



Deliverable 5.3

PILOT DESCRIPTION AND ASSESSMENT

Fluvia and La Muga rivers delta plain (Catalonia)

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This report is part of a project that has received funding by the European Union's Horizon 2020 research and innovation programme under grant agreement number 731166.



Deliverable Data	
Deliverable number	D5.3
Dissemination level	Public
Deliverable name	Pilot description and assessment
Work package	WP5: ASSESSMENT OF SALT-/SEA WATER INTRUSION STATUS AND VULNERABILITY
Lead WP/Deliverable beneficiary	IGME
Deliverable status	
Version	Version 3
Date	26/03/2021

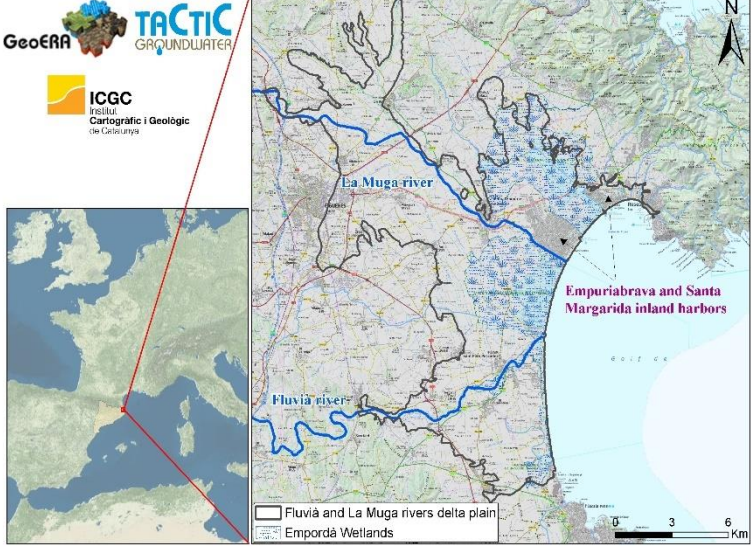
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LIST OF ABBREVIATIONS & ACRONYMS

ACA	Catalan Water Agency
CC	Climate Change
GC	Global Change
GSO	Geological Survey Organisations
LULC	Land Use and Land Cover
NBL	Natural Background Level
SWI	Sea Water Intrusion
TV	Threshold Value

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Pilot name	Fluvià and La Muga rivers delta plain	  
Country	Spain	
EU-region	Mediterranean region	
Area (km ²)	166 km ²	
Aquifer geology and type classification	Sedimentary delta plain (gravel and sand layers in a silty and clay matrix). Porous media aquifer.	
Primary water usage	Irrigation / Drinking water	
Main climate change issues	The Fluvià and la Muga delta plain correspond to a very flat and low altitude area. Adjacent to the coastline there is a protected area called “the Natural Park of the Empordà Wetlands” recognized by the International Treaty of RAMSAR where mixed saline and fresh water coexists. On the north the inland harbors of Empuriabrava and Santa Margarida constructed between the 1960 and 1975 are one of the biggest marine urban areas in the world. These settings and an important demand of water for agriculture purposes combined with the expected rise in temperatures and the decrease in rainfall (consequent reduction in evapotranspiration) make this area particularly vulnerable. Additionally, the frequency of storms such “Gloria 2020” would notably increase. In this very flat area near the coastline, low air pressure during the storms causes surface salt water to move forward inland producing natural saltwater recharge from the surface to the target aquifers.	
Methods used	Assessment of the SWI status on the aquifer system by means of the proposed methods, using the time series available since 1995 is the main objective of this project. For the temporal evolution of the status, the proposed index methods have been used. It has been necessary to work mainly with GIS interpolation methods based on an iterative finite difference interpolation technique. In the future a density dependent flow 3D model of the area (not available for this project) would allow different future simulations based on climate change scenarios.	
Key stakeholders	Catalan Water Agency (ACA), agricultural irrigators communities, water supply companies.	
Contact person	Víctor Camps (ICGC); victor.camps@icgc.cat	

1 EXECUTIVE SUMMARY

The aquifer system of the Fluvià and la Muga rivers delta plain is located in the Northeast of the Iberian Peninsula. It is a porous media which consists of quaternary detrital deposits overlapping the Neogene detrital sediments of the Empordà basin. It is a typical Mediterranean fluviodeltaic aquifer system with an unconfined upper aquifer and a discontinuous confined deep aquifer. Between them a clay and silt sediments layer acts as aquitard. The extension of the aquifer is 166 km². The maximum thickness of the total aquifer system reaches at least 50 meters in the areas closest to the coastline. Upstream the two aquifers converge into a single aquifer of unconfined behavior.

The transmissivity of this aquifer system ranges between 200 - 3000 m²/day (ACA, 2005) and the storage coefficient ranges from 0.15 and 10⁻⁴ (ACA, 2005). It should be pointed out that the aquifer system presents an important lithological spatial heterogeneity and therefore its behavior and hydraulic parameters can change substantially from one site to another one.

The study area had been mainly agricultural until the end of the 1960s and early 1970s, when (like other Mediterranean areas) the construction of tourist infrastructures were intensified. The paradigm of this situation is found in the inland harbors of Empuriabrava and Santa Margarida constructed between the 1960 and 1975 in the north of the study area. With more than 30 Km of inland navigable channels are one of the biggest marine urban area in the world. This fact caused a significant overexploitation with an increase in SWI problems in some areas. These effects were mitigated by the search for water supply alternatives in the late 1980s. Even so the largest pumping of water is related with agriculture purposes (18.9 hm³/year), followed by water supply (2.35 hm³/year) and other industrial uses (0.78 hm³/year) (ACA, 2005).

Opposite to this, in an area adjacent to the coastline and surrounding the Empuriabrava harbor there is a very wild natural protected area called “the Natural Park of the Empordà Wetlands” recognized by the International Treaty of RAMSAR (site No. 592 of RAMSAR Convention Bureau, 1990) where mixed saline and fresh water coexists.

SWI has been a permanent problem in the areas closest to the coast. Therefore, a study of the available historical series can show the trend in order to complete the study in the future with a density dependent flow 3D model, which could simulate future climatic scenarios. Therefore, the main objective in this project has been to assess the status and vulnerability of the aquifer system on SWI throughout the available time series with the proposed index methods in TACTIC WP5.

For the evaluation of the status, an analysis of the available time series of the chloride concentration (data mainly provided by ICGC main stakeholder, the Catalan Water Agency) has been carried out. By defining the chloride Natural Background Level (NBL) in the Fluvià and la Muga rivers delta plain aquifer system and the corresponding chloride Threshold Value (TV), a SWI affected area has been established for each time period as proposed by the first index method (SWI status). The same affected areas and volumes estimation have been made using another kind of threshold value: the GALDIT vulnerability index. The GALDIT method has been applied to see the evolution of the moderate and high vulnerability throughout the time series. The results from both methods (the SWI status and the vulnerability assessment) have been summarized in conceptual 2D cross sections.



A slightly increase of the affected volume by SWI is observed in the last 25 years. More variability is observed in the outcomes of the SWI status method. Even so, the variation of the SWI affected areas is not homogeneous in the study area and more variability can be observed in the center and south part where the variation on the pumping exploitation rates is the most important anthropogenic process to be considered. The Empuriabrava inland harbors in the north and the Empordà Wetlands causes bigger SWI affected areas, but they existence also could favor the stability of the SWI over time.

The obtained results give a good overview of the evolution of the SWI in the area and its areal distribution concluding that the SWI status proposed method is useful in that sense. It could be applied systematically in different potential coastal areas affected by SWI and obtain comparable results among them.

It is also highlighted the need for develop 3D numerical flow and transport models (density - dependent) in the most sensible areas to simulate future scenarios related with the climate change and to obtain better and more accurate outcomes.

2 INTRODUCTION

2.1 General introduction

Climate change (CC) already have widespread and significant impacts in Europe, which is expected to increase in the future. Groundwater plays a vital role for the land phase of the freshwater cycle and has the capability of buffering or enhancing the impact from extreme climate events causing droughts or floods, depending on the subsurface properties and the status of the system (dry/wet) prior to the climate event. Understanding and taking the hydrogeology into account is therefore essential in the assessment of climate change impacts. Providing harmonized results and products across Europe is further vital for supporting stakeholders, decision makers and EU policies makers.

The Geological Survey Organizations (GSOs) in Europe compile the necessary data and knowledge of the groundwater systems across Europe. In order to enhance the utilization of these data and knowledge of the subsurface system in CC impact assessments the GSOs, in the framework of GeoERA, has established the project “Tools for Assessment of Climate change Impact on Groundwater and Adaptation Strategies – TACTIC”. By collaboration among the involved partners, TACTIC aims to enhance and harmonize CC impact assessments and identification and analyses of potential adaptation strategies.

TACTIC is centered around 40 pilot studies covering a variety of CC challenges as well as different hydrogeological settings and different management systems found in Europe. Knowledge and experiences from the pilots will be synthesized and provide a basis for the development of an infra structure on CC impact assessments and adaptation strategies. The final projects results will be made available through the common GeoERA Information Platform (<http://www.europe-geology.eu>).

2.2 The Fluvià and la Muga rivers delta plain

The present document reports the TACTIC activities in the pilot Fluvià and la Muga rivers delta plain aquifer system located in the Mediterranean coast of Spain, Girona province, in the NE of Catalonia. It is a quaternary detrital aquifer system composed by two main aquifers: an uppermost shallow unconfined aquifer and a lowermost confined aquifer. The known aquifer system thickness ranges from 10 m to more than 50 m downstream near the coastline. Upstream the two aquifers converge into a single aquifer of unconfined behavior. The detrital deposits of this aquifer system are very heterogeneous, so hydraulic parameters have a wide range of values.

