



7 CATALONIA: THE ST. QUINTI AND CARDENER SPRINGS

7.1 Overview

The 'St. Quintí spring' and 'Cardener springs' area located inside the hydrological system of the Port del Comte Massif (PCM), a high mountain karst aquifer (HMKA) formed by Lower Eocene fissured and karstified limestones and dolomites. The HMKA is located in the southernmost part of the Catalan Pyrenees (northeastern Spain). The elevation of the massif ranges from 900 m a.s.l. to 2387 m a.s.l. The area of the massif occupies approximately 100 km². The watershed of the massif divides the river basin of the Cardener River at the E and S and the river basin of the Segre River at the NW and SW. The hydrological system mainly discharges through the 'Cardener' springs (at the E) into the homonym river (which is the main tributary of the Llobregat River, the first water resources provider to the city of Barcelona, in NE Spain); and through the 'St. Quintí' spring (at the SW) which discharge to the 'Ribera Salada' basin in SW, tributary to the Segre River and finally to the Ebro Basin. The mean groundwater discharge of (~15 hm³/yr) postulates this aquifer as one of the most important HMKA of the eastern Pyrenees.

7.2 Geology

The HMKA belongs to the PCM thrust sheet that presents complex structural relationships in its contours. On the E, the PCM mantle borders on the mantle of Cadí, coinciding with the point of origin for the Cardener River and the position of the 'Cardener springs' (spring S-04; *Figure 25*). To the NE and NW, the PCM is limited by the tectonic plates of the mantles Montsec and Boixols thrust sheets. To the S, the PCM mantle overlaps with the conglomeratic materials of the Ebro Basin, the southern foreland basin of the Pyrenees. The internal structure of the PCM mantle is formed by a set of folds and thrusts detached above the Triassic. These folds have a constant direction NE-SW parallel to the NW limit of the mantle (Vergés, 1999). The stratigraphic series contains materials from the Triassic, Jurassic, Cretaceous and Paleogene (Eocene-Oligocene) with a total of more than 1300 m thickness at the top. The PCM constitutes an independent structural and regional hydro-geological unit and contains one of the most important karst aquifers of the Catalan Pyrenees, formed by Lower Eocene – fissured and karstified limestones and dolomites.

7.3 Geomorphology

From the geomorphological point of view, the PCM has a smooth rounded landscape with a plain in the highest part without vegetation cover and with almost no soil, which corresponds to approximately 10% of the total area. The rest of the massif is covered by mountain meadows (29%) and forest (61%) with scarce soil depth up to medium developed soil cover. Different karstic forms progressively appear from 1950 m a.s.l. upwards, being well developed at 2050 m a.s.l., (see *Figure 25*, indicated as 'Area with well-developed karst landforms') with sinkholes, dry caves, dolines and karren fields, generating a heterogeneous karstified hydrogeological system.

