

European Association of Remote Sensing Companies

**Sentinels Benefits Study (SeBS)**

A Case Study

# Water Resources Management in Spain

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Using Sentinels to monitor groundwater resources in Catalan aquifers



Source of the picture: <https://www.bbc.co.uk/news/world-europe-65129735>

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## Setting the Scene

In the village of Lloret de Mar, near Barcelona, the Gandía family has been dedicated to market gardening for generations. Their small farm, known for producing a variety of vegetables, has been a cornerstone of the local farmers' market. The Gandía have been using a well for generations, a right they hold under Spanish water law, which allows private use of wells drilled before 1985. However, in recent years, the family has faced severe challenges due to increasing water shortages.

The troubles began when a luxury golf course was developed nearby, along with several hotels featuring private swimming pools. Additionally, a large commercial farm moved into the area, drawing significant amounts of water from the local aquifer. On top of that, the effects of climate change have led to more frequent and severe droughts, further depleting water resources. The Gandía family began to notice a drastic reduction in their well water levels, which are essential for their irrigation needs.

Water has always been a finite and precious resource in Catalonia, and its management is tightly regulated. However, the family started to suspect that some of their new surrounding neighbours might be tapping into the aquifer illegally. This suspicion is well-founded as Catalonia, like many regions in Spain, faces issues with illegal wells. In addition, the golf course and the commercial farm seemed to have an unending supply of water, even as the Gandía struggled to keep their crops alive.

The situation reached a boiling point, last February, when the local authorities imposed strict water restrictions due to the ongoing drought. The Gandía family, like many others, was ordered to reduce their water usage drastically. Meanwhile, they noticed the golf course and large farm continued their operations unaffected. Frustration turned to anger, particularly towards the tourists who kept their leisure activities as if there was not drought nor water shortage.

In response, the Gandía joined forces with other local farmers to raise awareness about the issue. They organized meetings and approached local government representatives, demanding stricter enforcement of water rights and penalties for illegal extraction. Moreover, they actively participated in protests against mass tourism in Barcelona, which locals blame for exacerbating water shortages and increasing the cost of living. These protests saw thousands of residents taking to the streets, spraying tourists with water and carrying signs that read "Tourists go home" and "Barcelona is not for sale." The demonstrations aimed to highlight the negative impacts of mass tourism on local resources and advocate for more sustainable tourism practices.

Their efforts paid off when the Catalan Water Agency started incorporating satellite imagery alongside traditional measurement methods to more effectively monitor water usage and identify - and close - illegal tapping of the aquifer. Furthermore, thanks to the new monitoring methods, the agency revised the concessional rights of wells in the region, ensuring a fairer distribution of water resources among local industries, farmers, and citizens. The agency also used earth observation imagery to communicate to citizens about the urgency of reducing their water consumption.

The Gandía family's story demonstrates the ongoing struggle for fair and sustainable water management. It also highlights the societal and psychological impacts as well as potential conflicts resulting from such an important resource. Finally, it underscores the urgent need for robust regulatory frameworks, advanced monitoring technologies, effective communication, and community activism to protect vital water resources from overuse and illegal exploitation.

*This story is entirely imaginary, although realistic based on our knowledge gained through the case interviews. The places are real, although the characters, the conversation and the situation are entirely fictional.*

## Executive Summary

Catalonia, a semi-arid region suffering from **frequent droughts**, relies heavily on groundwater for agricultural irrigation, domestic and industrial use, with aquifers providing almost half (44%) of the total water consumption in the Catalan River Basin. This dependence is even more pronounced for the **agricultural sector**, which is the largest consumer of water. Effective management of these groundwater reserves is essential not only for maintaining the sustainability of water resources but also for ensuring the **economic viability** and **social cohesion** of many communities and industries across the region. Given the key role water plays in the daily lives of citizens and the stress and conflicts that could arise when it is scarce, even modest improvements in water management can lead to substantial positive changes.

This underscores the importance of utilizing Earth Observation (EO) technologies in water management. In this context, Sentinel-1 satellites, equipped with Synthetic Aperture Radar (SAR), offer a good tool for monitoring ground deformation caused by aquifer exploitation. It **complements other methods to measure the groundwater quantity** and provides extensive measurements in terms of surface monitoring, access to historical measurements and (almost) real-time variations.

In Catalonia, this innovative service results from a collaboration between the **Cartographic and Geological institute of Catalonia (ICGC)** and the **Catalan Water Agency (ACA)**, which leverages Sentinel-1 data to monitor groundwater. ICGC being the service provider of Sentinel data and ACA being the first user. This service has improved the monitoring of ground subsidence resulting from groundwater exploitation. While Sentinel data cannot directly measure groundwater levels, ground movement provides indicators to prioritize monitoring areas and hence optimize in-situ monitoring.

Improving the monitoring of groundwater (over-)extraction enables the ACA to take actions for a **more sustainable water management**. More specifically, potential modifications to **concessionary rights** may be considered as well as enforcement when there is a detection of **illegal groundwater extraction**. The aim of better water allocation through effective concessionary rights involves tapping less water from critical aquifers and minimizing non-essential water use. This prevents **saltwater intrusion**, which can make water unusable for citizens, industries, and agriculture, and avoids aquifer **compaction**, which can reduce the overall capacity and long-term availability of groundwater.

The use of Sentinel data provides benefits to a broad spectrum of stakeholders in the value chain from data providers to end-users. The **ACA** leverages Sentinel data to improve its **groundwater monitoring** and consequently **improving water resource management**. This also contributes to its regulatory compliance and could boost public awareness on water use, leading to more efficient water allocation. **Municipalities and water utilities** benefit from such services by **mitigating**

**damage** from subsidence due to excessive groundwater extraction while improving **groundwater management**.

**Citizens and society** benefit from a more sustainable and equitable **water supply**, better **social cohesion**, **lower water bills** and efficient **irrigation** for better agricultural yields, which are all **crucial during drought periods**. They also benefit from avoided subsidence damages.

In addition, Groundwater-Dependent Ecosystems (GDEs) rely as well on the sustainable management of aquifers. When large amounts of groundwater are extracted for agriculture or industry use, less water may be available for GDEs causing springs, wells, and other water sources to dry up. This affects plants, animals, and human communities that depend on these sources.

***The economic benefits of the use of EO quantified in this case are estimated at 1,78 to 3,58 million euros per year in Catalonia (all figures explained in Chapter 5) and are mainly derived from ACA improving the allocation of its monitoring budget and agricultural sector having a more sustainable access to water. When extrapolated for the whole of Spain, these figures could lead to significantly higher economic benefits across the country, i.e. 11,05 to 22,16 million euros per year.***

**WATER RESOURCES MANAGEMENT IN SPAIN**



**The Satellite Data**

Copernicus Sentinel-1 provides free-of-charge, frequent, all-weather, day-and-night C-band radar images over Catalonia approximately every 6 days.



**The Service Provider**

The ICGC leverages Copernicus Sentinel-1 data to offer satellite-based services for ground deformation monitoring in Catalonia.



**The Primary User**

The ACA utilizes ICGC's services on ground deformation to improve aquifer monitoring and efficiently manage groundwater resources across Catalonia. This includes optimizing wells concession rights, detection of illegal extraction and mitigating issues such as aquifer salinization and subsidence.

▼ Catalonia: €25K - €75K pa; Spain: €155K - €465K pa



**Secondary Beneficiaries**

Municipalities and water utilities benefit from such services by mitigating damage from subsidence due to excessive groundwater extraction while improving their own management of water resources.



**Society & Citizens' Benefits**

Local communities benefit from sustainable water management practices and improved water allocation. It leads to reduced inequalities and water stresses, especially during drought periods. The agricultural sector particularly benefits from better crop yields.

▼ Catalonia: €1,75m - €3,50m pa; Spain: €10,85m - €21,70m pa

This case study serves as a valuable model for other regions with similar challenges, promoting the adoption of EO technologies worldwide. It demonstrates how Sentinel satellites can play a key role in managing vital natural resources more effectively, ensuring sustainability while fostering economic stability and environmental preservation.

Finally, the potential **developments of EO for water resources management are immense**. Not only such technology can be widely spread around the world but also used together with all different types of water monitoring tools for a holistic water management —including reservoirs, lakes and rivers, water rights enforcement, crop irrigation, drought management, water transfers, hydraulic centrals, etc.

## 1 Introduction & Scope

### 1.1 The Context of this study

The analysis of the case study ‘*Water Resources Management in Spain*’ is carried out in the context of the ‘[The Sentinel Economic Benefits Study](#)’ (SeBS). This five-to-six-year study aims to develop cases showing how EO-derived products, based on data generated by one or more Sentinel satellites, deliver value to society and citizens. The [Sentinel](#) satellites form a crucial part of EU’s [Copernicus Programme](#), providing space-based observations on a full, free and open basis. Data coming from the Sentinels – together with other data collected by contributing missions and ground, sea or airborne instruments – are used to support key economic or societal areas such as agriculture, insurance, disaster management, climate change monitoring, etc. Sentinel data are thus a key component of the [Copernicus Services](#), and a crucial source used by companies to deliver products and services helping different users across the Globe.

### 1.2 What is the Case all about?

The subject of “aquifer management” is relatively unknown to the average person. Yet, it is truly a critical subject, if one considers that **nearly half of all drinking water in the world and over 40% of the water used for irrigation is sourced from groundwater**<sup>2</sup>. Moreover, with many areas in the world experiencing more frequent and more severe droughts – a direct result of climate change – the sustainable management of groundwater resources becomes essential for the well-being of communities depending on them. However, the interests of these communities often conflict, with **farmers, residents and tourists competing against each other – especially in large urban areas – over the increasingly scarce water resources**<sup>3</sup>.

As a result, and due to the lack of appropriate water management policies, for many years now, the typical response to extended drought periods – most prominently in semi-arid and arid regions around the world – has been the over-exploitation of aquifer groundwater. This, together with the extended pressure from climate change, has led to a **global groundwater crisis**<sup>4</sup>, whereby groundwater resources in many areas around the world are being depleted. The over-exploitation of aquifer groundwater has further adverse effects, both direct and indirect, on the environment

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<sup>2</sup> See “Groundwater and Climate Change” -

[http://www.idaea.csic.es/sites/default/files/Groundwater\\_and\\_Climate\\_Change.pdf](http://www.idaea.csic.es/sites/default/files/Groundwater_and_Climate_Change.pdf)

<sup>3</sup> See <https://www.nytimes.com/interactive/2019/08/06/climate/world-water-stress.html>

<sup>4</sup> <https://www.ecowatch.com/groundwater-being-rapidly-depleted-2642909578.html?rebelltitem=1#rebelltitem1>

(for instance streamflow for native fish populations<sup>5</sup>), on land management (in particular in connection to land subsidence<sup>6</sup>), on social cohesion and on local economies<sup>7</sup>.