The study area had been mainly agricultural until the construction of one of the biggest inland harbors in the world; the Empuriabrava and Santa Margarida marine urban area which is placed in the north of the study area. In addition to the impact on the SWI status that this civil work caused itself, the tourism pressure caused a significant increase of the exploitation of the aquifer system. Adjacent to the coastline and surrounding the Empuriabrava inland harbor there is a very wild natural protected area called “the Natural Park of the Empordà Wetlands” recognized by the International Treaty of RAMSAR (site No. 592 of RAMSAR Convention Bureau, 1990) where mixed saline and fresh water coexists. Thus, SWI has been a permanent problem in the

areas closest to the coastline and due to both natural and anthropogenic conditions. In late 1980s seawater intrusion contaminated some groundwater supply wells (ACA, 2005).

The expected climate change scenarios could push forward worsening the SWI status. Therefore, the main objective in this project has been to assess the SWI status and vulnerability assessment of the aquifer system throughout the available groundwater chloride concentrations time series by applying the proposed index methods in TACTIC WP5. These data have allowed to evaluate in a general way how the SWI status has been evolved in the last 25 years.

The assessments in the Fluvià and la Muga delta plain aquifer system have been carried out by the Hydrogeology and Geothermal Unit of the Cartographic and Geologic Institute of Catalonia (ICGC).

3 PILOT AREA

3.1 Site description and data

3.1.1 Location and extension of the pilot area

The pilot area is the Fluvià and La Muga rivers delta plain, which is located in the Roses Gulf within the Girona province at the NE of Catalonia (Figure 1). The study area is characterized by dry Mediterranean climate and flat terrain and it occupies an area of 166 km². Due to favorable climate and geographical location, the area attracts numerous tourists and is suitable for agriculture. That is, the delta plain associated with the rivers Fluvià (south) and La Muga (north) and part of the alluvial zone associated with these upstream watercourses (Figure 1). The length of the pilot parallel to the coastline is about 16 km. Perpendicular to the coastline, the delta plain extends over 4 km, but the extension inland following the course of the La Muga river reaches 18 km.

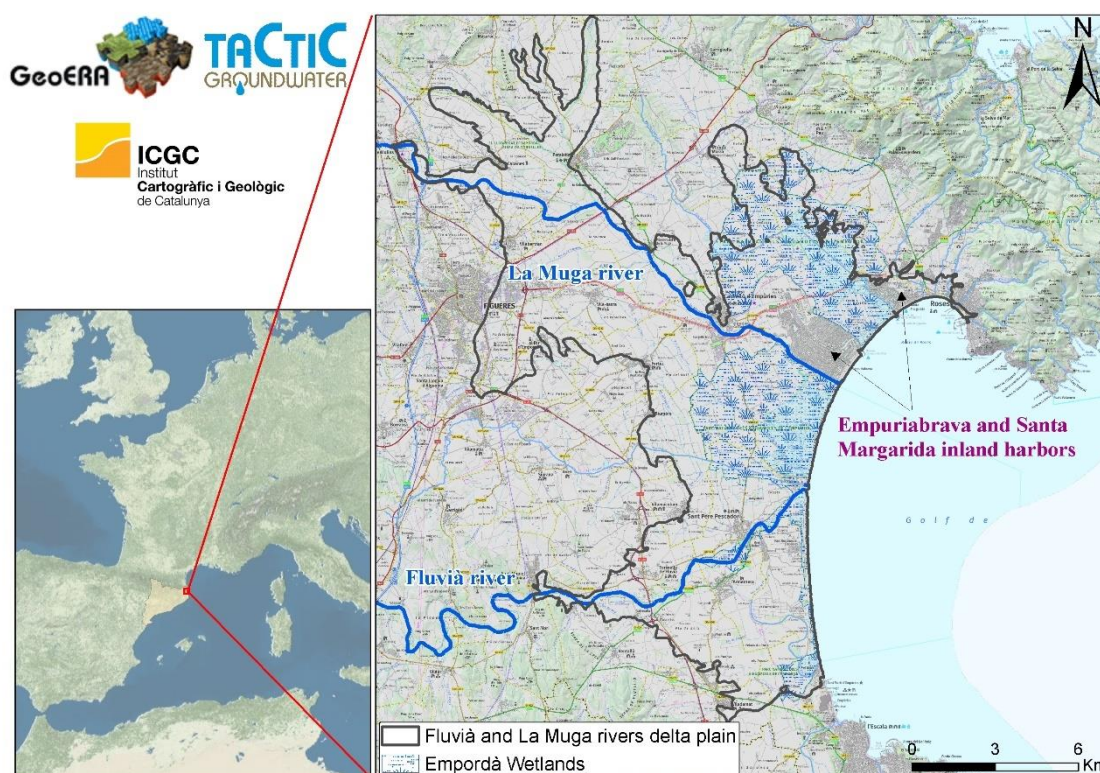


Figure 1: Location of the Fluvià and La Muga rivers delta plain pilot area (Catalonia, ICGC).

3.1.2 Geology/Aquifer type

The Fluvià and La Muga rivers delta plain is a quaternary detrital aquifer system. Downstream, on the flat area of the delta plain, the aquifer system is composed by two main aquifers:

- a) an uppermost shallow unconfined aquifer formed by very heterogeneous detrital deposits of sands, silt, clay and gravels (ASFM in Figure 3jError! No se encuentra el origen de la referencia.). It has a thickness up to 20 meters.



b) a lowermost confined aquifer formed mainly by sands and gravels. The confined conditions are discontinuous over the study area (APFM in Figure 3). On top of this deep aquifer, silt and clay layers act as an aquitard. The confined aquifer (including the aquitard) has a known thickness of at least 30 meters. Upstream the two aquifers converge into a single aquifer of unconfined behavior.

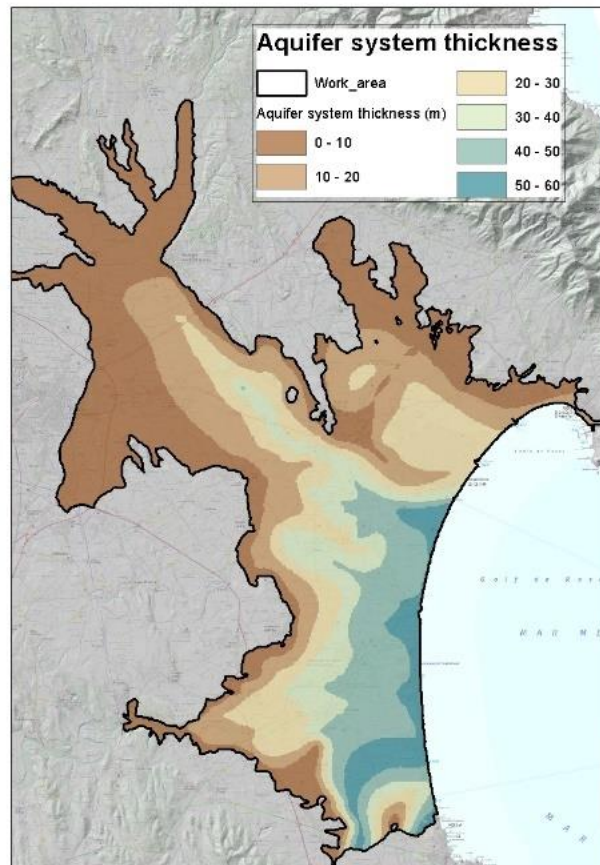


Figure 2: Total aquifer system thickness obtained by interpolation methods. Based on the data collected from the geological and hydrogeological maps at scale 1:25.000 (ICGC, 2015) and the available hydrogeological cross sections.

Given the heterogeneity of the aquifer system materials, the hydraulic parameters have a wide range of values. According to available pumping tests results the uppermost unconfined aquifer has a wider range of hydraulic conductivity (50-280 m/d) than the lower one (50-70 m/d). Storage coefficient range between 0.01 to 0.15 in the uppermost aquifer and reaches 10^{-4} in the deep confined aquifer. Thus, the transmissivity values range from 200 and 3000 m^2/d and the storage coefficient range from 0.15 and 10^{-4} (ACA,2005).



