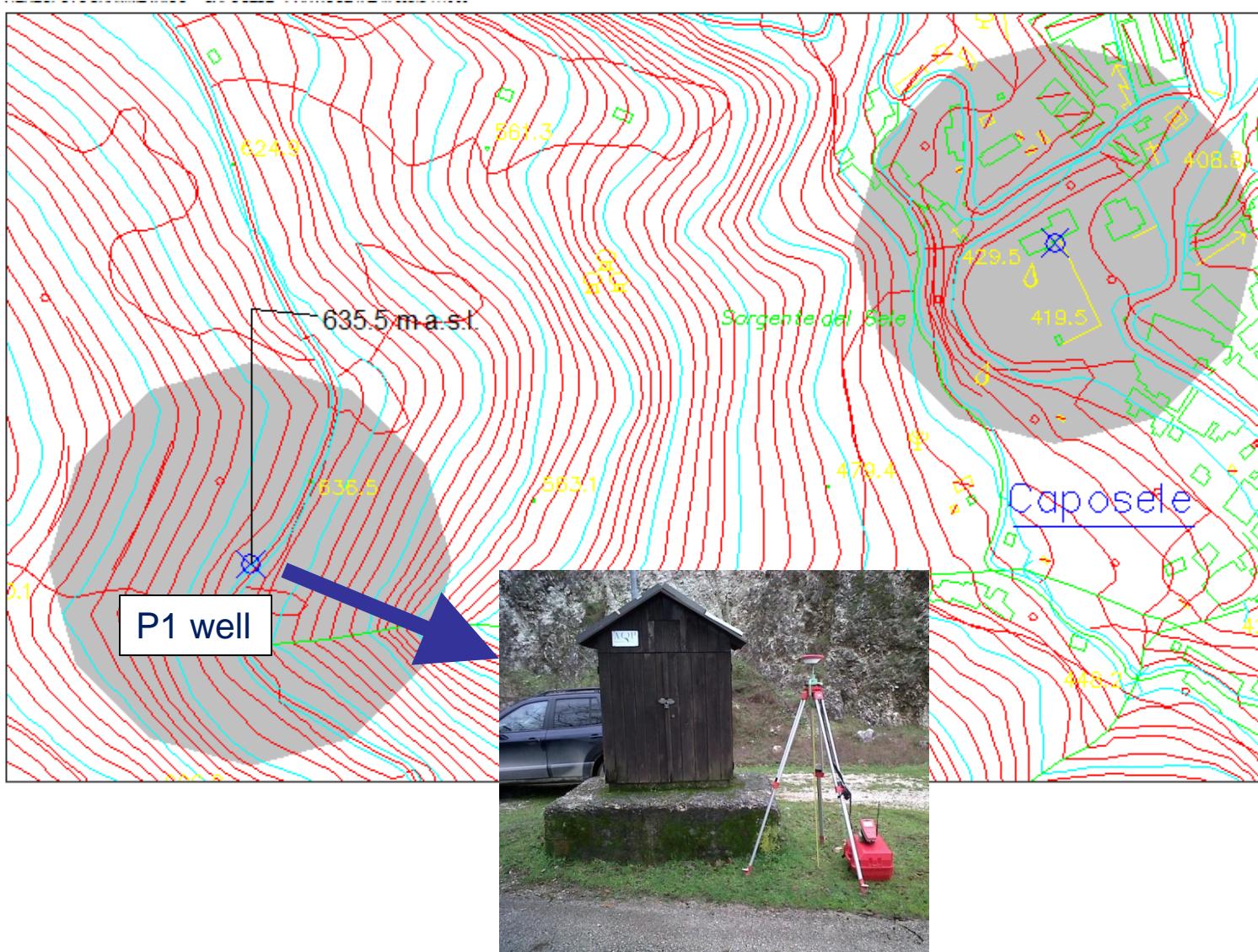
$$\frac{\alpha^{(II)}}{\alpha^{(III)}} \approx \frac{n_{eff}^{(III)}}{n_{eff}^{(II)}}$$