In light of this, **the importance of sustainable aquifer management becomes apparent**. In their efforts to achieve this, **the authorities responsible for groundwater management can use the help of Earth Observation services**. Thus, thanks to the free, full and open access to Copernicus Sentinel data (in particular to the Sentinel-1 SAR), innovative companies can offer reliable services that allow the authorities responsible for groundwater management to monitor ground subsidence and take informed decisions on the operation of groundwater wells.

We came across the case of Catalonia, Spain. **ICGC (Institut Cartogràfic i Geològic de Catalunya)**, the Cartographic and Geological Institute of Catalonia, globally recognized for delivering ground deformation maps, has teamed up with the **ACA (Agència Catalana de l'Aigua)**, the Catalan Water Agency, to support aquifer management efforts in Catalonia.

In this report, you will discover both the story and the rigorous analysis around the benefits experienced by different value chain actors of this case. The analysis relies on clear and openly presented assumptions which have been shaped with the help of the stakeholders we interviewed (see Section 1.5).

The primary objective of this study is to compile a list of benefits that demonstrate the potential impact of Sentinels data on water resources management. Additionally, it is valuable to provide estimates of these benefits. While we acknowledge that the **product is not yet fully operational and these estimates should be considered preliminary**, EO has already shown some impact on monitoring efficiency, quality of life, and many other areas.

### 1.3 How does this case relate to others?

This case is one of the portfolio cases being developed and analysed within the frame of the SeBS project. It is the second case which explores aquifer management. The first case on this subject was conducted over Murcia (Spain). This case investigated the various and important benefits of data coming from Sentinel-1. This brought forward invaluable information on the added value generated by Sentinels for aquifer monitoring. This case in Catalonia not only confirmed several of the key findings, but also brought to light additional information, especially with its geographic, geologic and economic specificities. More specifically, this case in Catalonia estimates the benefits for all the stakeholders benefiting from better water resources allocation (thanks to Sentinel-1). In the case of Murcia, in opposition, benefits related to “avoided costs from damages on buildings” (due to ground deformation due to groundwater extraction) were estimated. In the case of Catalonia, such damages are less obvious and hence much less significant, we were therefore not able to estimate such “avoided costs”. In terms of satellite data, Sentinel-1 data is the main information used for

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<sup>5</sup> <https://wildlifemanagement.institute/outdoor-news-bulletin/february-2016/research-identifies-impact-groundwater-pumping-great-plains>

<sup>6</sup> <https://geochange.er.usgs.gov/sw/changes/anthropogenic/subside/>

<sup>7</sup> <https://truthout.org/articles/global-groundwater-is-threatened-by-unsustainable-practices-amid-climate-crisis/>

aquifer monitoring through Earth Observation as it measures ground deformation resulting from aquifer exploitation.

It is also important to note that cost savings in the context of the groundwater network monitoring are not straightforward, unlike most other SeBS cases in which EO data measures more directly the variable of interest. In this specific case, Sentinel data cannot directly measure groundwater levels but can provide indirect indicators that help prioritize areas for more intensive monitoring. Hence, the benefit of the first user is not a direct saving but rather an **improved allocation of the monitoring budget**, enabling ACA to cover more critical areas without significantly increasing costs.

## 1.4 More About the Study

Each case study analysed in SEBS focuses on products and services which use data coming from Sentinel satellites, measuring the impact of that product or service throughout the value chain. The starting point is the primary user of the satellite data, followed by a step-by-step analysis whereby the operations of beneficiaries in each subsequent link of the value chain are analysed, all the way down to citizens and society.

In this process, the main aim is to understand and demonstrate the value which is generated using satellite-based Earth Observations (EO) and particularly the data coming from the Copernicus Sentinel satellites. Each case study thus underlines the causal relationship between the use of Copernicus Sentinel satellite data and benefits resulting from their use, including increased productivity, more efficient and environmentally friendly operations, economic gains and improved quality of life, among others. The evaluated and demonstrated benefits can be used by:

**Decision makers:** Having access to a portfolio of concrete cases where the benefits from the operational use of Sentinel data in decision making are clearly articulated, helps decision makers not only to justify future investments but also to direct them towards areas that most matter in their country or organisation.

**Users:** Moving beyond a vague idea of how EO services can support more effective operations requires a concrete understanding of the benefits they can actually bring in similar cases. In this regard, it is both numbers and stories that can resonate with users and attract them to explore further or deeper uses of EO in their operational activities.

**Service providers:** Solid argumentation around the economic and environmental benefits stemming from the use of EO, coupled with powerful storytelling, can become an effective marketing tool for service providers seeking to promote their solutions and for EARSC to promote the sector.

In the framework of this project, more than 20 case studies are developed with reports to be published on each one. The study has started in March 2017 and ended in mid-2024.

## 1.5 Acknowledgements

Producing this case study report would have been impossible without the invaluable insights and kind assistance of key stakeholders. They helped us navigate across the various aspects of groundwater and ground movement monitoring. In particular, we wish to thank **Jordi Corbera** (Head of Earth Observation - Research and Development Department - at the Institute of Cartography and Geology of Catalonia, ICGC) who introduced us to a number of the experts we have consulted. We also would like to thank him for his useful insights and his time dedicated to this case. We also wish to thank very much the following persons for their time spent talking with us to develop the case and the incredibly precious information they shared with us.

- **Teresa Garrido**, Technical Project Manager, Catalan Water Agency
- **Xavier Carreras**, Hydrogeologist Technician in the groundwater unit, Catalan Water Agency

## 2 Water Management in Catalonia Overview

Despite the efforts conducted by Catalan authorities to sustainably manage water resources, they face ongoing challenges, especially during drought periods through which water scarcity generates lots of damages. To address these concerns, it is imperative to explore the factors influencing water resources, regulatory frameworks, and effective interventions.

### 2.1 Water resources in the region

#### 2.1.1 Geological conditions

Catalonia is situated at the convergence of tectonic plates which have resulted in significant geological activity over millions of years. The region is influenced by the collision between the Eurasian Plate and the African Plate, leading to complex tectonic interactions giving rise to the Pyrenees mountains to the north and the Catalan Coastal Ranges to the east. These mountain ranges play a crucial role in capturing precipitation which contributes to the recharge of groundwater aquifers and feed rivers and streams.

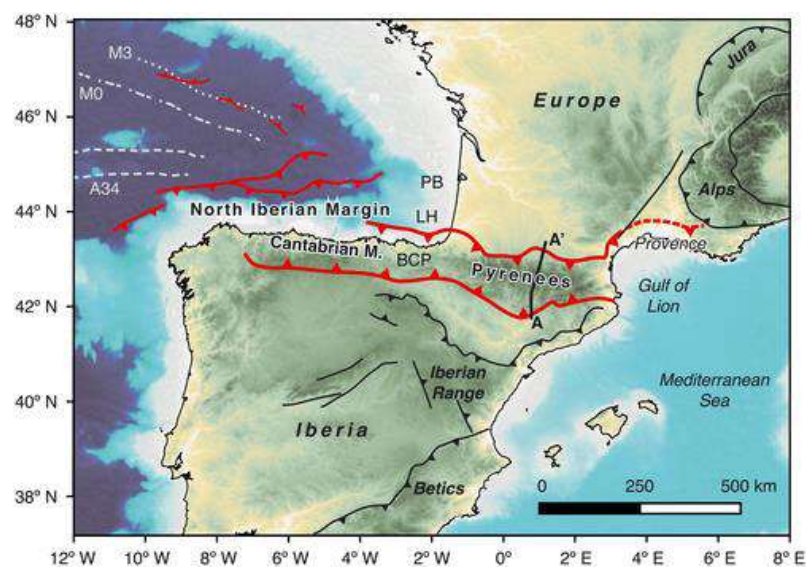


Figure 2-1: Iberic Peninsula<sup>8</sup>

Originating from the Pyrenees Mountain range, various rivers feed the region with water. These are the Ebro, Ter, Llobregat, and Segre rivers, among others. These rivers flow through Catalonia, shaping the region's landscapes. The Ebro is the most important river in Spain in terms of length (928 km) and area of drainage basin.<sup>9</sup>

<sup>8</sup> Source: <https://agupubs.onlinelibrary.wiley.com/doi/full/10.1029/2018GC007840>

<sup>9</sup> <https://en.wikipedia.org/wiki/Ebro>



**Figure 2-2 Main rivers in Catalonia<sup>10</sup>**

The geological composition of Catalonia encompasses a wide range of rock types, each with its own propensity of erosion and deformation. Sedimentary rocks, such as sandstone and limestone, are common in many parts of the region and are susceptible to dissolution by water, leading to the formation of karst landscapes characterized by sinkholes, caves, and underground drainage systems.<sup>11</sup>



**Figure 2-3 One of the many karst landscapes hidden from view in the cave systems in Catalonia<sup>12</sup>**

<sup>10</sup> Source : [https://www.freeworldmaps.net/europe/spain/catalonia.html#google\\_vignette](https://www.freeworldmaps.net/europe/spain/catalonia.html#google_vignette)

<sup>11</sup> Source : <https://www.geoparcorigens.cat/en/science/heritage/caves-and-karst/>

<sup>12</sup> Source : <https://council.science/current/news/year-caves-karst-2021-22/>

### 2.1.2 General sources of freshwater in the region

Catalonia has different sources of freshwater in order to guarantee use, especially during the dry period as the region regularly suffers from droughts.<sup>13</sup>

On the one hand, there are the **reservoirs**, with a maximum capacity of around **700 hm<sup>3</sup>/year** and have a double function: to store water and hold it back in order to avoid damage.



Figure 2-4 Eleventh century church emerges from dried-up reservoir during drought<sup>14</sup>

On the other hand, there are the **aquifers** whose reserves contribute around **600 hm<sup>3</sup>/year of water to the internal basins** (see figure 2-8). In this river basin, we can see that both aquifers and reservoirs offer approximately the same level of contribution to the overall water consumption.