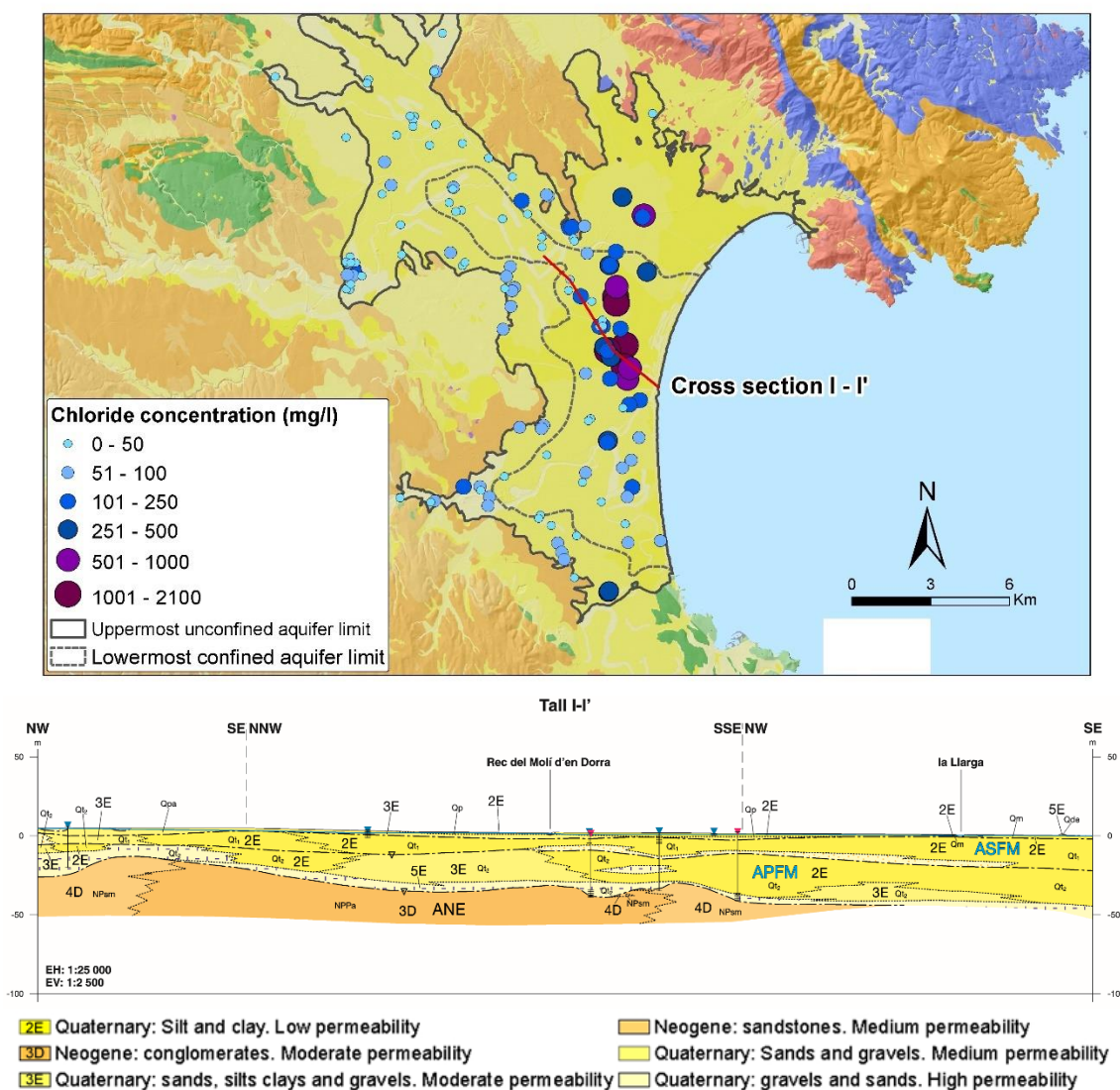


Figure 3: *Delimitation of the uppermost and lowermost aquifers and distribution of chloride concentrations (median of the historical time series analyses) . At the bottom, representative cross section of the Fluvia and la Muga rivers delta plain aquifer system (ICGC, 2015). ASFm is the upper unconfined aquifer and APFM is the deep confined aquifer. ANE corresponds to the lower Neogene aquifer system. Detrital deposits are classified into permeability classes as follows: 2E is low permeability (between 10^{-4} and 10^{-2} m/d), 3E is moderate permeability between (10^{-2} and 1 m/d), 4E and 4D is medium permeability (between 1 and 50 m/d) and 5E is high permeability (more than 50 m/d).*

3.1.3 Topography and Land Uses

The study area is very flat specially near the coastline where the topographic gradient is low. According to digital elevation model (DEM), elevation of pilot zone range between 0 to 80m a.s.l. (Figure 4).

Agriculture is the most important land use in the pilot area related mainly with rice and fruits crops. Urban areas are also important as tourism and agriculture are the main economic activities of the area. There are also forests and natural land, water bodies and beaches. Their distribution is shown on Figure 4.

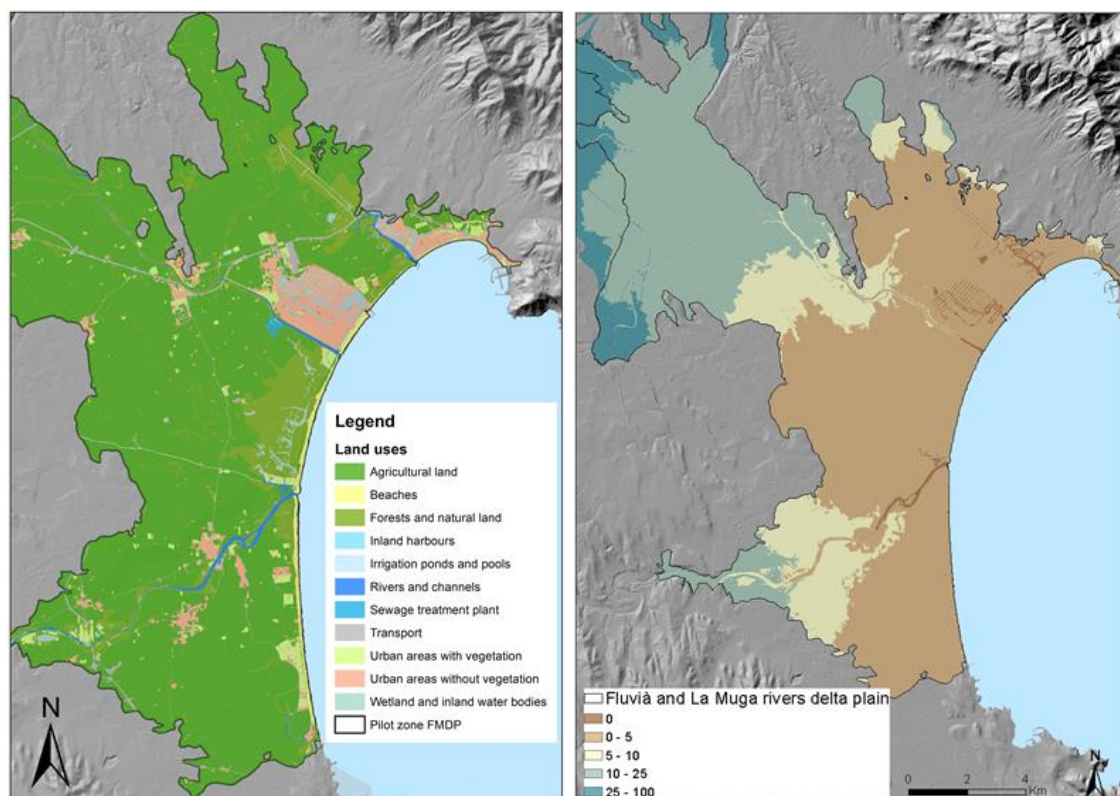


Figure 4: Land uses map (CREAF, 2009) and digital elevation model (DEM) at 5 m resolution in the pilot zone.

3.1.4 Surface water bodies

The most important surface water bodies in the pilot area are placed in the Natural Park of the Empordà Wetlands (4.784 Ha). There mixed saline and fresh water coexist. It is an area with high ecological interest in which there are permanently flooded bodies of water. It is recognized by the RAMSAR convention (site No. 592 of RAMSAR Convention Bureau, 1990) where is defined as “a series of coastal saline and freshwater wetlands in the floodplains of two rivers (Fluvià and La Muga), separated from the sea by dunes. The site includes lagoons, pools, marshes and drainage channels supporting salt-resistant vegetation.”



In addition, the Fluvià and la Muga rivers, to which the studied aquifer system is associated, have a perennial stream with very variable flow rates due to the typical Mediterranean rainfall episodes with very variable yearly frequency and intensity.

The Fluvià and La Muga rivers are usually connected with the groundwater level. Depending on the area and the position of the groundwater table respect the elevation of the river surface water the rivers have an influent or effluent stream character. In the driest times of summer, the stream of the two rivers in their respective mouths are blocked by a sand bar. The area includes an extensive network of irrigation channels that spans the entire delta plain and distributes water from surface streams.

Finally, near the Empuriabrava inland harbor, there is the Castelló lake area which corresponds to an old lake drained in the 18th century that in our days is an endorheic zone used for agriculture purposes.

3.1.5 *Hydraulic head evolution*

Groundwater in the study area is shallow and has an overall gradient eastward ranging between 10^{-3} and $5 \cdot 10^{-3}$. Due to the discontinuity of the confined conditions of the deep aquifer, the uppermost and the lowermost aquifers have similar groundwater levels. In general, groundwater table near the coastline is around 1m asl. and inland it increases up to 10 - 12m a.s.l within the pilot area considered (Figure 5).

Piezometric groundwater level has been monitored by the Catalan Water Agency at two representative control points between 1989 and 2009 (data available at SDIM-ACA). The evolution of the piezometric levels in both aquifers is shown in Figure 6. It is observed a slight tendency to a generalized decrease on the groundwater levels (the variation throughout the observation period does not exceed 0.5 m) but a heavy seasonal oscillation that could be around 4 m at the location of the control points.

Taking into account that there are not enough data to obtain annual piezometric maps, the piezometric surface made with available data from 2011 (Figure 5) has been taken as reference piezometric surface. It is therefore assumed in this case that the final results for the SWI assessment could vary if annual piezometric surfaces were available. Even though, due to the slight tendency to a generalized decrease of groundwater levels observed in Figure 6, it has been considered that the results may be little dependent on this variable.