Example of a karst aquifer, tectonically bounded by impervious terrains

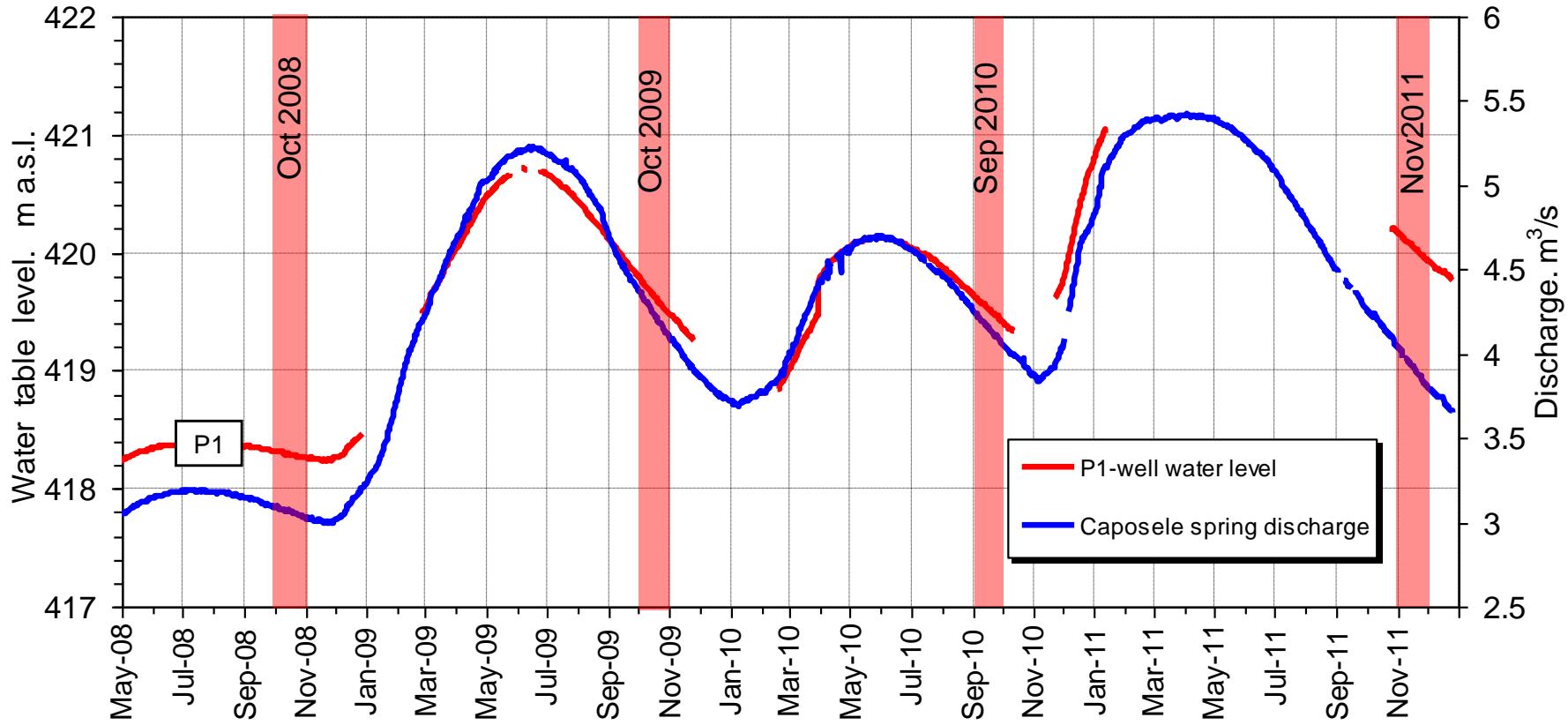
Conduits, shafts, vadose zone and saturated zone with different effective porosity are shown



Caposele spring discharge and water level monitored in well P1



Caposele spring discharge and water level monitored in well P1



Caposele spring discharge and water level monitored in well P1

Recession period	Discharged water volume at spring $D_w (m^3 \times 10^6)$	Water level decrease in P1 $\Delta L (cm)$	Discharged volume for unit of water level decrease $V_w = D_w / \Delta L (m^3/cm \times 10^6)$
October 2008	8,2	6	1,37
October 2009	11,3	31	0,36
September 2010	10,8	24	0,45
November 2011	9,8	23	0,43