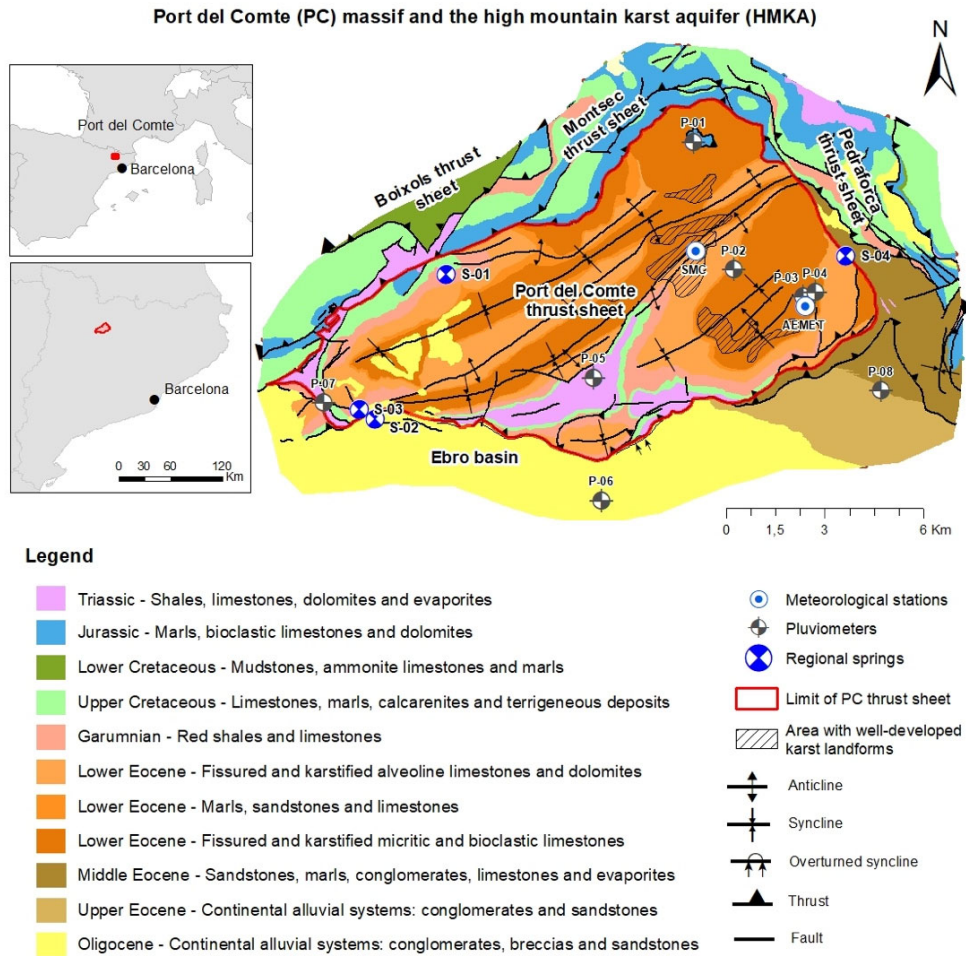


Figure 25: Geological map of the PCM and the location of 'St. Quintí spring' (S-02) and 'Cardener spring' (S-04) (modified from ICGC, 2007). P-0X indicates the position of eight temporal pluviometers implemented to collect rain water samples and used for the period des13 – des15. There are two official meteorological stations, one from AEMET (Spanish Meteorological Agency) and the other from SMC (Meteorological Service of Catalonia).

7.4 Climate

From a climatic point of view, and according to the Köppen-Geiger classification (Peel et al., 2007), the study zone has a cold climate without dry season and temperate summer. At the meteorological station SMC (Figure 25), which is located at 2315m a.s.l., the average values of precipitation, temperature and potential evapotranspiration calculated with the 'Hargreaves' method are 1055 mm/yr, 3,24 °C and 525 mm/yr, respectively. The snow cap is present in the upper zones of the basin in winter and spring, maintained annually for 3 to 4 months since 1800m a.s.l., meaning that precipitation is partly produced as snow. Despite the high average rainfall above 1000 mm/yr, in most of the area the surface runoff is almost nonexistent due to the epikarst development in these altitudes, and it is not observed until reaching lower altitudes.



7.5 Hydrogeology

The geologic structure and stratigraphy of the PCM thrust strongly influence the location of the existing karst springs, their groundwater geochemistry and their hydrologic behaviour. The lower Upper Cretaceous/Paleocene (Garumnian facies) substrate materials underlying the Lower Eocene karstic aquifer are composed of sandstone, siltstone and shale. These materials constitute an impervious layer for the overlaying aquifer system.

The hydrogeological conceptual model of the PCM aquifer system considers that recharge is produced by infiltration of precipitation as rainfall and snowmelt. The magnitude and distribution of infiltration is conditioned by the development of the karst landforms. The infiltration is produced: 1) in a concentrated way through the local karstic elements such as dolines and, 2) in a diffuse way by rain and snowmelt along the whole PCM area. The infiltrated water flows vertically through the unsaturated zone (NSZ) towards the saturated zone. The hydrogeological system naturally discharges through a large number of existing springs of different entity. Approximately 100 springs have been found in the PCM showing large discrepancies in their mean discharge flow rate, ranging from values $<0,1$ l/s up to values > 100 l/s. Most of these springs discharge small-scale local sub-surface water flows that often re-infiltrate or are captured for small uses. The main groundwater discharge points of the hydrogeological system are four springs: the 'Aiguaneix spring', 'St. Quintí spring', 'Can Sala spring' and 'Cardener spring' (S-01, S-02, S-03 and S-04 in *Figure 25* respectively). There is also a diffuse discharge of groundwater to the north through the 'Riu Fred' sub-basin that should help to drain the system. Of the four springs, the 'Cardener spring' and 'St. Quintí spring' are the main. Their inferred catchment areas by means of integrated modelling (Herms, 2019) represents more than 44 km^2 . (*Figure 26*). All of them have been monitored regularly between set 2013 until oct 2015, showing that they have a highly variable discharge flow rate (*Figure 27*). The four springs discharges the system approximately at elevation of 1000 a.s.l. and specifically, the 'Cardener spring' and 'St. Quintí spring' are located at 1032m a.s.l. and 944 m a.s.l. respectively. Through these two main springs, the hydrogeological system discharges at two principal watersheds: the Cardener River watershed to the east and the Segre River watershed to the northwest. Groundwater flow direction is conditioned by the geological structure of PCM.