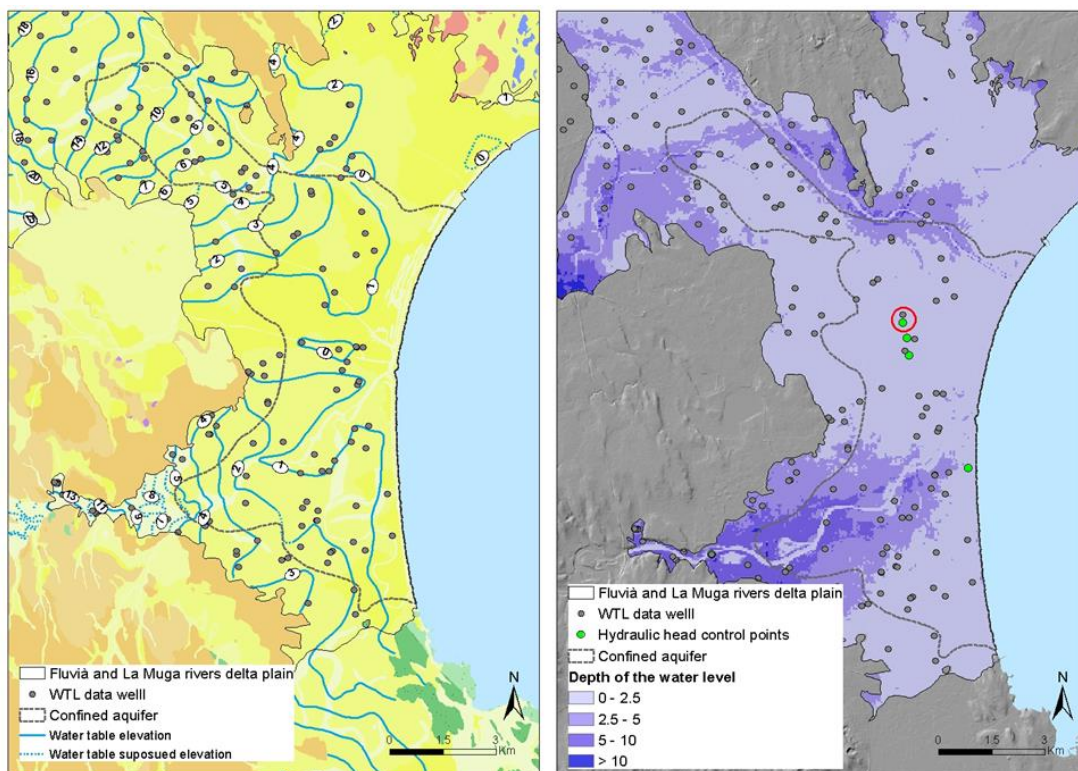


Figure 5: Mean groundwater table distribution (left) in m asl (ICGC, 2015) and depth of the water level in the study area (right). This has been considered as the surface of the reference water table to apply the SWI status and the GALDIT vulnerability assessment method. Red circle indicates the position of the control water point of Figure 6.

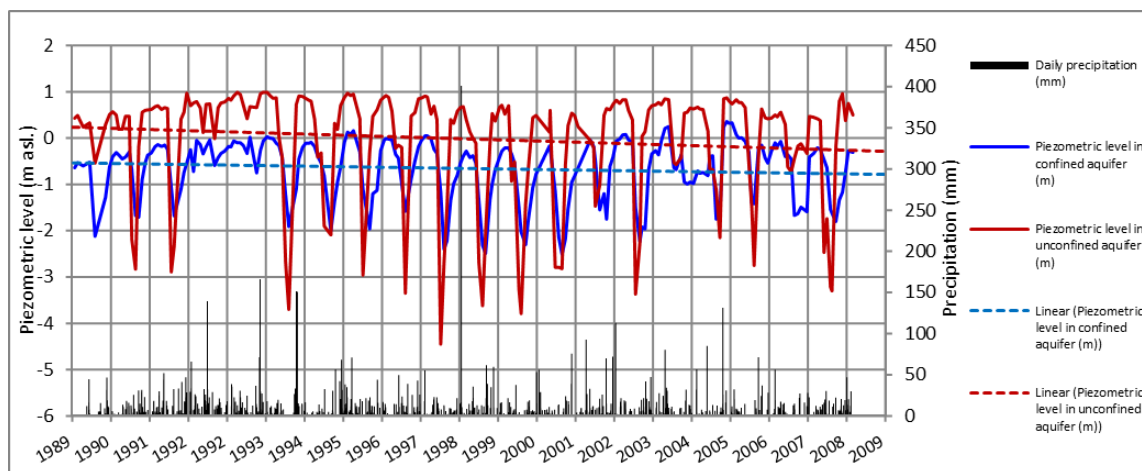


Figure 6: Piezometric level series in the unconfined and confined aquifers between 1989 and 2009 (control piezometer is highlighted in the Figure 5 with red circle).

3.1.6 Climate

Pilot area has a typical Mediterranean climate with dry summers and rainy autumn and winters. According to Köppen-Geiger climate classification, local climate belongs to Csa group, i.e., hot-



summer Mediterranean climate (Kottek M. et al 2006). The annual average temperature between 1991 and 2017 was 15° C, with lowest temperatures in January and the highest ones in July. Annual precipitation was 628 mm/year during the same period.

The annual period with the highest freshwater demand coincides with lowest rainfalls rates, i.e., July has an average precipitation of 24,9 mm whereas January, October and November have higher values of 67 mm, 93 mm and 66 mm, respectively (Figure 7). The annual average potential evapotranspiration (ETP) is 889.2 mm/year, with highest rates in July (161.4 mm) and lowest ones in January (17.4 mm).

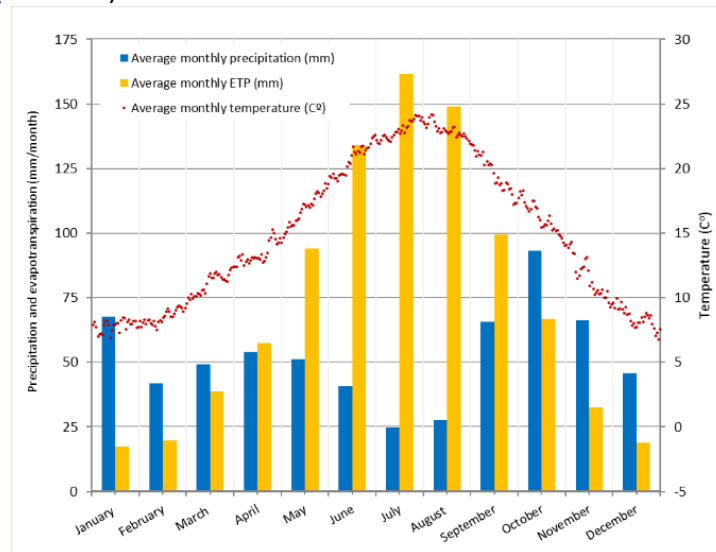


Figure 7. Average precipitation, temperature and evapotranspiration in the study area between 1991 and 2017. ICGC (2015).

3.1.7 Hydrochemical data

Hydrochemical analysis from the period 1995 to 2017 have been collected both from the Catalan Water Agency database (SDIM-ACA) and from the ICGC hydrogeological database. Regarding chloride concentrations, on which the SWI status assessment is focused, in the Fluvià and La Muga delta plain pilot area there are more than 600 available samples at around 150 water wells and control points. For each water point the number of samples available during the studied period (1995-2017) is quite variable. In some wells there are a maximum of 1 or 2 samples whereas at some control points more than 25 samples have been considered. Therefore, the spatial distribution of chloride data per year is quite variable and sometimes not enough to apply annually the SWI status and SWI vulnerability methods. The depth of sampling is not available in most cases, so it has to be assumed that is equivalent to the depth of the water point considered.

For the NBL and the corresponding TV estimation and in order to assure that long time series do not bias results and that all sampling sites contribute equally, chloride time series at each monitoring point were converted to median. Near the coastline the median values increase up to 2000 mg/l (Figure 8). Upstream, the values are quite homogeneous and range from 20 to 80 mg/l.