Caposele spring discharge and water level monitored in well P1

Check the formula

$$\frac{\alpha^{II}}{\alpha^{III}} \approx \frac{n_{eff}^{III}}{n_{eff}^{II}}$$

2008 and 2009 years

$$\frac{n_{eff}(2008)}{n_{eff}(2009)} \approx \frac{V_w(2008)}{V_w(2009)} = \frac{1.37 \times 10^6}{0.35 \times 10^6} = 3.91$$

$$\frac{n_{eff}(2008)}{n_{eff}(2009)} \approx \frac{\alpha_{(2009)}}{\alpha_{(2008)}} = \frac{0.00230}{0.00060} = 3.83$$

2010 and 2011 years

$$\frac{n_{eff}(2010)}{n_{eff}(2011)} \approx \frac{V_w(2010)}{V_w(2011)} = \frac{0.45 \times 10^6}{0.43 \times 10^6} = 1.05$$

$$\frac{n_{eff}(2010)}{n_{eff}(2011)} \approx \frac{\alpha_{(2011)}}{\alpha_{(2010)}} = \frac{0.00170}{0.00160} = 1.06$$

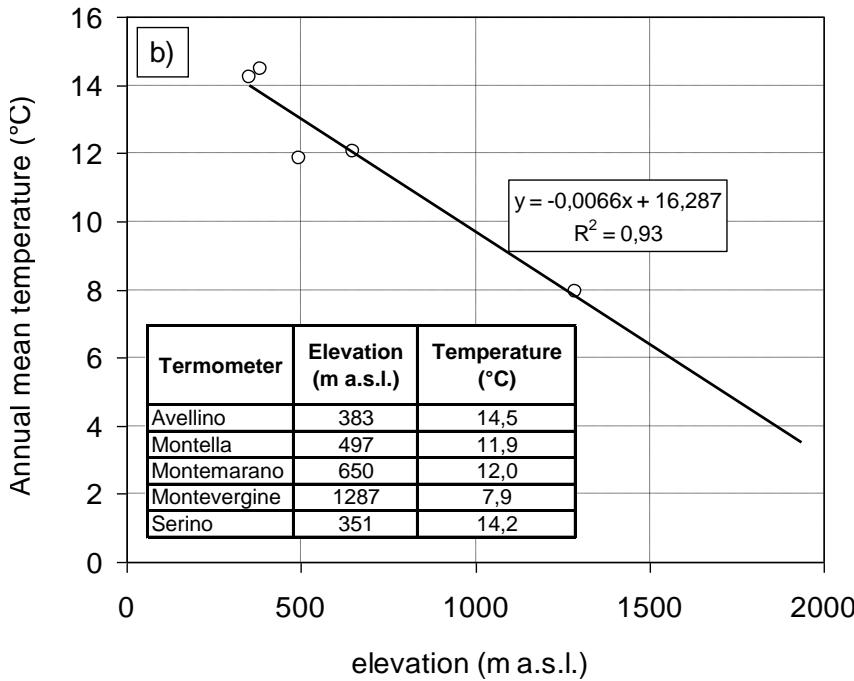
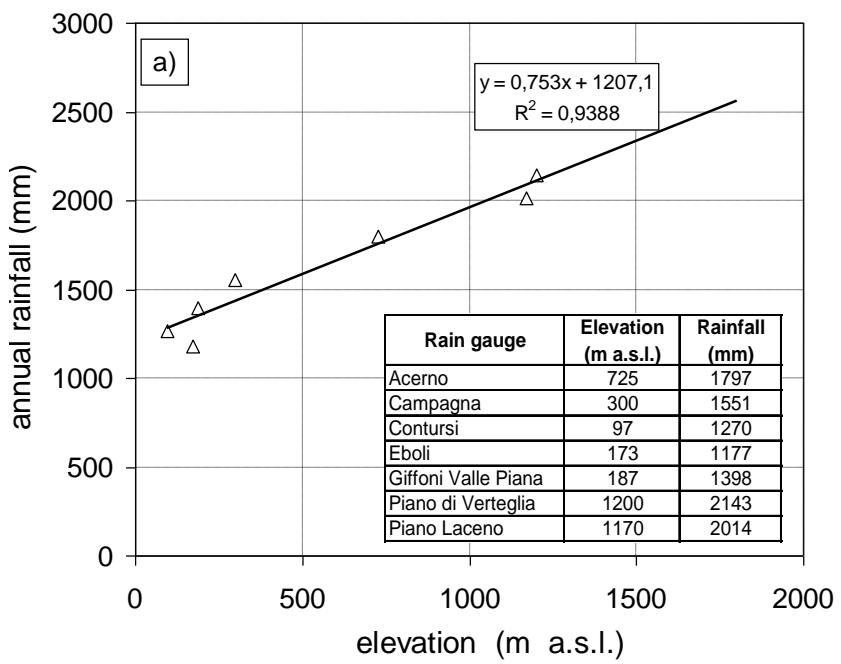
Recharge processes in the spring catchment (Cervialto massif)