The analysis of stable isotopes for the period between set2013 until oct2015 indicates that the range of recharge altitudes for both springs vary slightly: for 'St. Quintí spring' are suited between 1750m a.s.l. to 2300m a.s.l. with a main elevation estimated at 2038m a.s.l. according to a regression model (Herms, 2019), whereas for the 'Cardener spring' are suited between 1925m a.s.l. to 2250m a.s.l. with a main elevation estimated at 2099m a.s.l. The exact position of the regional groundwater table in the aquifer is not known. There are only 2 water wells located just at the boundaries of the system that pump very low rates for drinking purposes. There aren't water wells or piezometers inside the aquifer. Only in 2002, a water well was drilled for a particular purpose to a depth of more than 400 m from 1700 m.a.s.l. which not only found the phreatic level, but intense karstification was observed. Although no tracer tests are available for this aquifer (task that remains for future field-works), it is estimated that the value of effective porosity for the massif must be high. Applying the hydraulics principles of the KARSYS approach (Jeannin et al. 2012, and others) -which assumes that the volume below the main perennial spring in well-developed karst aquifers is normally water saturated, and that the expected high degree of karstification cause the hydraulic gradients upstream from the karst springs at low-water stage could be close to 0% or a 1% at most - the regional saturated zone

for the PCM aquifer could be situated between 1000m a.s.l. to 1100m a.s.l. Consequently, the epikarst NSZ in the highest areas of the PCM may presents a thickness close to 1000m.

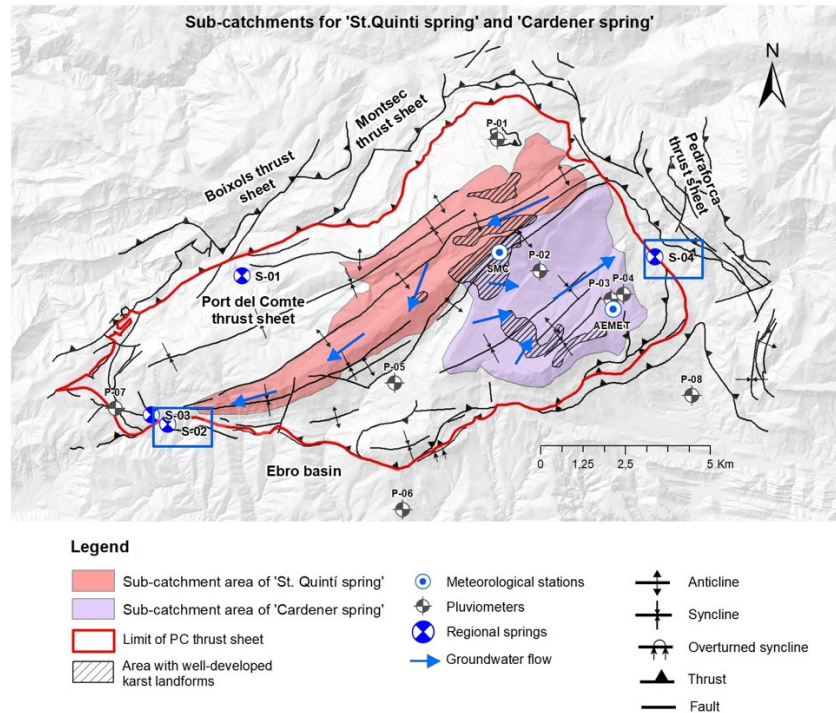


Figure 26: Scheme of the 'St. Quintí spring' and 'Cardener spring' catchment and discharge areas (Hermis, 2019).