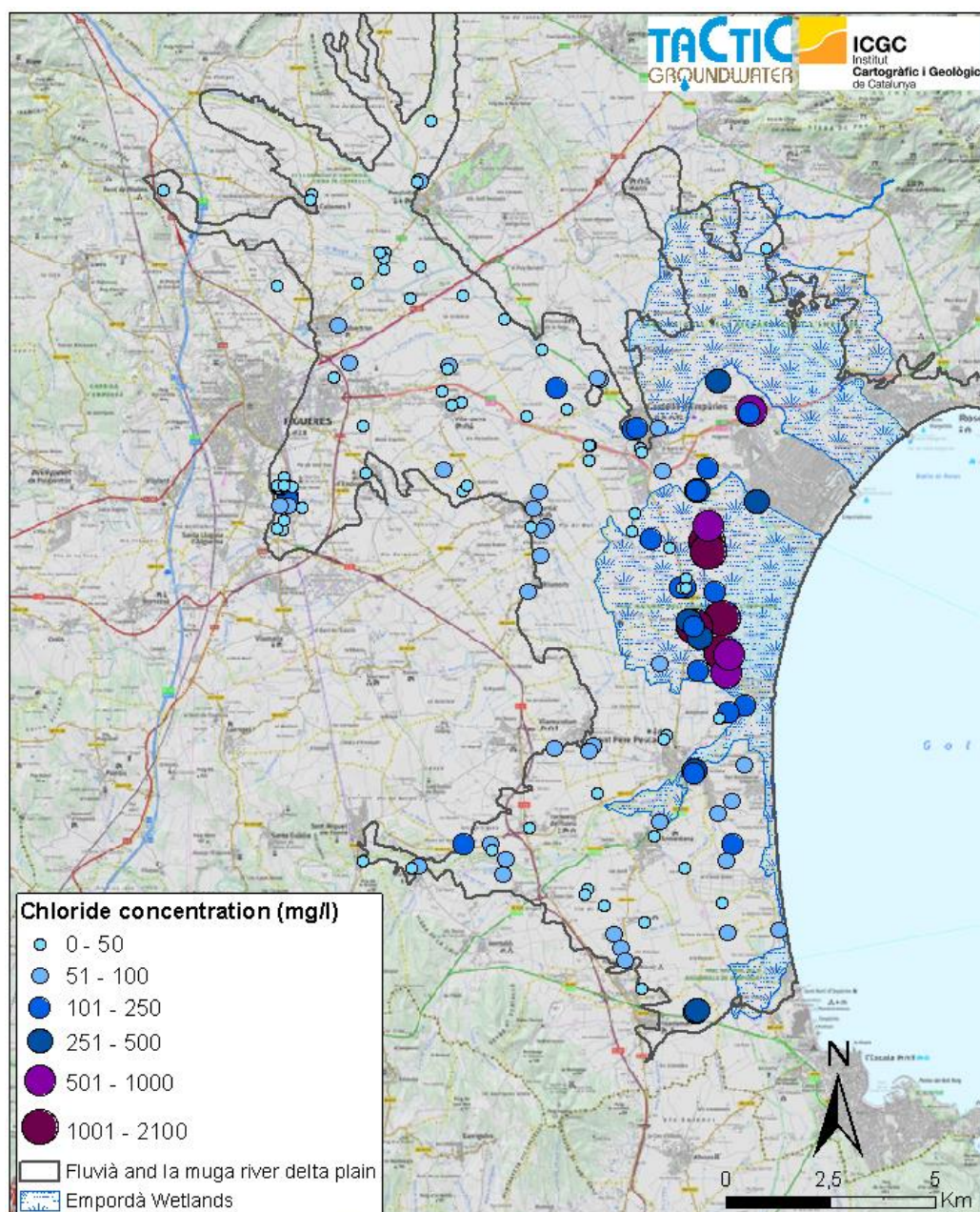


Figure 8: Chloride concentration median values at Fluvià and la Muga rivers delta plain.

Chloride concentration in groundwater has been monitored by the Catalan Water Agency at several representative control points between 1995 and 2017 (data available at SDIM-ACA). Taking into account individual samples, chloride concentration in control points located near the coastline registered maximums up to 1500 mg/l and in particular cases up to 3000 mg/l (Figure 9). The number of annual samples per each control point are not enough to determine annual or stational oscillations of the chloride concentration values.

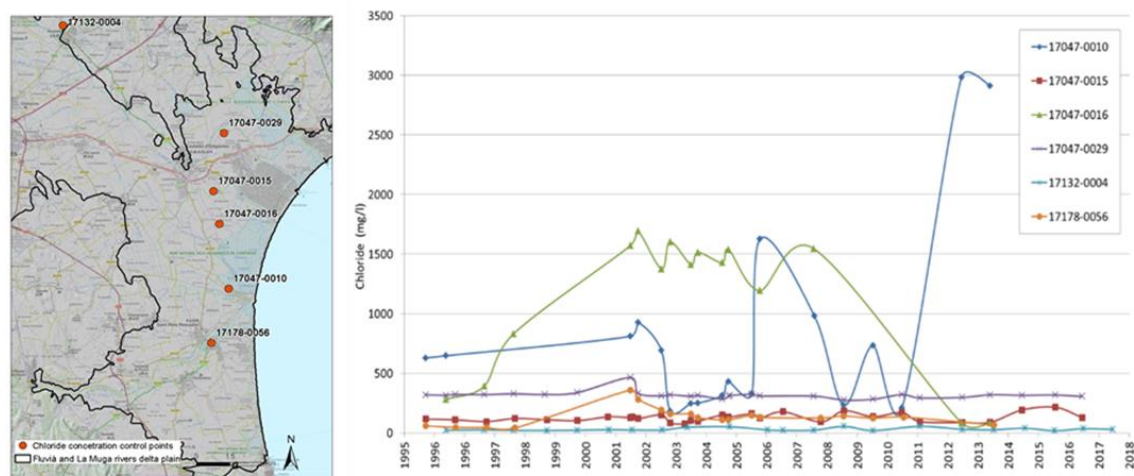


Figure 9. Chloride concentration in groundwater between 1995 and 2017.

With all the available data, annual chloride concentration maps have been made using GIS interpolation methods (based on an iterative finite difference interpolation technique) to evaluate the evolution of SWI throughout the historical series (Figure 10). The number of available sampling points per year varies depending on the year between 18 and 53. Years in which the data were not enough to apply interpolation methods have been excluded of the SWI status assessment. Finally, 16 maps of chloride concentration were interpolated between 1995 and 2018.

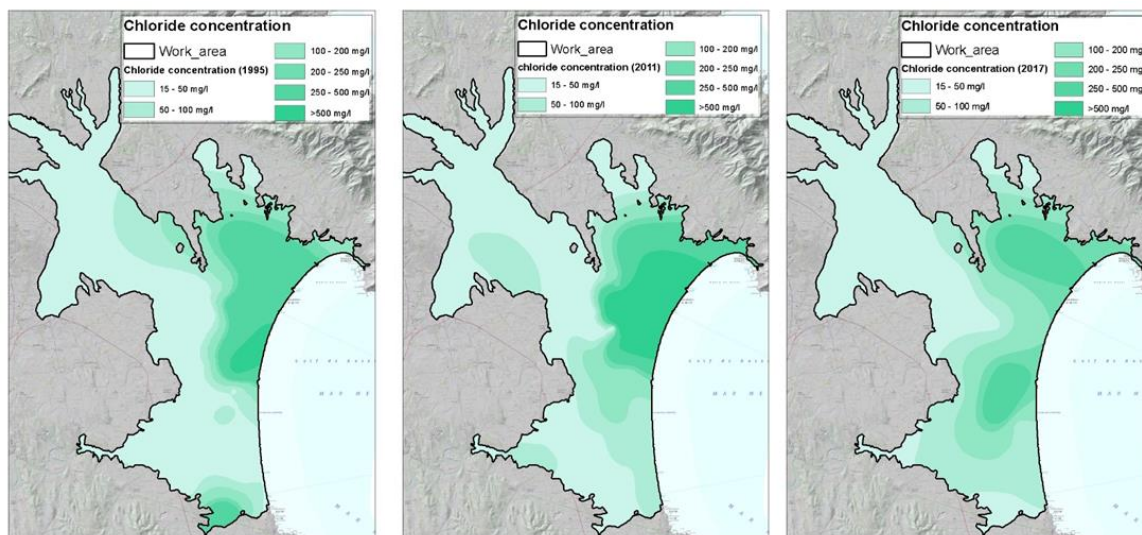


Figure 10: Example of chloride concentration maps. Annual chloride concentration maps have been created using GIS interpolation methods. The figure shows an example of maps obtained for the years 1995, 2011 and 2017.

In addition, concentration of other components such HCO_3^- or NO_3^- have also been collected. Groundwater geochemistry available analyses indicate that groundwater is mainly Ca-HCO-SO4 type and near the coastline it becomes at certain locations to Cl-Na type. Other chemical elements, such nitrates and ammonium are significantly present as well (ACA, 2005).

3.2 Climate change challenge

According to EEA report, Mediterranean transnational region, including El Golf de Rosas, is facing inevitable consequences of climate change (EEA, 2018). It is projected that temperature will increase, and precipitation rates will decline. Consequently, it is expected that duration and intensity of heatwaves will increase, more frequent droughts will occur, water availability and river flows will decrease. Higher temperatures and lack of water would negatively affect agriculture and overall quality of life. It is expected that due to climate change crop yields would decrease, risk of desertification and fire would increase. Due to changing climate, it is possible that tourism in Mediterranean region would decrease during the summer and would potentially increase during other seasons.

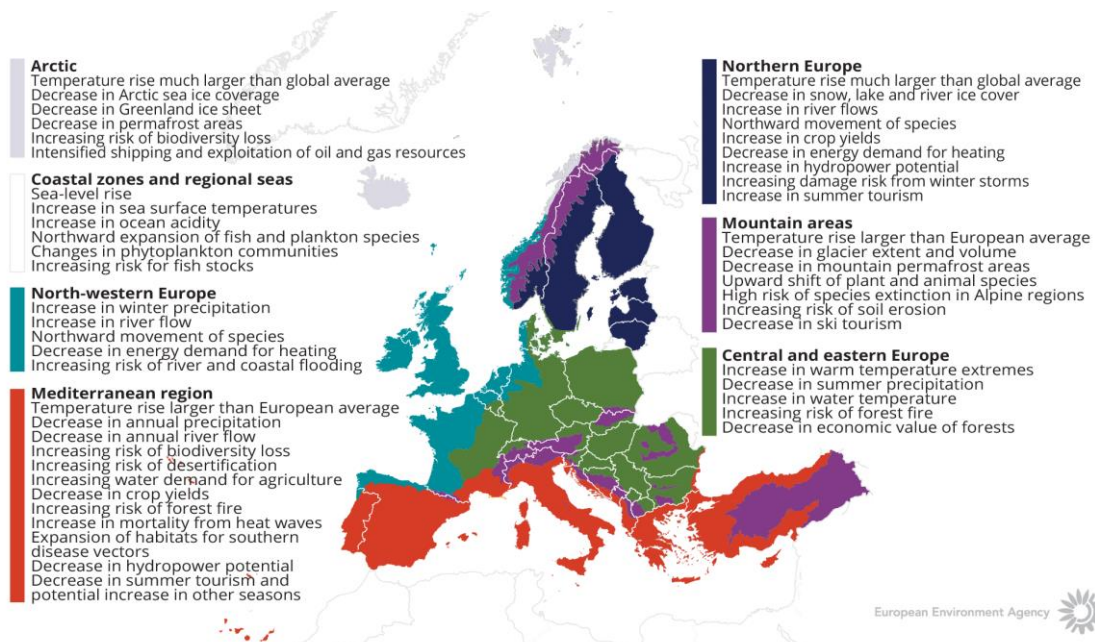


Figure 11: How is climate expected to change in Europe. The European Environment Agency map.