Estimation of the long-term recharge (ratio between discharge volume and rainfall on the catchment)

Then, a daily recharge model, calibrated on the previous annual scale estimation, allows to simulate the recharge and the runoff at daily scale

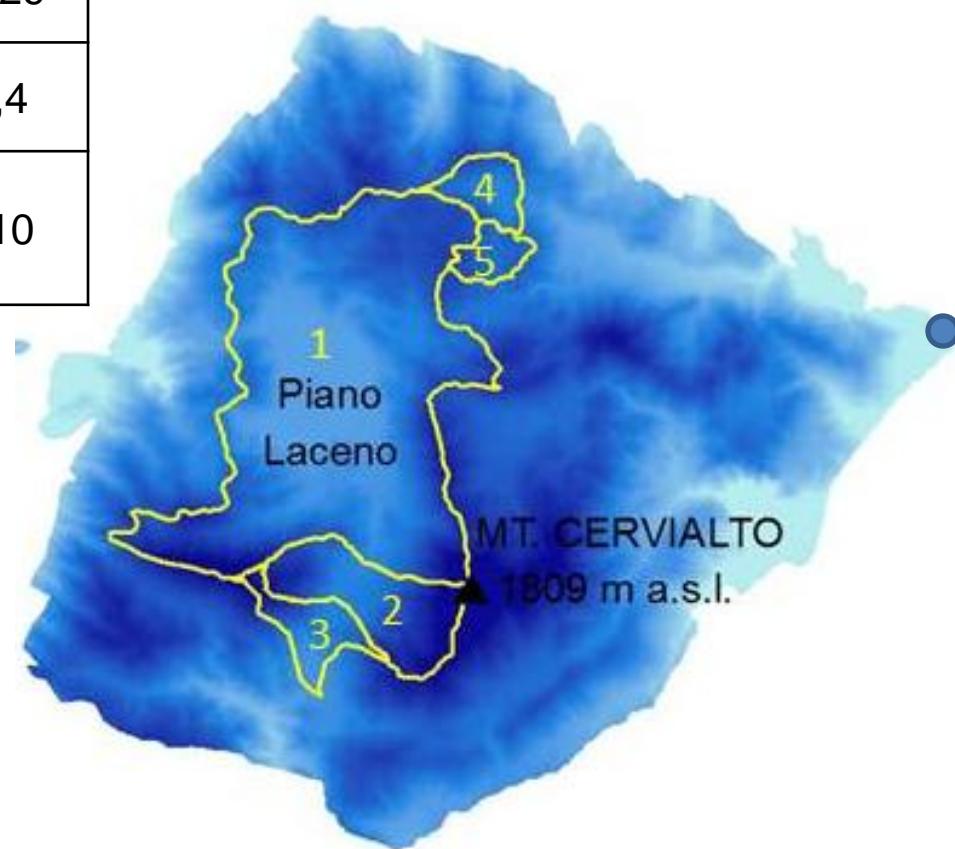
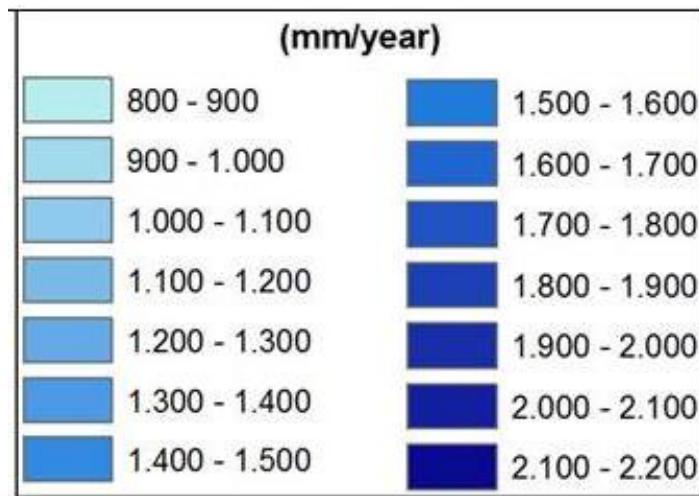
The model have to distinguish the *endorheic areas* (closed morphological zones, where runoff cannot escape from the spring catchment) from the rest of the catchment (*open areas*)