7.6 Hydrodynamic characteristics of the springs

The flow rates measured in the karst springs at 'St. Quintí spring' and 'Cardener spring' vary widely in dependence on climatic conditions and above all as a function of the snowmelt periods (Figure 27). For the 'Cardener spring', the dataset available from its old gauge station (ACA, 2010) for the period between 2000 until 2010, indicates that the flow rate ranged between 58 l/s and a punctual value of 4018 l/s (May 2001), with an average of 325 l/s. For the monitored period between set2013 until oct2015 (Hermis 2019), the flow rate ranged between 58 l/s and 903 l/s, with an average of 221 l/s (the maximum was registered in April 2014 just after the beginning of the snowmelt period). For the 'St. Quintí spring', the flow rate for the monitored period between set2013 until oct2015 ranged between 70 l/s and 575 l/s, with an average of 189 l/s (the maximum was also registered in the same moment as the 'Cardener spring' just after the beginning of the snowmelt period). For both springs, during dry periods, the flow rates almost reach a steady state. The discharge hydrographs for the same period show, in general terms, the same tendency. Nevertheless, although the 'Cardener spring' has greater flow rate oscillations (58-903 l/s vs. 70-575 l/s), the hydro-geochemistry in the 'St. Quintí spring' shows a slightly greater seasonal variability (e.g. the CE and T^0 for 'St. Quintí spring' varies between 221-331 $\mu\text{S/cm}$ and 7,7 -10,5 $^{\circ}\text{C}$ whereas for 'Cardener spring' between 216-265 $\mu\text{S/cm}$ and 6,7 -7,92 $^{\circ}\text{C}$, which is as a proxy among other that it receives recharge water from a little lower altitudes.