4 METHODOLOGY

The present work has been based on the historical evaluation of the SWI status and the GALDIT vulnerability assessment of the Fluvià and La Muga rivers delta plain methods (Baena-Ruiz et al., 2018). No 3D flow and transport hydrogeological model is available, thus simulation of future scenarios of the vulnerability status couldn't be performed in the framework of TACTIC WP5.

In general, both methods aim to calculate the SWI affected area and groundwater volume by considering threshold values. In the SWI status method the Threshold Value (TV) considered is a chloride concentration value based in the Natural Background Level of the aquifer (NBL), whereas for the GALDIT vulnerability assessment the limit between moderate and high vulnerability ranges is the reference TV used.

Time series analysis of the available data and **spatial Interpolation** (based on an iterative finite difference interpolation technique) of groundwater levels and chloride concentration values are the two main tools used on this TACTIC WP5 project for the Catalan pilot area.

4.1 SWI status

4.1.1 Determination of NBL and TV

For the numerical determination of the threshold value for the SWI status assessment, first it is mandatory to determine the chloride Natural Background Level (NBL). Different methods have been used and compared with the maximum chloride acceptable value provided by the Spanish drinking water legislation (RD 140/2003); the BRIDGE method (Müller et al, 2006) and the Walter probability plots method (Walter et al., 2006 and Giuliano & Blarsin, 2014).

4.1.1.1 The BRIDGE method

The “BRIDGE” EU research project (Background Criteria for the Identification of Groundwater Thresholds) was established to develop and test a methodology for derivation of groundwater threshold values to support the development of a common methodology for EU Member States. Based on the preselection of samples by considering several criteria (Müller et al, 2006), it aims first to the determination of the NBL and then determine the corresponding Threshold Value (TV).

The application of that method for the SWI status assessment in the Fluvià and La Muga rivers delta plain, has revealed some limitations regarding the preselection of valid samples to establish the NBL. Main criteria applied for the exclusion of samples (as indicated in the BRIDGE method) have been:

- Samples with incorrect Ion balance (exceeding 10%)
- Samples with total $[Na^+]+[Cl^-] > 1000$ mg/l
- Samples with median nitrate concentrations above 10 mg/l
- The REDOX conditions criterion has not been applied due to insufficient available data

In order to assure that long time series do not bias results and that all sampling sites contribute equally to the NBL derivation time series at each monitoring point are converted to median values.

The application of this criterion implies a reduction from 633 samples to 108 (more than 80%) and the reduction from 152 points with available data to 58 (almost 40%). Furthermore, the study area has characteristics that raise doubts about the suitability of these criteria:

- The pilot area is a zone with extensive and intense agricultural activity and mainly source of nitrate are the fertilizers.
- There are analysis with nitrate concentration above 10 mg/l in non-affected (SWI) area and conversely analysis with concentrations below 10 mg/l in affected (SWI) area.

With the final available and selected samples, the BRIDGE method provides a chloride NBL of 148.56 mg/l for the 90th percentile and a chloride NBL of 336 mg/l for the 97.7th percentile. These results are presumed **to be excessively high**, since the limit for the $[Cl^-]$ in the legislation regarding drinking water is 250 mg/l and upwards and in areas clearly not affected by SWI, the chloride concentrations in the aquifer system are below 50 mg/l.

4.1.1.2 Estimation of NBL using Probability plots (Walter et al., 2006; Giuliano & Blarsin, 2014)

Alternatively, another method has been tested. Proposed by Walter et al, (2011) it is focused on the determination of the NBL by applying an iterative statistical process using probability plots. This method seeks to eliminate extreme values (which could be considered as values affected by processes that modify natural conditions). The starting point is all the available samples.

To ensure that the time series at the same sampling point do not bias the results and that all sampling sites contribute equally to the NBL calculation, these time series are converted to median values.

The initial assumption is that there are two different families of samples: natural and affected values (for instance by SWI). This assumption must be checked by doing the normal and lognormal probability plots distribution graphics (Figure 12).

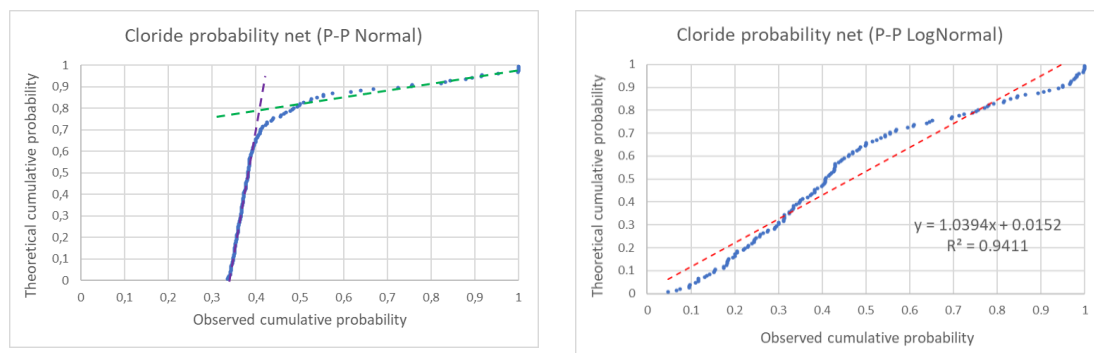


Figure 12: Statistical distribution of chloride values from groundwater samples at Fluvità and La Muga rivers delta plain. Normal and Lognormal probability plots.



Once this assumption has been checked, the iterative process could be applied. For the first iterative process, the 90th percentile is calculated. Data that exceed this value are excluded from the next step. For the second and consecutive steps, in which the 90th percentile is recalculated to exclude samples with a higher value. The iterative process stops when the distribution of the data is normalized. The result of the NBL is obtained from the samples that have remained (selected) by calculating the median of the studied parameter.

For the case study in The Fluvial and the Muga river delta Plain, normal distribution of the data has been achieved after 5 iterations by means of the Shapiro-Wilk test. Histograms of frequency and cumulative probability are shown on Figure 13. At this point, 99 sample points remain from the initial 150 available. The Chloride NBL ranges from 10 mg/l to 61 mg/l. A value of 37 mg/l and a value of 55 mg/l are obtained by calculating the median and the 90th percentile respectively.

The NBL value of chloride obtained by this method, is presumed to be much closer to the natural conditions of the aquifer system not affected by SWI. From that NBL value obtained, a TV of **200 mg/l** has been derived following the BRIDGE methodology.

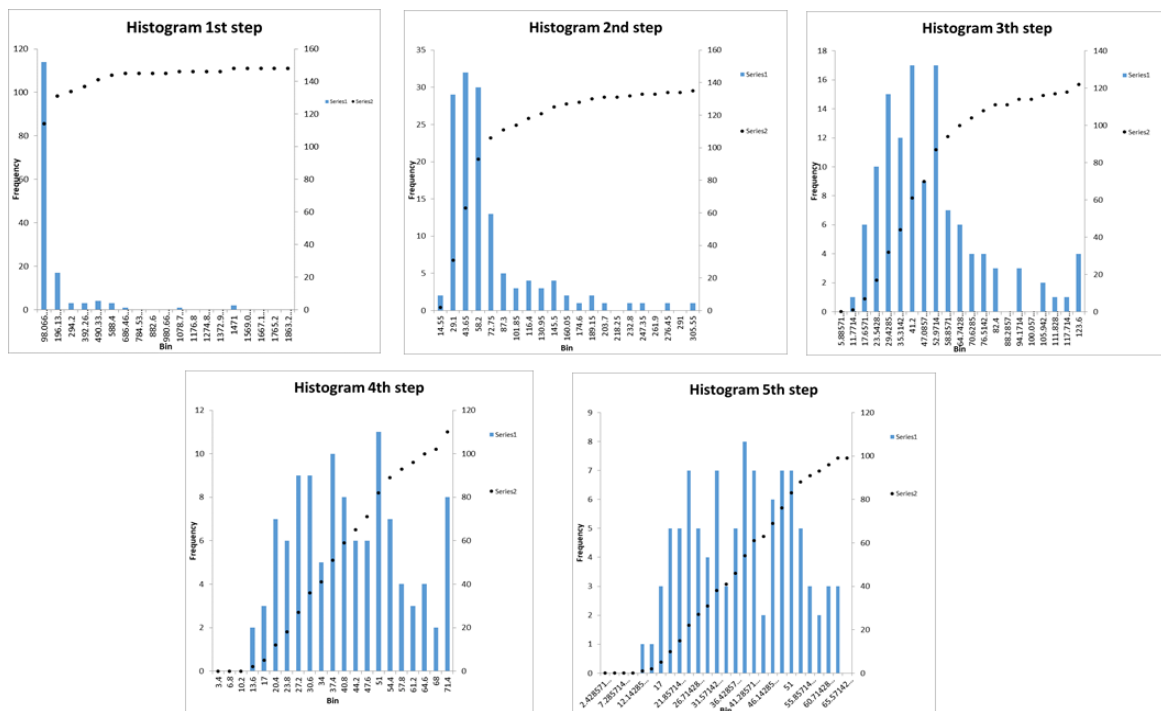


Figure 13: Iterative process using probability plots (Walter et al, 2011). Iterative elimination of outliers (chloride concentration values above the 90th percentile is considered outliers in each iteration).