<sup>13</sup> Source : <https://www.nature.com/articles/sdata2018214>

<sup>14</sup> Source : <https://www.bbc.co.uk/news/world-europe-65129735>

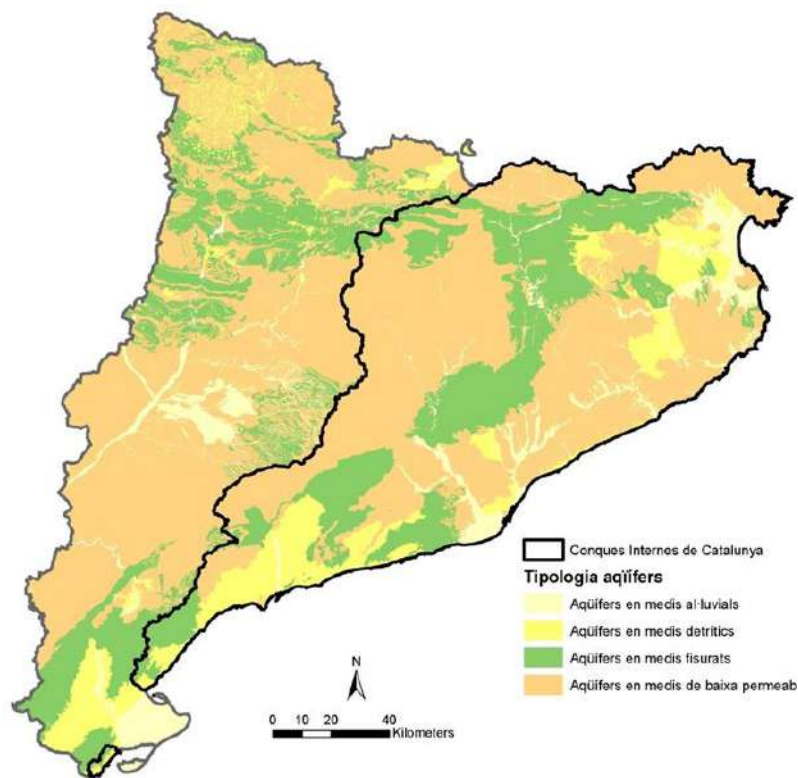


Figure 2-5 Aquifers in Catalonia<sup>15</sup>

Catalonia also utilizes alternative water sources, including **recycled water** (regenerated water) and **desalination plants**. Currently, two operational desalination plants exist: one located in Prat de Llobregat and the other in Tordera (Blanes), collectively capable of producing 80 hm<sup>3</sup> per year. This capacity is equivalent to the water consumption of the metropolitan area of Barcelona over a span of four months. The hydrological plan for the period 2022–2027 envisages **doubling the production capacity of desalinated water**, going from 80 to 160 hm<sup>3</sup> per year in order to have more resources available in a context marked by climate change. As such, the expansion of the Blanes plant by 20 hm<sup>3</sup> per year and the construction of a new desalination plant in the Foix area are planned. With regard to regenerated water, around 50 hm<sup>3</sup> per year are produced annually for industrial, agricultural, recreational or municipal purposes and this volume is expected to triple in the coming years with an expected investment of €150 million. As a result of the last development, for example, in April 2021, rivers supplied 63% of Barcelona's drinking water, groundwater contributed 34%, and desalination accounted for just 3%. In 2023, desalination provided 33% of the city's drinking water, while the contribution from groundwater decreased to 23% and rivers to 19%.<sup>16</sup>

<sup>15</sup> Source: [https://sig.gencat.cat/visors/VISOR\\_ACA.html](https://sig.gencat.cat/visors/VISOR_ACA.html)

<sup>16</sup> <https://www.euronews.com/green/2023/06/05/can-desalination-help-combat-europes-water-crisis-drought-struck-barcelona-is-banking-on-i>



**Figure 2-6 Desalination plant on the left, recycled water on the right<sup>17</sup>**

The last source of water comes from outside of the river basin through inter-basin water transfer schemes. For example, various canals and pipelines have been constructed to transfer water from the Ebro River basin to other regions within Catalonia. These transfers help supplement local water resources, especially during times of drought or when local sources are insufficient to meet demand.<sup>18</sup>

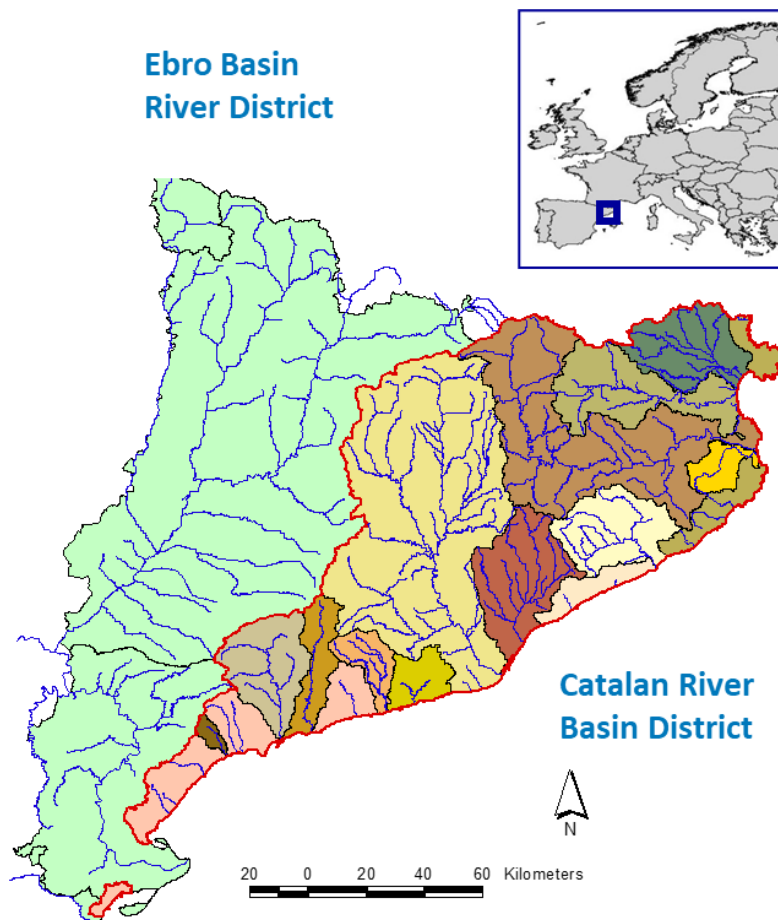
## **2.2 Water Management in Catalonia**

### **2.2.1 Water resources management**

Catalonia is divided into two water basins for management purposes: the internal basins or the Catalan River Basin District (rivers that begin in Catalonia and end in the Mediterranean) and the interregional basins (rivers that run through various autonomous communities, such as the Ebro, the Segre, the two Nogueres and the Garona). The Catalan Water Agency (ACA, which stands for “*L’Agència Catalana de l’Aigua*”) has full authority for the inner basins, but its authority regarding the interregional basins is shared with the Spanish government through the Ebro Hydrographic Confederation (CHE) and the Júcar Hydrographic Confederation (CHJ).<sup>18</sup>

<sup>17</sup> Sourced from the Catalan Water Agency

<sup>18</sup> Ibid



**Figure 2-7 The two regions representing two different water management in Catalonia<sup>18</sup>**

The Catalan River Basin District on the east (See Figure 2.7), where ACA has full authority, is challenging as it concentrates 92% of the Catalan population but present the less natural freshwater available (40% of the total).<sup>19</sup>

The two regions present very different patterns in terms of water use due to the different population density, water availability and agricultural and industrial activities. Catalan Ebro basin uses mainly its fresh water for agricultural irrigation while the Catalan River Basin District is more divided into agriculture, domestic and industrial use of water (See Figure 2-8).

<sup>19</sup> <https://togetherforwater.com/water-catalonia/>

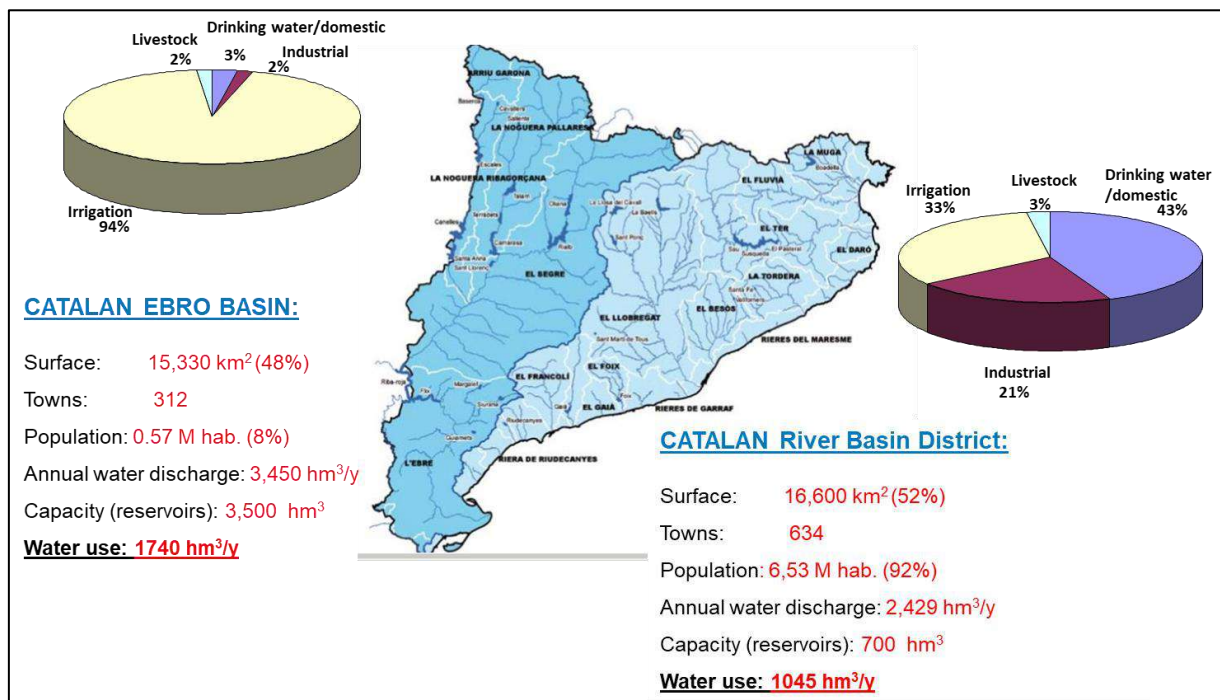


Figure 2-8 Water use in Catalonia<sup>20</sup>

One of the main **challenges** faced by the water management authorities in Catalonia is its specific climate. Catalonia is conditioned by the **Mediterranean climate**, which alternates long periods of drought with episodes of intense and short-lasting rain. These phenomena are becoming more pronounced due to **climate change**. This requires sustainable water management making balanced use of the available supply sources (reservoirs, aquifers and desalination plants).