Annual mean rainfall and annual mean temperature in relation to ground-elevation period 1970 - 1999



Main hydrological features of the Cervialto massif *long-term annual values*

		Mean	Max	Min
Mt. CERVIALTO (spring catchment)	Elevation <i>m (a.s.l.)</i>	1179	1809	417
	Afflux <i>mm/year</i>	2109	2621	1529
	Temperature <i>°C</i>	8,5	13,5	4,4
	Actual evapotr. <i>mm</i>	529	688	410



Main hydrological parameters estimation (*long-term annual scale*)

effective afflux, F_{eff} , in a specific area, A

$$(F_{eff})_A = \frac{\sum_{1}^n P_{eff}}{n} \times A$$

recharge amount, R , in endorheic area, A_E

$$(R)_{A_E} = (F_{eff})_{A_E}$$

recharge in the open areas, $(R)_{Ao}$,

$$(R)_{Ao} = Q_s - (F_{eff})_{A_E}$$

effective recharge coefficient, C_R

$$(C_R)_{Ao} = \frac{(R)_{Ao}}{(F_{eff})_{A_O}} \quad (C_R)_{A_E} = 1$$

Main hydrological parameters of Cervialto catchment

Springs			Massif Cervialto	Area	Item	Elevation (minimum) m a.s.l.	km ²	F m ³ ×10 ⁶	F_{eff} m ³ ×10 ⁶	RO m ³ ×10 ⁶	Q_p m ³ ×10 ⁶	R m ³ ×10 ⁶	C_R
Group	m ³ /s	m ³ ×10 ⁶											
Caposele	3,96	128,5	Cervialto	Piano Laceno	1	1047	20,5	43,8	32,9	0,0	0,0	32,9	1
				Piano Acernese	2	1168	3,3	7,4	5,8	0,0	0,0	5,8	1
				Piano dei Vaccari	3	1164	1,4	3,0	2,3	0,0	0,0	2,3	1
				Valle Rotonda	4	1156	1,1	2,3	1,8	0,0	0,0	1,8	1
				Raia dell'Acera	5	1246	0,7	1,5	1,2	0,0	0,0	1,2	1
				Closed areas, A_E	-	-	27,0	58,0	44	0,0	0,0	44,0	1
				Open areas, A_O	-	-	83	172,4	128,3	43,8	0,0	84,5	0,66
				Springs catch., A_C	-	-	110	230,4	172,3	43,8	0,0	128,5	0,75

F , afflux

F_{eff} , effective afflux

RO , run off;