4.1.2 Area and volume determination of the aquifer system affected by SWI

Once the threshold value has been established (200 mg/l) it has been applied to the chloride concentration interpolated maps to determine the area and volume of the affected aquifer (Figure 14). The aquifer thickness distribution map and the representative groundwater level



surface (see chapters 3.1.2 and 3.1.5) have been used in the SWI status assessment. A representative value of porosity of 0,05 for the overall aquifer system was considered.

From these values, the methodology has been applied to calculate the MaRT index, the resilience, the trend and the conceptual 2D cross sections as proposed in the **SWI status method** (Baena-Ruiz et al., 2018) and in the Deliverable 5.2.

SWI Status. TV: 200 mg/l

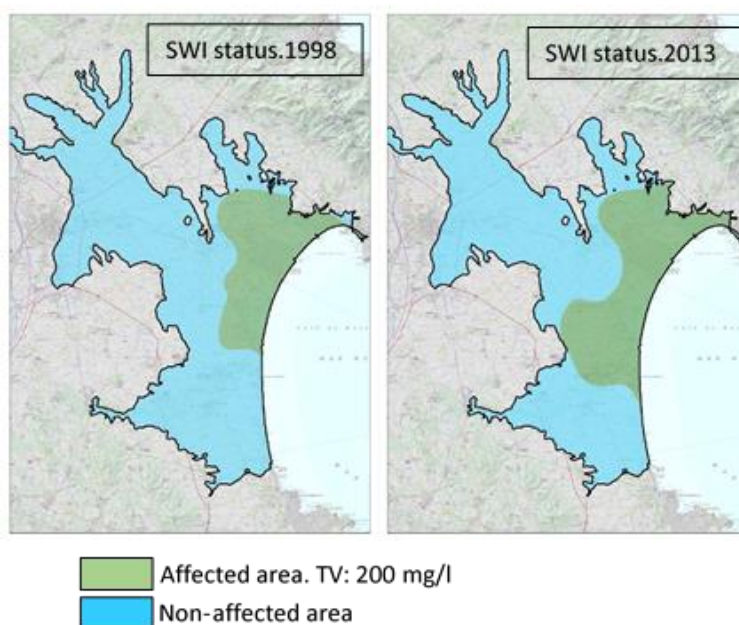


Figure 14: Examples of SWI status maps of the years 1998 and 2013. The estimated groundwater volume by SWI is 29% and 42% respectively.

4.2 GALDIT vulnerability assessment

Similarly, work has been done to apply the SWI vulnerability assessment method. Annual maps (from 1995 to 1998, 2002 to 2006, 2008 to 2011, 2013, 2014 and 2017) have been made following the GALDIT method (Chachadi & Lobo-Ferreira, 2001) for calculating vulnerability to SWI in the Fluvià and la Muga rivers delta plain.

For the application of the GALDIT method the type of aquifer considered ("G" parameter) was confined for the area where the lowermost aquifer is located and unconfined for the rest of the area. The hydraulic conductivity parameter of the aquifer system ("A" parameter) was defined based on the hydrogeological map of Catalonia at 1:25.000 scale (ICGC, 2015). Regarding the impact of existing status of SWI ("I" parameter) not all the samples collected with chloride concentrations had also bicarbonates values. Thus, a correlation was made between the available values of the $\text{HCO}_3^-/\text{Cl}^-$ ratio and the Cl^- concentration values in order to map the "I" parameter.



GALDIT maps were obtained for the same years as for the SWI status method (in total 16 maps) (Figure 15). The limit between the high and the moderate vulnerability were established as the TV after considering that, based on the knowledge of the area, there are large areas characterized with moderate vulnerability that are far from the known affected areas.

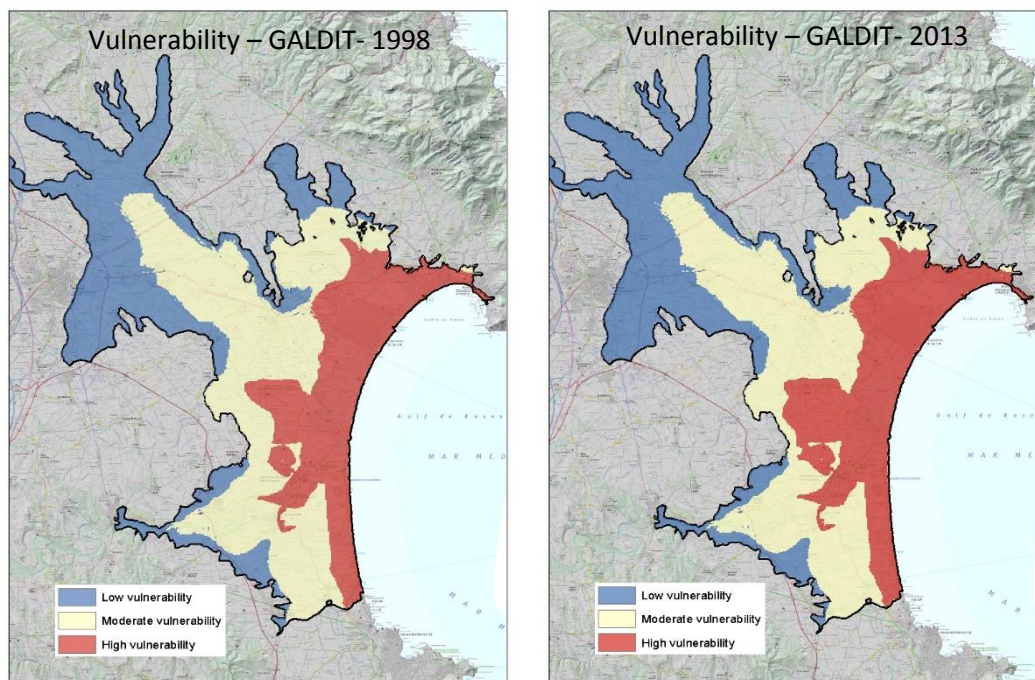


Figure 15: Example of vulnerability maps (GALDIT method) for the years 1995 and 2013 with minimum differences of the spatial distribution of each vulnerability classes.

From the considered threshold, affected areas and volumes have been calculated, and represented in the conceptual 2D cross sections.

5 RESULTS AND CONCLUSIONS

5.1 SWI method results: SWI status and vulnerability

From the 16 maps of SWI status and the 16 GALDIT vulnerability maps and taking into account the TV considered respectively (200 mg/l for the SWI status method and the high vulnerability class for the GALDIT vulnerability assessment method), the evolution of the total groundwater volume affected by SWI from 1995 to 2017 is shown in Figure 16 and Figure 17.

For the SWI status method, the affected groundwater volume of the aquifer system ranges between 18% and 42% with a mean value of 32% (Figure 16) whereas for the GALDIT vulnerability assessment method the obtained results show less variability in the total volume affected by SWI which ranges between 45 – 48% probably because most of the parameters considered in the GALDIT method are intrinsic of the aquifer system and therefore constant over time.

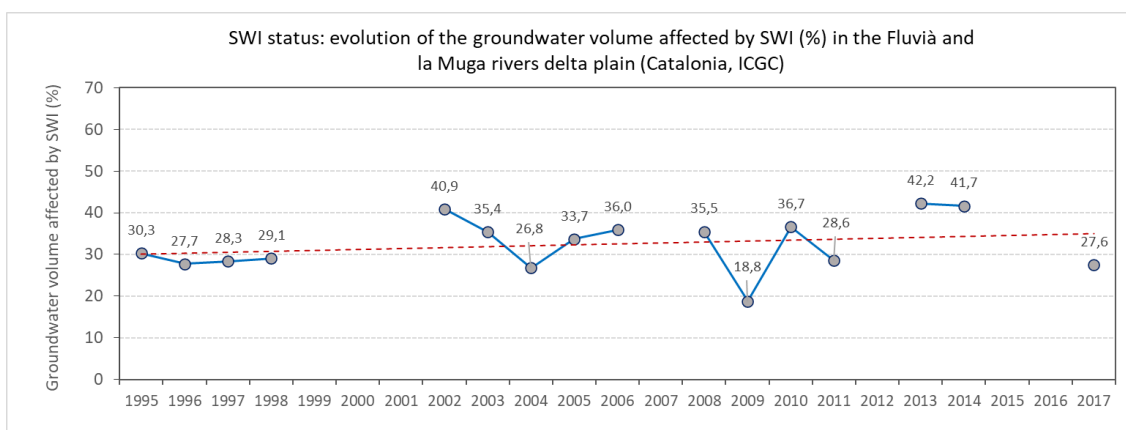


Figure 16: Volume of the aquifer system affected by SWI (%) applying the SWI status method with a TV of 200 mg/l of chloride concentration.