A second growing challenge is the **tourism and leisure industry**. Tourism peaks during the summer are substantially increasing water demand in coastal and urban tourist hotspots like Barcelona. Significant water consumption comes from hotels, recreational facilities, and golf courses. For instance, Barcelona city hall estimates that local households use 99 litres of water per person per day, far below the Spanish and European average, while tourists staying in hotels use 163 litres per day. Some 30 million people visit Barcelona annually, with numbers peaking in the hot and dry summer months. While tourism is an economic gain to the city, there is also rising local resentment against tourists, who are seen as an overburden of public services, houses, and resources.

**Unsustainable water use in agriculture** is also another issue, particularly livestock farming. Spring and summer may be peak tourism season in Barcelona, but it is also when Catalonia's farms are most in need of irrigation.<sup>21</sup>

<sup>20</sup> Sourced from the Catalan Water Agency

<sup>21</sup> <https://www.politico.eu/article/spain-barcelona-tourists-catalonia-anger-rain-water-drought/>

The interests of these communities often conflict, with **farmers, residents and tourists competing against each other – especially in large urban areas – over the increasingly scarce water resources**<sup>22</sup>.

To overcome the different challenges resulting in water stresses, in January 2020, the Government of Catalonia approved the **Drought Plan**, a mechanism for managing episodes of water shortage in the internal basins. This plan applies measures in advance and locally. The plan divides the area of the internal basins into 18 units, depending on their main source of supply, and establishes specific measures where there is a shortage of water. The measures include water consumption limit and restrictions, monitoring and enforcement as well as public awareness and collaboration.<sup>23</sup> For example, earlier this year (2024), when reservoir levels dropped to 15 percent due to a lack of rain, authorities had no option but to **enforce drastic emergency measures**. Since February, over 200 Catalan municipalities have been limited to 200 litres of water per person per day, encompassing domestic use such as drinking and washing, as well as other non-industrial uses including those in the hospitality sector. If the drought would have intensified, this limit could be reduced to 160 litres. Industry and agriculture are also subject to significant cuts, with the emergency decree slashing water use for crop irrigation by 80%, for livestock by 50% and for industry by 25%. **The tourism industry did not face any restrictions until mid-April**. However, under increasing pressure, the government announced that in municipalities where the 200-litres limit had been exceeded for three months or more, tourists in hotels would be limited to using 100 litres of water per day.<sup>24</sup> Later on, in May 2024, the ACA activated the state of *exceptionality* (which is better than the emergency status before). The exceptional situation makes it possible to have a water supply per inhabitant per day of 230 litres (vs the 200 litres in emergency situation).



**Figure 2-9 Picture of drought in Catalonia<sup>25</sup>**

To limit the use of water, some **Public Awareness Campaigns** have also been successfully conducted. It has induced significant changes in consumer habits, such as reduced water use in households (to 99 litres per person per day in Barcelona). In addition, the Catalan Government planned to reduce tap pressure for six million people or to bring in water by boat.

Besides reducing consumption, Catalonia also needs to **reduce its dependence on rainfall**. This is why the ACA is planning to immensely invest in several **new treatment and desalination centrals**. More specifically, as seen above, the hydrological plan for the period 2022–2027 envisages doubling

<sup>22</sup> See <https://www.nytimes.com/interactive/2019/08/06/climate/world-water-stress.html>

<sup>23</sup> Information sourced from the Catalan Water Agency

<sup>24</sup> Ibid

<sup>25</sup> <https://www.aiguesdebarcelona.cat/ca/estat-actual-sequera>

the production capacity of desalinated water, going from 80 to 160 hm<sup>3</sup> in order to have more resources available in a context marked by climate change. In addition, the volume of regenerated water is expected to triple in the coming years with an expected investment of €150 million<sup>26</sup>.

### 2.2.2 Aquifer Management

Effective aquifer management is crucial in Catalonia as groundwater is an essential resource, supporting the population and a wide range of economic activities, including agriculture and industry. In this region, groundwater contributes significantly, accounting for approximately 22.8% of the region's total water demand – and 44% of the demand in the Catalonia River Basin (where Barcelona is).<sup>27</sup>

Before developing the subject of groundwater management in Catalonia, it is helpful to understand how aquifers are managed in general. An aquifer is an underground layer of water-bearing permeable rock, rock fractures, or unconsolidated materials such as gravel, sand, or silt. Wells can be drilled into aquifers to extract groundwater. Precipitation replenishes these aquifers by adding water to the porous rocks, thus completing the natural recharge cycle.

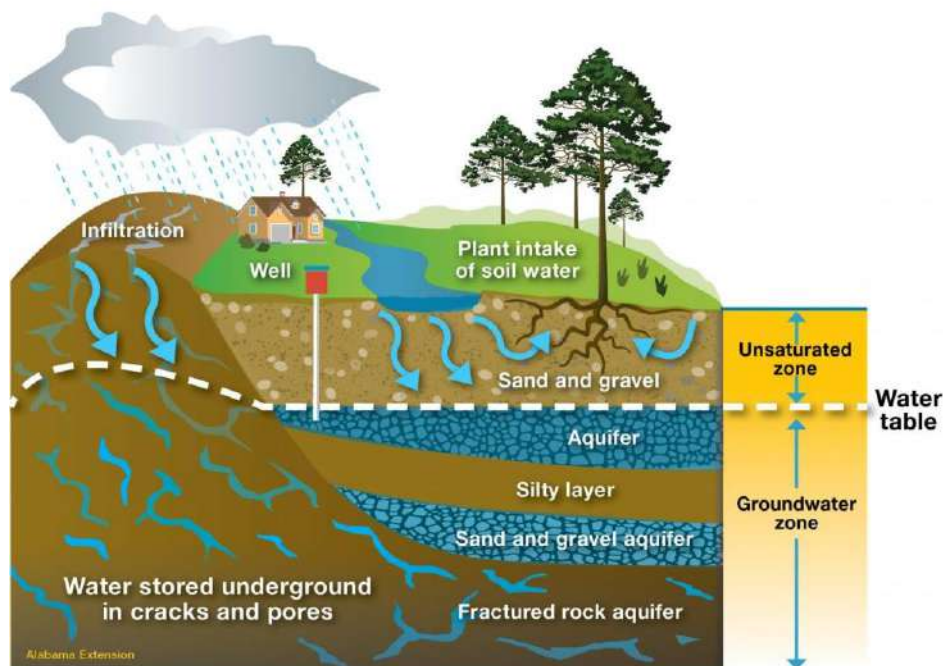


Figure 2-10 What is an aquifer<sup>28</sup>

Despite their underground presence, groundwater represents around 30% of the world's freshwater. This is especially significant considering that surface water sources like lakes and rivers

<sup>26</sup> Ibid

<sup>27</sup> Computation made from figure 2.13

<sup>28</sup> <https://www.aces.edu/blog/topics/fish-water/what-is-an-aquifer/>

are often limited (1.2% of world freshwater<sup>29</sup>). Consequently, groundwater from aquifers has become an invaluable resource over centuries, meeting needs for **drinking water, irrigation, and industrial use**.

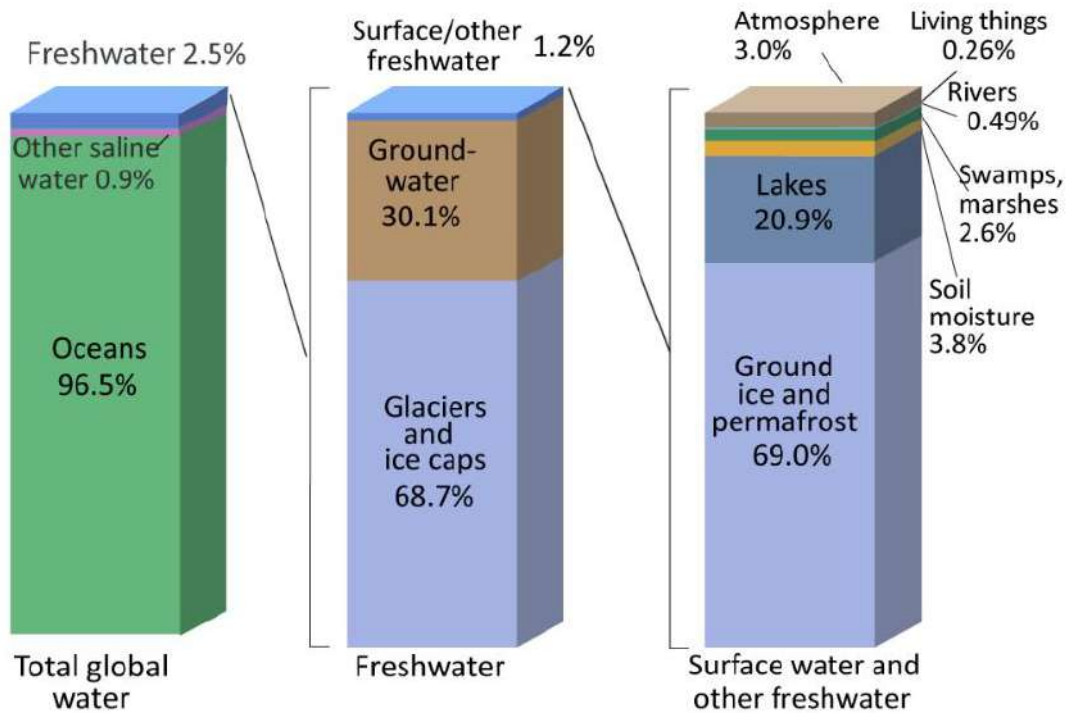


Figure 2-11 Where is Earth's Water?<sup>30</sup>

However, the demand for groundwater, influenced by factors like household consumption, agricultural irrigation, and industrial needs, often exceeds the available supply. This leads to overexploitation in about 20% of the world's aquifers, resulting in **serious consequences** such as **land subsidence and saltwater intrusion**. Furthermore, **pollution** has severely limited direct use of freshwater resources, with only 1% of it being available for consumption.