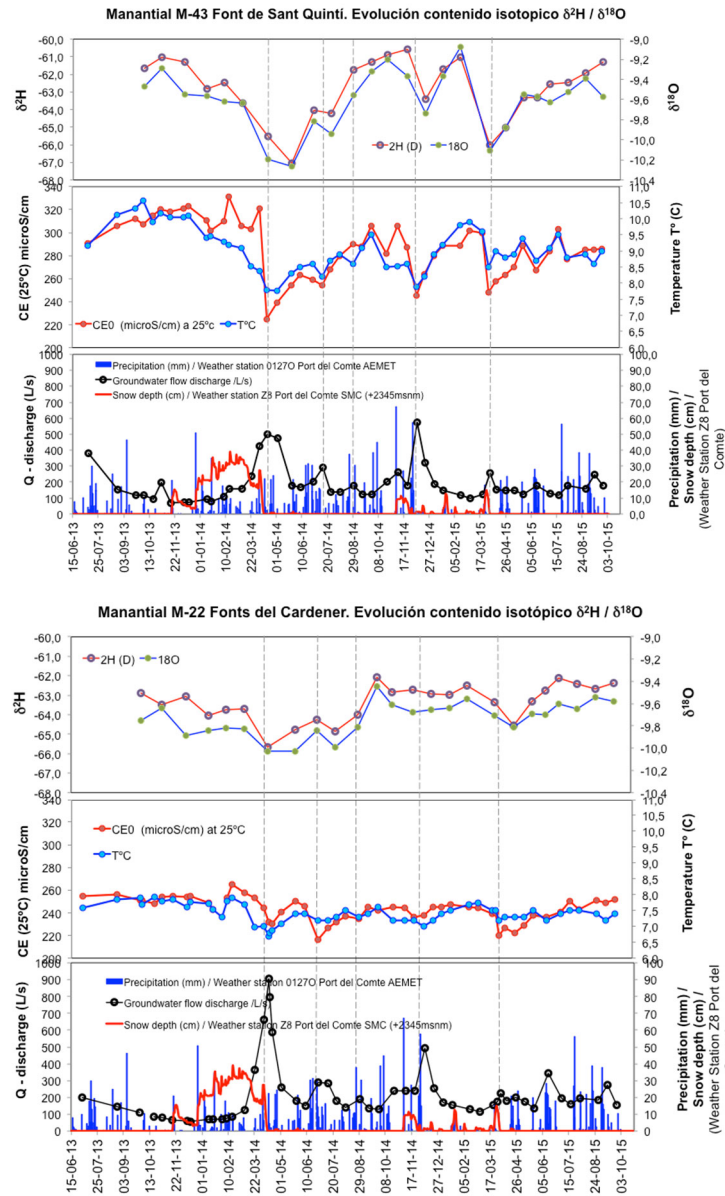


Figure 27: Hydrodynamic and physico-chemical graph data (CE, T, stable isotopes) of the 'St. Quintí spring' and 'Cardener spring' for the period Jul13 -Oct15 (Herms, 2017)

7.7 Data available for the project

1. St. Quintí Spring (Z - 1032m a.s.l.)			
Data type	Time step	Monitoring period	Time period
Flow-rate	fortnightly	2 years	Jul2013 – Oct2015
T°, Eh, Ph, CE, TDS	fortnightly	2 years	Jul2013 – Oct2015
Major anions/cations	monthly	2 years	Set2013 – Oct2015
Trace metals	monthly	2 years	Set2013 – Oct2015



Nutrients (*)	monthly	2 years	Set2013 – Oct2015
Stable isotopes (**)	monthly	2 years	Set2013 – Oct2015

2. Cardener Spring (Z - 944m a.s.l.)			
Data type	Time step	Monitoring period	Time period
Flow-rate	fortnightly	2 years	Jul2013 – Oct2015
T°, Eh, Ph, CE, TDS	fortnightly	2 years	Jul2013 – Oct2015
Major anions/cations	monthly	2 years	Set2013 – Oct2015
Trace metals	monthly	2 years	Set2013 – Oct2015
Nutrients (*)	monthly	2 years	Set2013 – Oct2015
Stable isotopes (**)	monthly	2 years	Set2013 – Oct2015

(*) NO_3^- , NO_2^- , NH_4^+ (**) $\delta^2\text{H}_{\text{H}_2\text{O}}$, $\delta^{18}\text{O}_{\text{H}_2\text{O}}$

3. AEMET-01270 Metereological station (Z - 1800m a.s.l.)			
Data type	Time step	Monitoring period	Time period
Precipitation	daily	> 10 years	Jan 1996- Apr 2016
Temperature	daily	> 10 years	Jan 1996- Apr 2016

4. SMC Z8 Metereological station (Z - 2315m a.s.l.)			
Data type	Time step	Monitoring period	Time period
Precipitation	daily	> 10 years	Oct 2002- Apr 2016
Temperature	daily	> 10 years	Oct 2002- Apr 2016

In addition, there are available the following information:

- Few samples and chemical data from precipitation water (snow) are available.
- Data from stable isotopes from 8 temporal rain gauges at quarterly basis from the period des2013 – des2015 are also available.
- For the Cardener spring, discharge data for two long periods with small gaps: a) period 27th February 1985 until 1st Oct 1996, b) 5th Sep 2000 until 1st Dec 2010 (daily) are also available.
- Monitoring objects are shown in Figure 1.



7.8 Summary

Pilot name	The 'St. Quintí and Cardener springs' (Port del Comte Massif (PCM) hydrological system (Catalonia, Southeastern Pyrenees, NE Spain)		
Country	Catalonia, Spain	EU-region	Southeastern Pyrenees Mountains
Area (km ²)	100 (for the whole PCM) 44 (both springs catchment areas)	Lithology	Limestone and dolomite
Short description: 'St. Quintí spring' (M-43 in the figure) and 'Cardener springs' (M-22) are the main discharge points of the Port del Comte karst hydrogeological system. Flow rates of both spings widely according to the snowmelt periods.			
Monitored objects	Springs (two), Metereological station (two), Temporal pluviometers (eight)		
Monitored data	Discharge flow rates, groundwater temperature, EC, Ph, CE, chemistry (major ion, trace elements, including nutrients), isotopic composition ($\delta^2\text{H}_{\text{H}_2\text{O}}$, $\delta^{18}\text{O}_{\text{H}_2\text{O}}$ either from groundwater and precipitation), and precipitation and temperature values from two meteo stations.		
Contact person	Ignasi Herms (ignasi.herms@icgc.cat)		

7.9 References

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