Q_p , groundwater abstracted

R , recharge

C_R , effective recharge coefficient

Daily scale model of the recharge

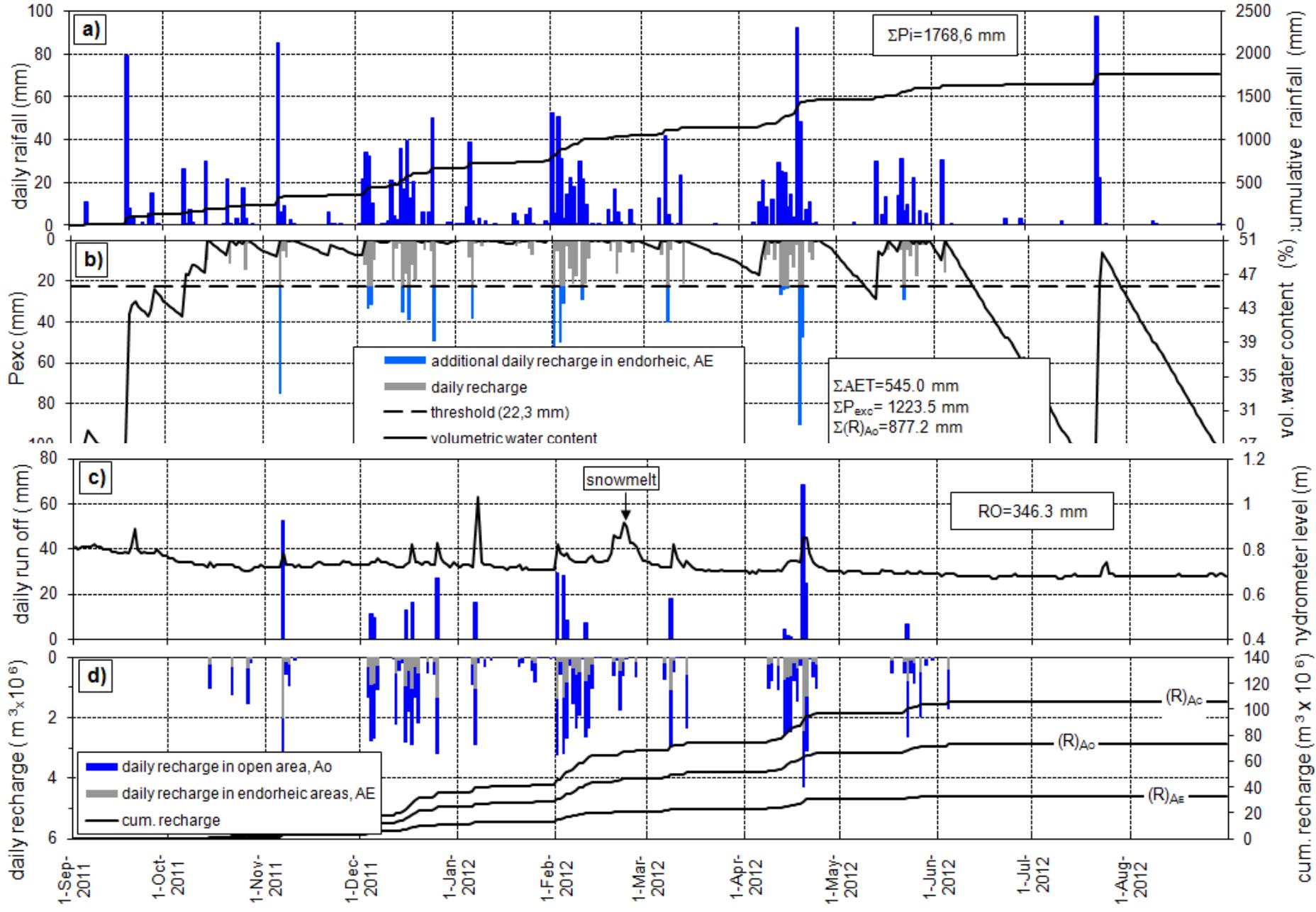
$$P_i = AET + \Delta\theta + P_{exc}$$

- excess rainfall, P_{exc} =daily recharge + daily runoff
- daily runoff occurs if P_{exc} exceeds a specific threshold values at daily scale
- the threshold is deducted from the long term annual scale : $(C_R)_{Ao} = \Sigma(R)_{Ao} / \Sigma P_{exc}$