Estimations indicate that the global groundwater footprint, or the total amount of groundwater extracted per year, surpasses the actual size of aquifers by about 3.5 times. Approximately 1.7 billion people live in areas where groundwater reserves are significantly threatened.<sup>31</sup>

Additionally, groundwater can be polluted especially due to agricultural and other industrial runoff in aquifers (see Figure 2-12).

<sup>29</sup> This number seems extremely low, in fact 68.7% of world freshwater is captured in glaciers and ice caps.

<sup>30</sup> [https://www.usgs.gov/special-topic/water-science-school/science/where-earths-water?qt-science\\_center\\_objects=0#qt-science\\_center\\_objects](https://www.usgs.gov/special-topic/water-science-school/science/where-earths-water?qt-science_center_objects=0#qt-science_center_objects)

<sup>31</sup> <https://pubmed.ncbi.nlm.nih.gov/22874965/>

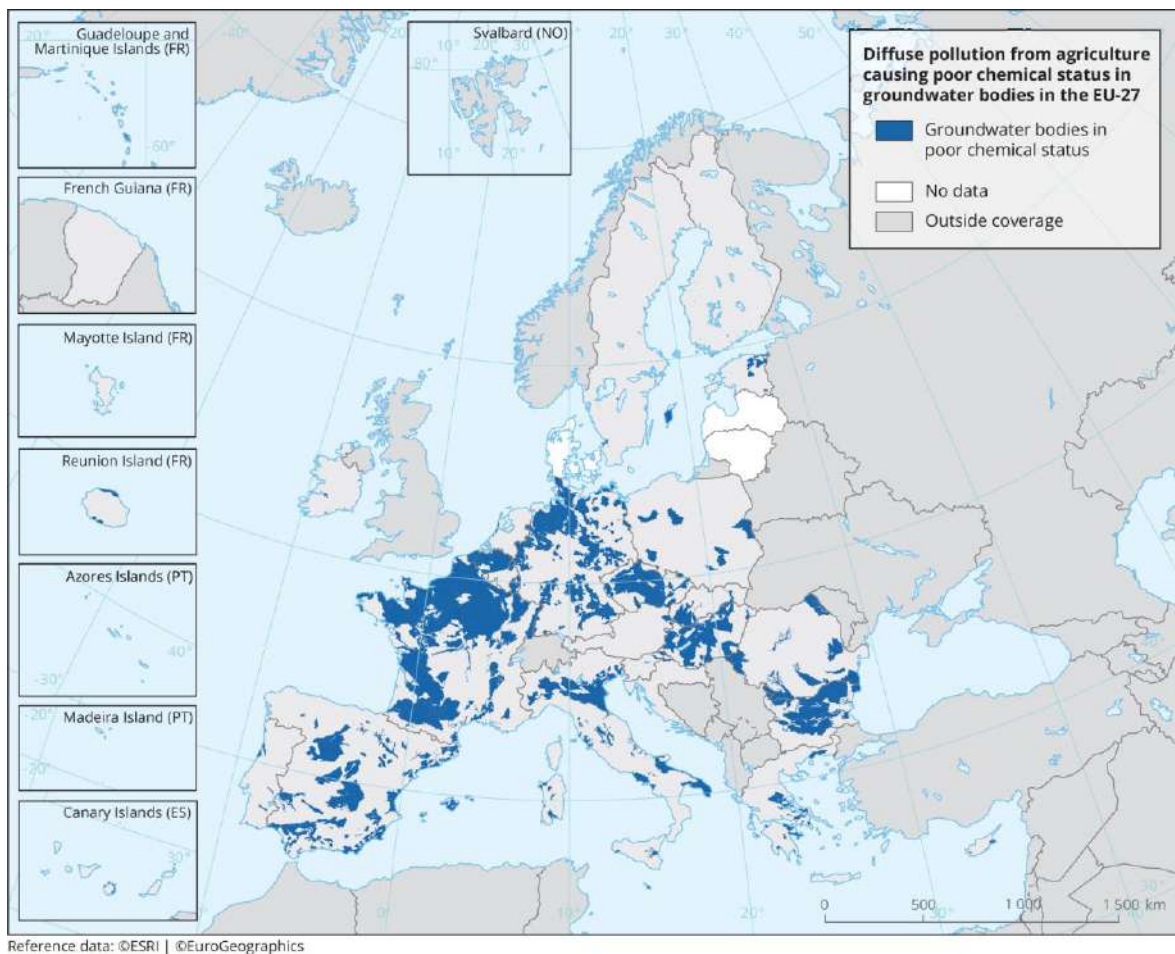


Figure 2-12 Chemical status of groundwater bodies in the EU<sup>32</sup>

To ensure sustainable use and long-term availability of groundwater, **effective management of aquifers is crucial**. This involves respecting a "safe yield," which refers to an extraction rate that doesn't cause adverse effects. The safe yield can vary but generally corresponds to either the total recharge rate or 50% of it, depending on scientific studies. Yet, all studies dealing with aquifer management agree that effective aquifer management should entail the objectives of **renewability** of the resources, **practical exploitations** and **consumption rationality**.<sup>33</sup>

Nevertheless, **unlicensed groundwater extraction** in Spain is posing a **major concern** that water authorities often find themselves struggling with. It is estimated that the number of **illegal wells** is between half a million and a million.<sup>34</sup> These wells are mostly found near areas of intensive agriculture but are also used in touristic areas, for example to fill-in swimming pools. To have a rough idea of what it represents in terms of quantity, if each illegal well abstracts an average of 100 cubic meters of water per year (which is a conservative estimate as it corresponds grossly to an

<sup>32</sup> <https://www.eea.europa.eu/publications/europes-groundwater>

<sup>33</sup> Ibid.

<sup>34</sup> [https://www.lemonde.fr/en/environment/article/2022/08/13/thousands-of-illegal-wells-in-spain-worsen-water-shortage\\_5993512\\_114.html](https://www.lemonde.fr/en/environment/article/2022/08/13/thousands-of-illegal-wells-in-spain-worsen-water-shortage_5993512_114.html)

average household consumption in Catalonia<sup>35</sup>), **half a million to a million illegal wells would correspond to 50 hm<sup>3</sup> to 100 hm<sup>3</sup> of water per year**, which corresponds to 8,3% to 16,6% of the total groundwater consumption (see figure 2-13).

In Catalonia, as in other parts of Spain, the climate specificities coupled with climate change pose additional significant challenges, given the region's **recurrent droughts which do not ensure fast renewability of groundwater**.

The exploitation of groundwater also damages aquifers in Catalonia due to **saltwater intrusion**. This issue is evident in the Llobregat Delta, where the aquifer is a crucial freshwater resource for the Barcelona area, with a capacity of 100 million cubic meters. This water is extracted through wells by numerous industries, agricultural activities, and the population. Overexploitation has caused the aquifer to become salinized, making 30% of it unusable.<sup>36</sup>The agricultural sector particularly suffers from such intrusion as salinized water is harmful to most crops. **Consolidation of aquifers** is also another problem resulting from groundwater exploitation in Catalonia, as excessive withdrawal can lead to the **compaction and reduced storage capacity of aquifers**. This phenomenon can further exacerbate water stresses and impact the long-term sustainability of groundwater resources in the region. A final issue resulting from groundwater extraction is the formation of a **cone of depression**, which can lead to reduced water availability around the cone of depression and potential land subsidence.

With regard to **groundwater use**, the total groundwater abstraction is estimated at **600 hm<sup>3</sup>/year**. A much higher abstraction rate in the Catalan River Basin (79%) compared to the Ebro Catalan Basin (21%). Groundwater represents also almost half (44%) of the total water demand in the Catalan River Basin (See Figure 2-13). It shows the **very high dependency of agriculture, industry and citizens in this region on groundwater** and hence the importance of efficient groundwater management practices.

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<sup>35</sup> This number was computed based on a total consumption of 99l/day per person (see previous section)

<sup>36</sup> <https://geographyfieldwork.com/LlobregatDeltaRisingSeaLevels.htm>

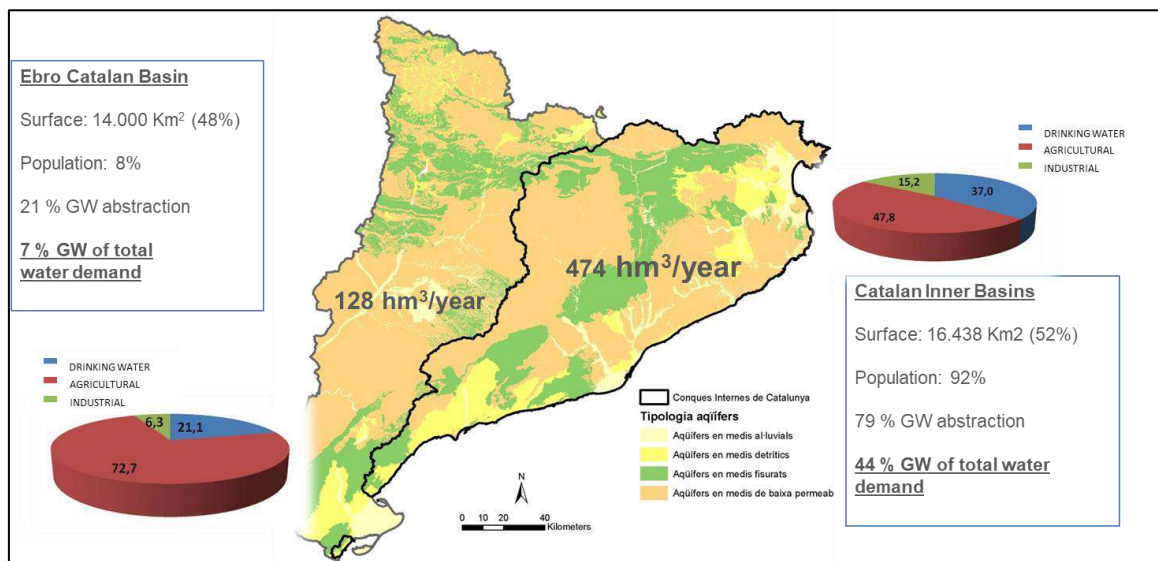


Figure 2-13 Groundwater use in Catalonia.