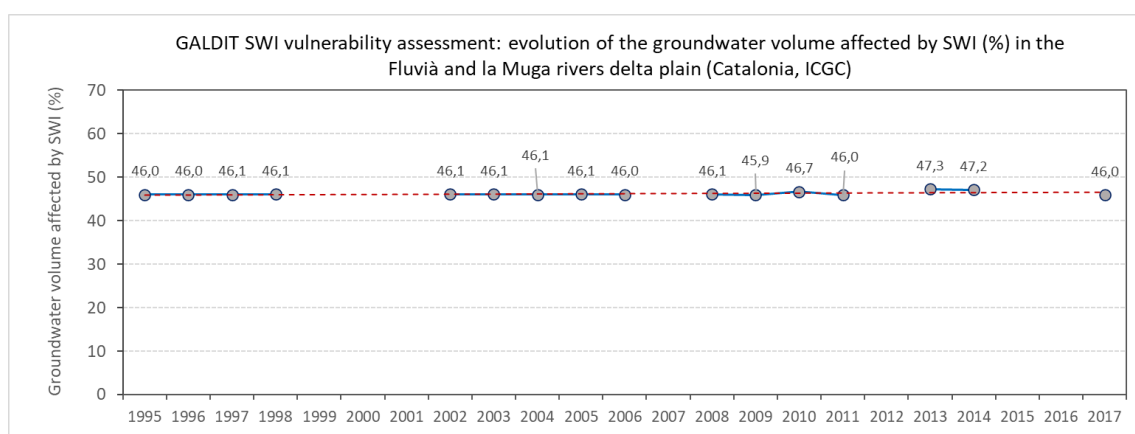


Figure 17: Volume of the aquifer system affected by SWI applying the GALDIT vulnerability assessment method and considering the area with high vulnerability to SWI.

These values can be considered high, since the extension of the aquifer system is large, and the maximum depth of the aquifer system is coincident with the SWI affected area. The affected volume varies depending on the year, but the trend shown by the available historical time series is slightly upward (especially considering the results obtained with the SWI status method). Even so, it is possible to establish some areas in which the SWI is permanent. As expected, in the area close to the town of Roses where the Empuriabrava and Santa Margarida inland harbor is located the SWI affection could be considered permanent whereas the central area and south area of the delta plain (where the Natural Park of the Empordà Wetlands is located) show a more irregular affection over time depending on the year considered. Furthermore, it can be confirmed that the inland areas of the aquifer have not been affected by SWI and can be considered as non-affected or non-vulnerable areas.

5.2 SWI method results: 2D conceptual cross-sections

In order to give a graphic idea of the groundwater volume affected by SWI, the volume and area data have been represented in conceptual 2D cross sections. The method proposed in sections 2.1.2 and 2.2.2 of deliverable 5.2 has been followed for this purpose.

The considered threshold of 200 mg/l of chloride concentration has been applied in the case of SWI status, and that of high vulnerability in the case of vulnerability to SWI. Conceptual 2D cross sections have been carried out for the year 2002, and for the mean of the entire historical series available both for the evaluation of the SWI status and vulnerability.

The results show, in the same way as previously explained, that an important part of the aquifer system in its area closest to the sea is affected by SWI. It must also be taken into account that the areas furthest from the coastline have not been affected by SWI in the entire historical series. Therefore, the proportion of volume affected would be even higher considering only the potentially affected areas.

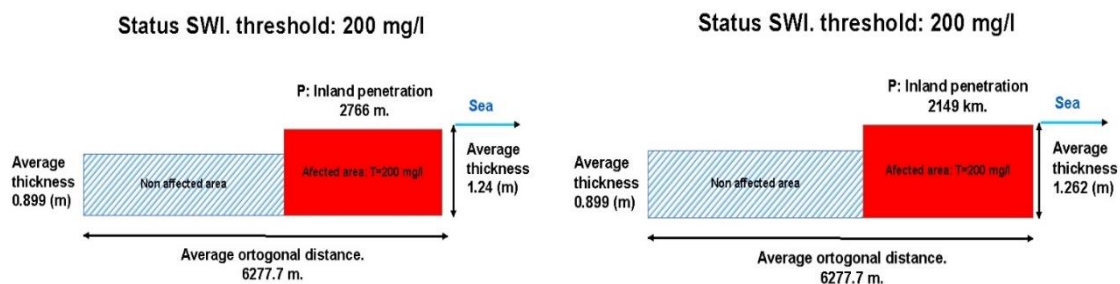


Figure 18: 2D conceptual cross-sections SWI status. Historical results in 2002 (left) and mean values for the period 1995 - 2017 (right) (Vertical exaggeration scale x1000).

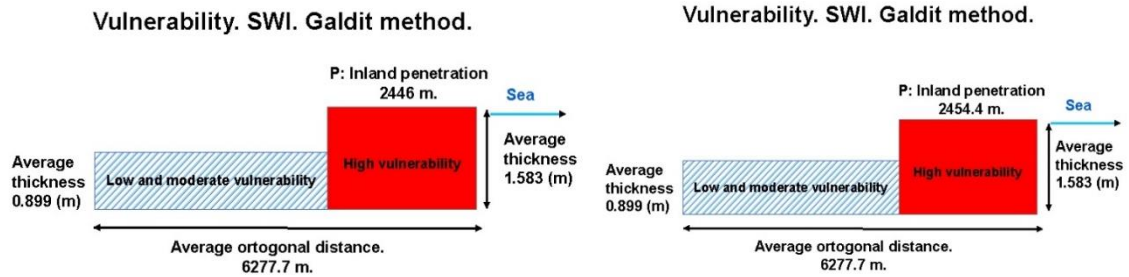


Figure 19: 2D conceptual cross-sections. Vulnerability. Historical results in 2002 (left) and mean values for the period 1995 - 2017 (right) (Vertical exaggeration scale x1000).

5.3 SWI method results: Lumped indices Ma and L-GALDIT.

Continuing with the application of the proposed methodology, the steps described in sections 2.1.3 and 2.2.3 of deliverable 5.2 have been applied to obtain the Ma and L-GALDIT indices for the SWI status method and the GALDIT vulnerability assessment method respectively (Baena-Ruiz et al., 2018).

The Ma index provides information about the intensity of SWI (Figure 20) whereas the L-GALDIT index assesses the overall vulnerability of the aquifer (Figure 21).

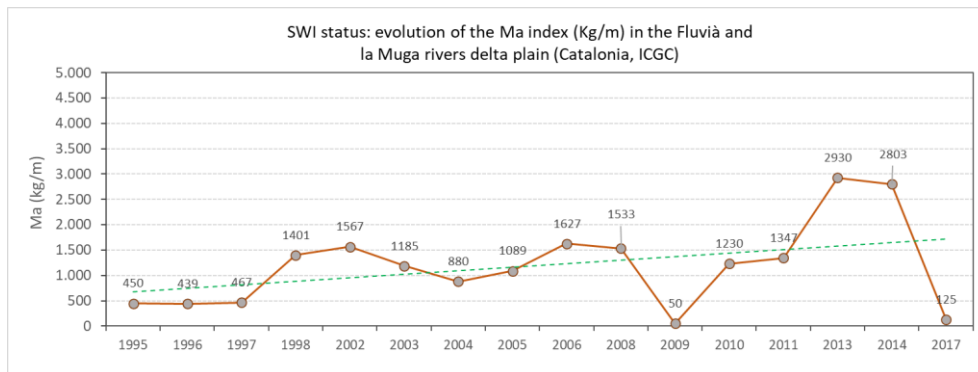


Figure 20: Time series of the Ma index for the period 1995 to 2017. It is observed high variability in the Ma values, but the trend considering the entire period is slightly upward.

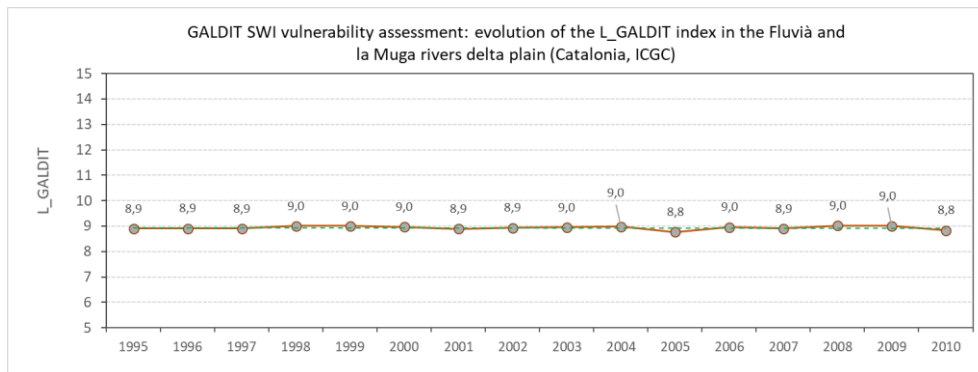


Figure 21: Time series of the L-GALDIT index for the period 1995-2017. It is observed that the L-GALDIT doesn't present the same variability as the Ma values and there is no detectable trend considering the entire period.



As shown by the volume of the aquifer system affected by SWI (%) applying the SWI status method (Figure 16), the Ma index evolution (which represents the intensity of the SWI) is also coherent with the hypothesis of a SWI worsening in the area in the last 25 years. It has to be mentioned that the results could be influenced by the distribution and temporal frequency of the available samples. Even though, the obtained results give a good overview of the evolution of the SWI in the area.

On the other hand, the L-GALDIT is constant over time due to the less variability on the time series vulnerability assessment. As mentioned before, most of the GALDIT vulnerability parameters are intrinsic of the aquifer system, so permanent over time. The use of a representative groundwater table map and the low weight of the "I" parameter (which has been calculated annually) produce low variability in the vulnerability maps and consequently in the L-GALDIT index values.

These are very remarkable conclusions, and they can be considered the kickoff to go further in the study of the SWI status of the Fluvial and la Muga river delta plain by means of a density-dependent 3D model to simulate future scenarios related with the climate change and to obtain better and more accurate outcomes.

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