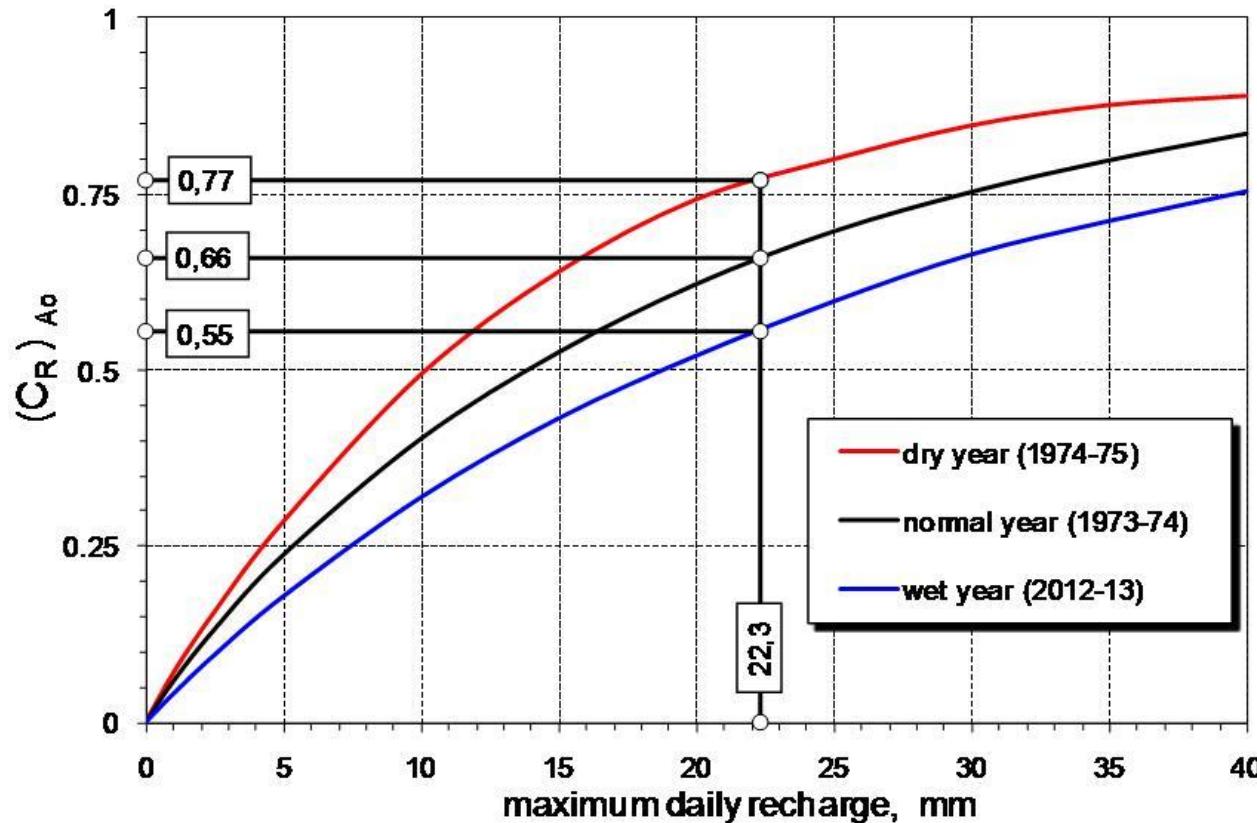
The model generally needs:

- *the thickness of the soil which is undergoing evapotranspiration processes, H ;*
- *the (volumetric) water content at field capacity, Θ_{max} ;*
- *the minimum water content reached at the end of dry season (summer), Θ_{min} ;*
- *the total and effective porosity of the soil.*

Daily scale recharge model. Mt. Cervialto catchment



Recharge coefficient for open areas, $(C_R)_{Ao}$ function of threshold of daily recharge, for different hydrological years



Conclusions

- Caposele spring is a fundamental water resource in southern Italy
- two hydrogeological aspects enhance its usability: absence of peaks (as a typical porous medium) and the regime almost opposite to that of precipitation
- drought reduces the discharge of following years as well, highlighting a memory effect of the aquifer
- the spring is *drough-resistant*, as the (exponential) recession coefficient decreases when initial discharge(Q_0) also decreases
- as the spring catchment is not interested by pumping (groundwater abstraction) and its environment is almost unchanged during the last century, spring discharge is a powerful indicator of climate

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Grazie!

Francesco Fiorillo

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