## 2.3 Regulatory framework and water management

In Europe, the EU Water Framework Directive (EU WFD) has played a pivotal role in promoting water quality and ecological preservation. This directive has not only reinforced environmental awareness but has also spurred European countries to streamline monitoring activities and counteract illegal wells. This section also explores how Spain has adapted its legislation.

### 2.3.1 EU regulatory Framework

The **EU Water Framework Directive (EU WFD)**<sup>37</sup> - adopted in 2000 – is setting out rules to cease deterioration in the status of EU water bodies and achieve **good status** for Europe’s **rivers, lakes and groundwater**. It has pushed many European countries to streamline monitoring activities and improve water quality. This has led to increased environmental awareness and increased demand to counteract the accelerating pollution of European water bodies.

The EU WFD sets standards for preventing pollution and deterioration of **groundwater quality** and requires member states to establish monitoring programs to assess the status of groundwater bodies. Illegal aquifer drilling can lead to contamination and overexploitation of groundwater, violating the principles of this directive.

Policies related to groundwater management are therefore impacted by the European Water Framework Directive (WFD), which in the Region of Catalonia is to be implemented by mainly the Catalan Water Agency (see 2.2.1). However, to adapt the WFD principles to both the hydro-climatic and socio-economic context of a southern Mediterranean country such as Spain is a highly challenging task.

<sup>37</sup> [https://ec.europa.eu/environment/water/water-framework/index\\_en.html](https://ec.europa.eu/environment/water/water-framework/index_en.html)

Another important directive influencing groundwater management is the recast **Drinking Water Directive (DWD)**, the EU's main law on drinking water. It concerns the access and the quality of water intended for human consumption to protect human health.<sup>38</sup> Good quality water at the source which can be groundwater would inevitably make it less difficult to have good quality drinking water.

### 2.3.2 Spanish framework on water management

With regard to **water management in Spain**, there is the **Water Law (Ley de Aguas)** which is a fundamental legal framework for the proper management of water resources in the country. This legislation establishes norms, rights and principles that guarantee sustainable and equitable use of water, as well as the protection of aquatic ecosystems.<sup>39</sup>

With regard to **aquifer management in Spain**, water has been recognised as a public domain resource as of 1985 (knowing the crucial importance of effective management and rational groundwater extraction). Thanks to this new legislation, water that is abstracted from wells drilled from 1986 onwards is for public use. Nevertheless, users that had installed private wells and exploited groundwater before that year were able to keep their water rights private. As a result, most water users opted for the latter alternative which is why most groundwater rights in the region are still held private until today.

There are **criticisms** regarding this **concession system**, with concerns about the potential for perpetual private ownership and the lack of effective review mechanisms. The rigid concession system has led to the solidification of private property rights over entire rivers, particularly by irrigators and the electric sector, undermining the notion of water as a public good.<sup>40</sup>

## 2.4 Informed decisions, coordinated actions and effective interventions

Preventing, reducing and mitigating the adverse impacts of groundwater exploitation and subsequent issues, i.e., land subsidence, shortage of water, consolidation of aquifers, worsen water quality, etc. requires that all actors work together and that all available sources of information are effectively used. Thus, having the best possible situational awareness – i.e., where and when groundwater is being extracted, is of utmost importance. Knowing where and when the extraction of groundwater from well-points is possible without harming the area of influence of that well-point and anticipating its effects on the communities living within the area is of utmost importance for the ACA and other stakeholders in the region to make informed decisions, effectively execute their mandate and avoid negative unintended effects.

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<sup>38</sup> [https://environment.ec.europa.eu/topics/water/drinking-water\\_en](https://environment.ec.europa.eu/topics/water/drinking-water_en)

<sup>39</sup> <https://www.boe.es/buscar/act.php?id=BOE-A-2001-14276>

<sup>40</sup> [https://www.researchgate.net/publication/318644066\\_Instruments\\_of\\_administrative\\_concessions\\_of\\_water\\_use\\_rights\\_in\\_Spain](https://www.researchgate.net/publication/318644066_Instruments_of_administrative_concessions_of_water_use_rights_in_Spain)

### 2.4.1 Collecting the necessary data

To fulfil its mandate, the ACA has built up and managed a control network of more than **500 stations** throughout the entire Catalonia that measure **groundwater levels** and spring flows. From this and further modelling, ACA can conclude the current amount of water in the aquifers.

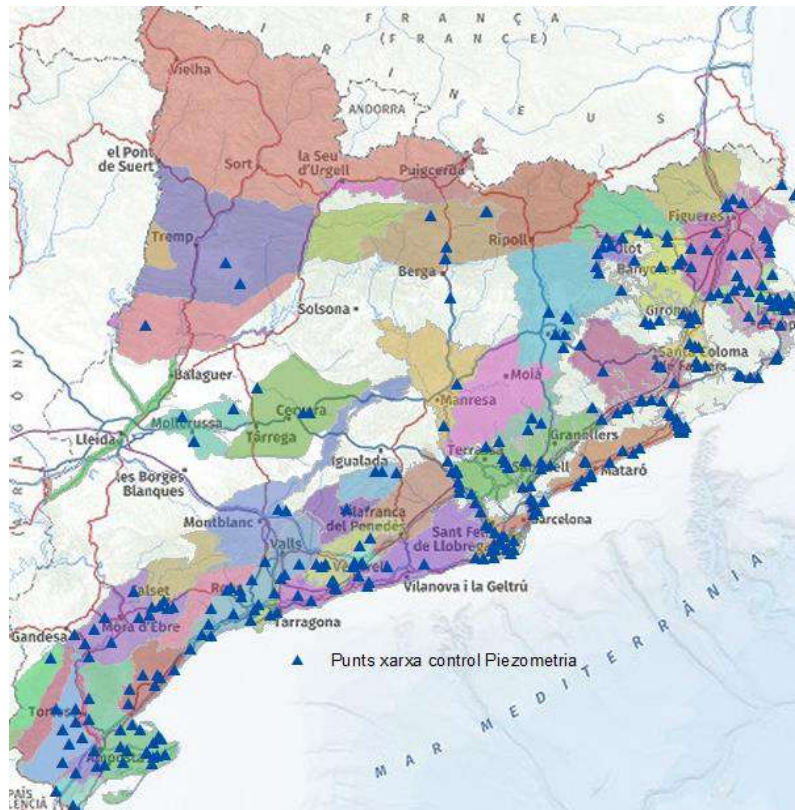


Figure 2-14 Ground Water level monitoring network.<sup>41</sup>

There are 500 monitoring sites distributed across all the different individual “sub-basins” and provide measurement at a **monthly frequency** – there are also 50 points providing data at an hourly frequency. According to the ACA, the control points at which the measurements are carried out are chosen depending on their significance of reflecting the overall behaviour of the water mass within the sub-basin in question. Depending on the geographical extent defined for each water body, measurement stations range from a single piezometer at a smaller surface area to several piezometers over the largest sub-basins with the largest geographic extent. The temporal evolution of groundwater levels from these in-situ monitoring sites provides crucial insights into major and problematic descending levels. Additionally, it offers information on general trends in groundwater levels (to assess quantitative status), groundwater characterization (flow directions, piezometric maps, mathematical model data), and the percentage of groundwater reservoir capacity.

<sup>41</sup> Sourced from the Catalan Water Agency

The ACA has also implemented a network of **1200 sites to monitor the chemical composition** of groundwater. These sites regularly measure various chemical parameters, including general characteristics, organic compounds, and nutrients.

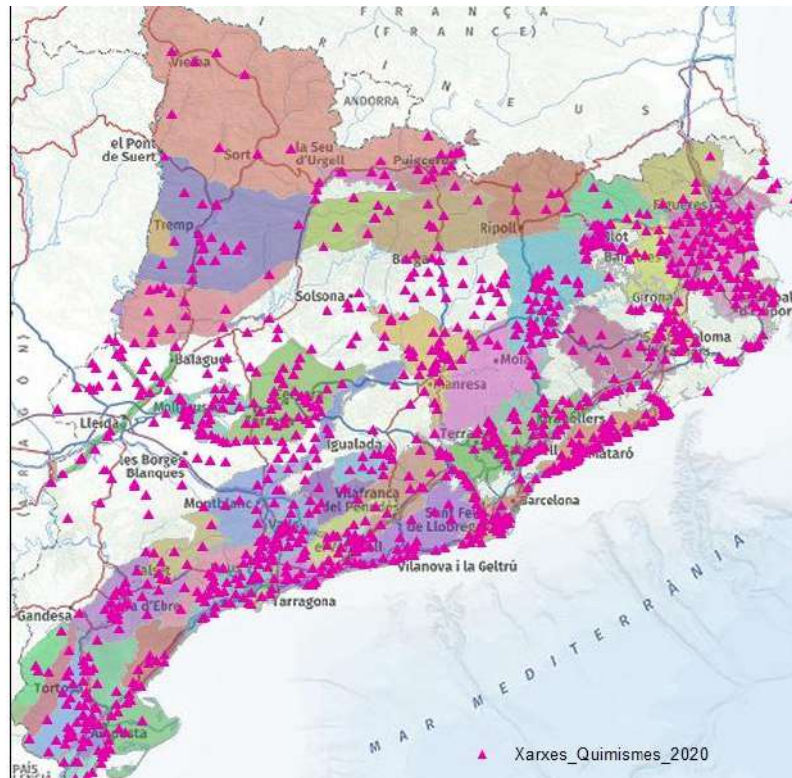


Figure 2-15 Ground Water Chemical monitoring network.<sup>42</sup>

#### 2.4.2 Limitations of conventional methods

While this ground control network can be a very useful in-situ tool to measure piezometric data and derive the level of subsidence, it is also bounded by certain limitations. These limitations give rise to important challenges faced by the authorities – especially during drought periods.

- **Constructing a broader picture:** The ability to have a region-wide picture of subsidence (reflecting on groundwater extraction patterns) is crucial for the coordinated extraction of groundwater and thus the allocation of resources. Achieving this with a traditional technique is difficult and costly.
- **Facilitating common understanding:** Communicating on the evolution of the subsidence and groundwater abstraction is highly critical both between the corresponding public authorities but also to the public, media and political hierarchy. Measurements with piezometric data can only provide a part of the overall picture/data which is not sufficient for an effective communication.

<sup>42</sup> Sourced from the Catalan Water Agency

- **Real-time monitoring:** in-situ sampling typically provides discrete data points at specific sampling times. At the moment, the ACA mostly gets measurements every month on groundwater levels. It may not offer real-time or continuous monitoring capabilities required to detect rapid changes.

All these limitations can – to a very large extent – be addressed by the use of satellite data. Therefore, a few years ago, the ACA started a cooperation with the ICGC (the Cartographic and Geological Institute of Catalonia) to support their monitoring activities related to ground deformation and aquifer management.

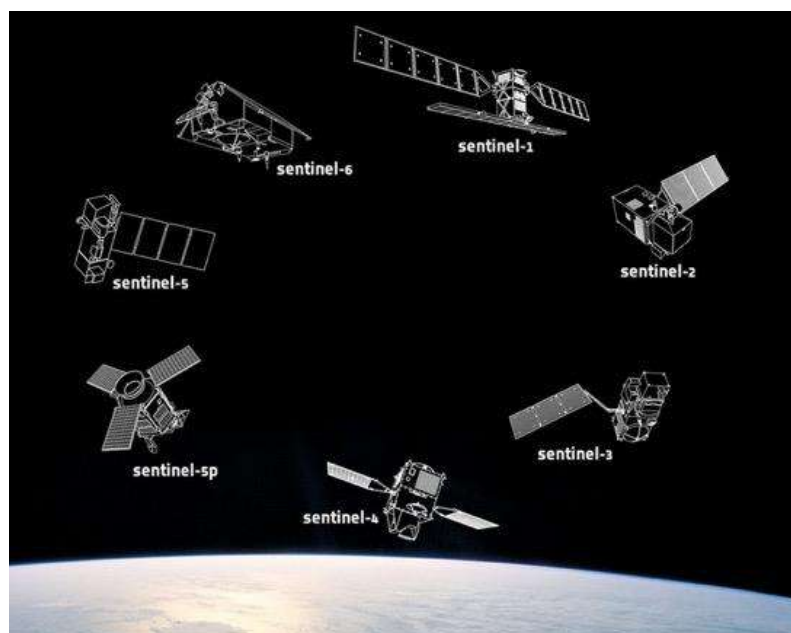
We will look into this service in the next chapter, followed by a thorough account of how it was used by the different actors (Section 4) and the concrete value it brings (chapter 5).

### 3 The Use of Sentinel Data

Before delving into the applications of aquifer monitoring using satellite-derived data, it is essential to grasp how these satellites capture Earth's surface changes, providing invaluable insights for water monitoring. The advantages and limitations of EO, including its wide geographical coverage and temporal resolution, are discussed in this section.

#### 3.1 How do sentinel data help with water management?

Satellites data is increasingly being used to support underground water monitoring. More specifically, data coming from both [Sentinel-1](#)<sup>43</sup> and [Sentinel-2](#)<sup>44</sup> (see the information boxes below) from the [EU Copernicus programme](#) (see figure below)<sup>45</sup> is used to observe different parameters supporting the management of aquifers. The most important parameter is the **subsidence related to water pumping**, this data is measured by **Sentinel-1**. In addition, Sentinel-2 data can also be used to estimate crop water consumption.



**Figure 3-1: Current Sentinel satellites**


As this case is defined by Sentinels 1 and 2, the figure below provides more detailed specifications about both satellites.

<sup>43</sup> <https://sentinel.esa.int/web/sentinel/missions/sentinel-1>

<sup>44</sup> <https://sentinel.esa.int/web/sentinel/missions/sentinel-2>

<sup>45</sup> <https://www.copernicus.eu/en>

**The satellite data:**




Sentinel-1 is the Copernicus radar mission, providing an all-weather, day-and-night supply of imagery of Earth's surface. The mission consists of two satellites embarking C-band synthetic aperture radars (SARs) in continuity of the ESA's ERS-2 and Envisat missions. The mission images the entire Earth every six days for the benefit of manifold applications such as, for example, monitoring of Arctic sea ice extent, surveillance of the marine environment, monitoring land-surface for motion risks, mapping for forest, water and soil management.

Copernicus Sentinels data are available under an open and free data policy.

Sentinel-2 data can be accessed at <https://scihub.copernicus.eu>

More info: <https://sentinels.copernicus.eu>

**The satellite data:**



Sentinel-2 carries an innovative wide swath (290km) high-resolution (10m) multi-spectral imager with 13 spectral bands, providing unprecedented views of the Earth with frequent revisit times.

The mission is mainly intended to support land monitoring: its images can be used to determine various indices related to the status of vegetation that are useful for e.g. agriculture and forestry. When imaging over crisis areas, Sentinel-2 contributes to disaster mapping, helping humanitarian relief efforts. Sentinel-2 imagery is also useful to monitor glaciers, lakes and coastal waters.

Copernicus Sentinels data are available under an open and free data policy.

Sentinel-2 data can be accessed at <https://scihub.copernicus.eu>

More info: <https://sentinels.copernicus.eu>

**Figure 3-2: Sentinel-1 and Sentinel-2 satellites**

The case of monitoring underground water relies mainly on data coming from [Sentinel-1](#)<sup>46</sup>. **Sentinel-1** is the latest SAR mission launched by ESA with the first Sentinel-1A being launched in 2014 followed by Sentinel-1B in 2016. Sentinel-1 carry Synthetic Aperture Radar (SAR) operating in C-band. This enables an **all-weather, day-night** capability to detect and quantify accurately small ground surface deformations. The technique is known as Interferometric Synthetic Aperture Radar (**InSAR**) and **uses several observations of the ground at intervals of days, weeks and sometimes months**. Using Multi-Temporal Interferometry (MTI) algorithms, one can detect **Earth surface movements of a few millimetres** which have occurred between the observations. In particular, the

<sup>46</sup> <https://sentinels.copernicus.eu/web/sentinel/missions/sentinel-1>

technique allows detecting and monitoring millimetric displacements occurring on selected point targets exhibiting coherent radar backscattering properties.

InSAR techniques are attractive for different areas of risk management such as monitoring of subsidence, volcanoes, tectonic movements, urban areas, infrastructure and slope instabilities. Using archive data from these missions, one can also perform ground instability analysis “back in time” almost all over the Earth.

Sentinel-1, by offering regular **global-scale coverage, free imagery, improved revisit time (up to 6 days) and long wavelengths (5.6 mm)** can guarantee wider and more efficient application for the global ground deformation monitoring. To accomplish the above, the satellites’ SAR instrument offers medium-to-high-resolution radar imagery.

**Sentinel-2**, which is planned to be used for future monitoring of irrigations, is a wide-swath, high-resolution, multi-spectral imaging mission. Sentinel-2 carries an optical instrument payload that samples 13 spectral bands: four bands at 10m, six bands at 20m and three bands at 60m spatial resolution. Normalized difference vegetation index (NDVI) is a simple graphical indicator that can be derived from Sentinel-2 data which helps to assess vegetation health based on how the vegetation reflects light at certain frequencies. Sentinel-2 helps in monitoring soil properties as well as vegetation conditions.

### 3.1.1 How can Satellites measure Ground Deformation?

The analysis of ground deformations and land subsidence in Catalonia, crucial for coordinating groundwater abstraction, can significantly benefit from affordable remote sensing systems SAR (Synthetic Aperture Radar) from Sentinel-1.

The **SAR** system emits microwave pulses (with a wavelength ranging from few centimetres to few tens of centimetres) and records the echoes from each pulse. The energy that is reflected or scattered back from the ground provides important information on the surface. Since microwave radiation penetrates the atmosphere with negligible absorption, SAR allows for monitoring during all weather conditions and at night. These characteristics for all-weather and night-day acquisitions make this technology very appealing for Earth surface monitoring purposes.

SAR data are intensively used for the measurement of ground and structure deformations and the technique used for the data processing is the **Multi-Temporal Interferometry** (MTI). It can measure ground deformation up to millimetres precision although the intensity of the reflected signal depends on the ground surface’s nature. For example, changes in **vegetation structure** (wing, growth) cause noises for measurements of ground movement. Another example is linked to the **slopes** in the ground surface, e.g. in areas with steep slopes, parts of the terrain may be hidden from the radar signal, leading to gaps in the data.

On the other hand, man-made surfaces such as urban areas and roads in Catalonia provide a strong reflection from single points which allows the measurement of ground movement to be very

precise. In other cases, strong reflectors (known as a corner reflector) may be placed to help measurements.

Another important limitation of such technology is **ground resolution** which basically determines how close together points on the ground can be detected. For example, if too many reflectors are present in the same measurement cell (pixel), then the measurement becomes confused and only an average movement can be measured. Higher resolution images help solve this problem but are generally commercial compared to the Sentinel-1 data which is free.

The **frequency of the observations**, which depends on how often the satellite passes overhead (and if images are being collected), also limits ground deformation studies. Sentinel-1 can provide images every three to six days over Spain.

In addition, there is a direct trade-off between the ability to measure single points on the ground compared to taking measurements on a regular basis. The availability of images from many satellites increases the ability to measure movements either in a closely spaced grid (high spatial resolution) or with a shorter delay between each measurement.

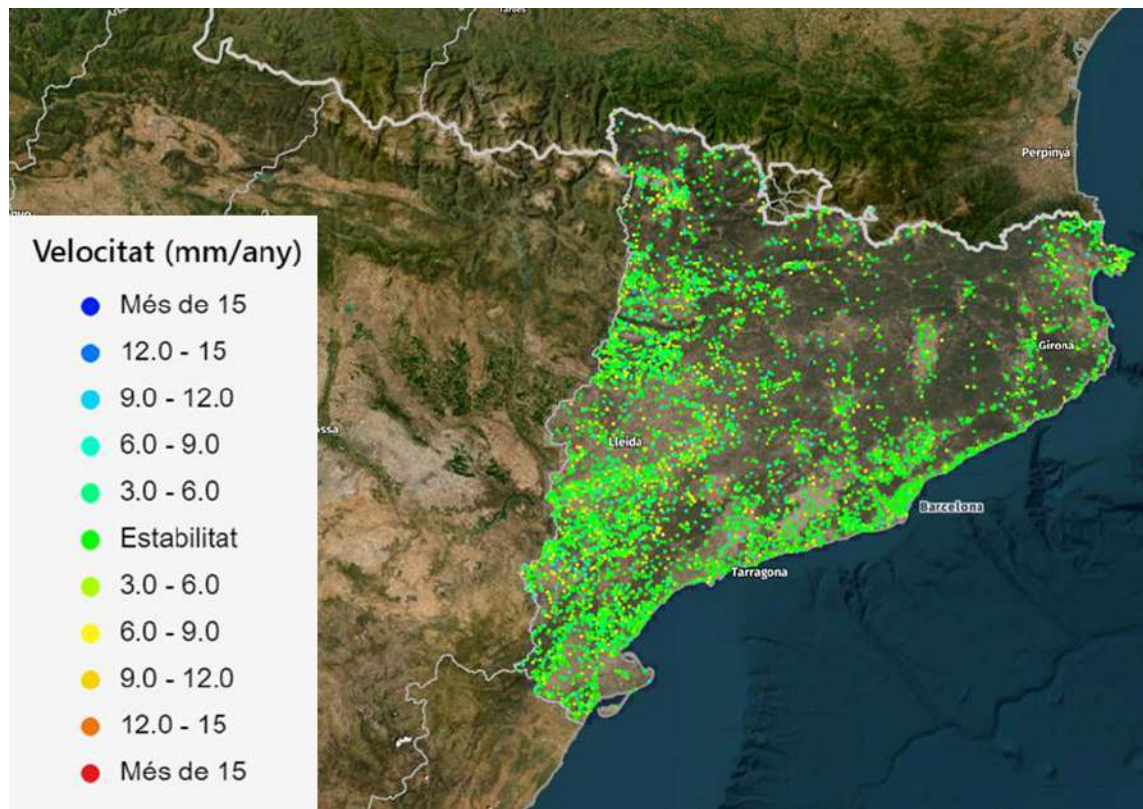
It is important to note that, on top of the previously stated limitations of SAR systems (such as ground surface movements – due to vegetation and wind for example - or slopes), satellite observations are **limited to surface information** and cannot directly assess groundwater. In fact, **aquifer overexploitation does not always lead to ground movement as it greatly depends on the ground structure**. In addition, in-situ monitoring reveals key insights such as general trends for assessing quantitative status, groundwater characterization, and reservoir capacity which cannot be measured with Sentinels. Therefore, such EO data is seen as a complement (not a substitute) to in-situ underground measurements for aquifer monitoring. More specifically, terrain movement data from EO can identify areas with potential subsidence problems which allows to optimize its in-situ monitoring efforts by focusing on critical areas.

### 3.2 The ICGC Service

In the framework of this case study, the ICGC utilizes its own EO workflows to assess **aquifer conditions which** are measured through ground deformation. With comprehensive coverage provided by satellite imagery, the ICGC has developed a methodology using artificial intelligence techniques to improve the interpretation of surface movement measurements for studying aquifer dynamics. This method helps to analyse subsidence (“land sinking”) and uplift (land rising) to understand groundwater extraction and replenishment at a regional scale. For example, subsidence suggests groundwater extraction for domestic or agricultural use, while uplift suggests natural replenishment or reduced extraction. By combining surface movement data with terrain information, such as well as locations and in-situ sensor networks provided by the ACA, this methodology enables accurate monitoring of aquifer status. It also helps public administrations in taking necessary actions when groundwater overexploitation is detected.

The techniques used by ICGC, known as DInSAR (differential interferometric SAR), measure millimetre-scale vertical deformations. ICGC's advanced DInSAR techniques can also isolate areas

with significant vegetation or water as well as mitigating atmospheric conditions, where movement calculation is challenging. They also enable the selection of suitable SAR images based on the study area and movement type, maximizing effectiveness. Results provides maps with an important number of points of ground movements (see below).



**Figure 3-3 ICGC service – map of ground movement in Catalonia (red points indicate more than 15 mm per annum of subsidence, green points are stable points while blue points are upward movements).<sup>47</sup>**

Each point of ground movement is associated to a time series graph that measures the vertical movement over time. As an example, the graph below shows a candidate for ground subsidence due to aquifer exploitation as the cyclical trend shows down lift movement during summer when more water is needed for agriculture, swimming pools, etc. In addition, there is a worrisome downward trend over the years which really needs further investigations. This point could therefore be further explored by the ACA to better understand the causes of such movements.

<sup>47</sup> <https://www.icgc.cat/en/Thematic-areas/Territori-sostenible/Sostenibilitat-urbana/Observacio-de-la-Terra/Ground-movement-measurement-service>

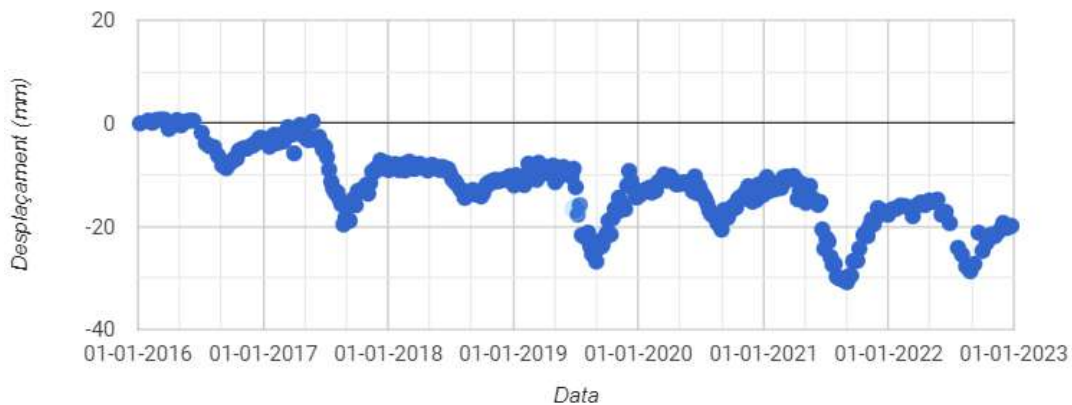


Figure 3-4 example of movement over time.<sup>48</sup>

After the subsidence detection, it is possible to do an exhaustive follow-up by means of the programmed acquisition of new images. The result is a map of the movement of the land to which ICGC adds complementary knowledge, such as geological information.<sup>49</sup> Below is another example of several areas presenting ground movements over the years with different trends.

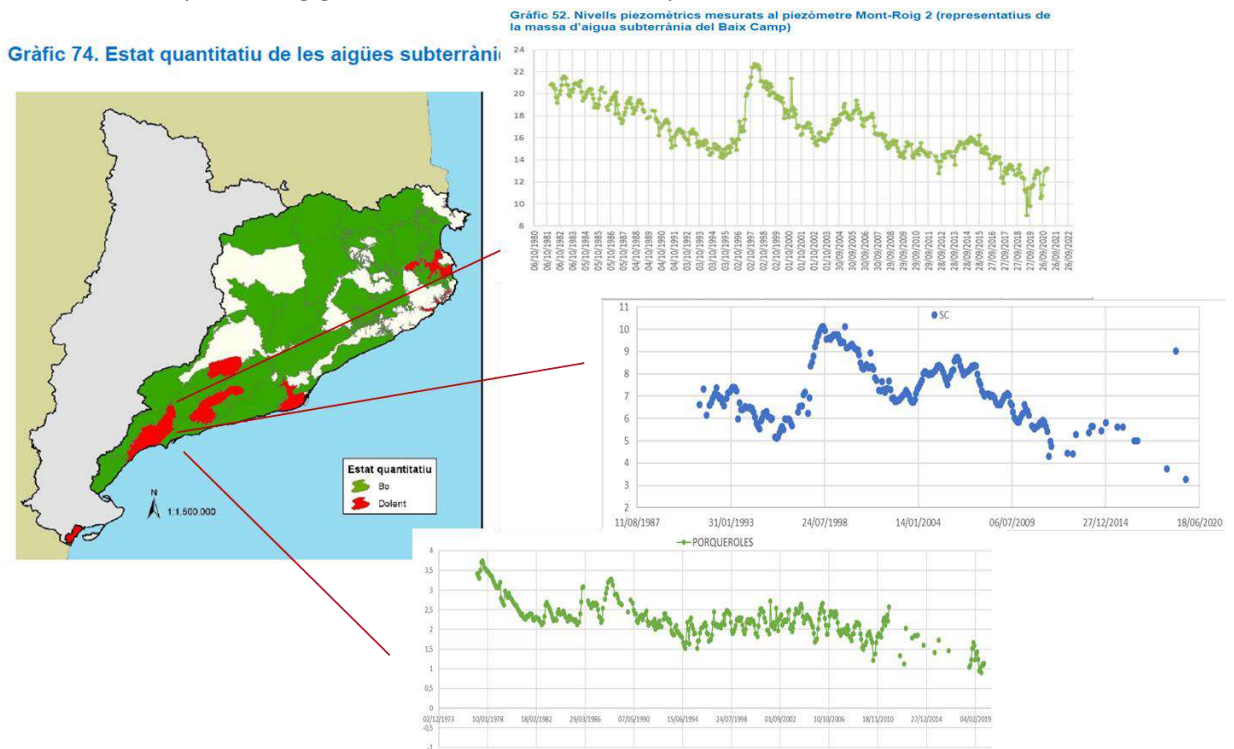


Figure 3-5 Quantitative assessment of groundwater bodies in Catalonia<sup>50</sup>

<sup>48</sup> Sourced from the Catalan Water Agency.

<sup>49</sup> <https://www.icgc.cat/en/Innovation/Custom-projects/Subsidence>

<sup>50</sup> Ibid.

### 3.3 Future evolution of the ICGC Service

In the future, the ICGC plans to use Sentinel-2 data on top of Sentinel-1 data for cross validation as well as providing information on crop irrigation. It is developing a workflow to automatize the provision by using Sentinel-2 data, the Leaf Area Index together with the NDVI (Normalized Difference Vegetation Index), as a proxy to identify irrigated zones. As a result, Sentinel-2 data coupled with machine Learning techniques can provide information about the timing and the areas of crops which are irrigated. It can help optimize irrigation practices, detect early signs of ground subsidence due to excessive water extraction and detect more easily illegal groundwater extraction for irrigation.

A future and additional evolution of the ICGC service will be to develop new filtering algorithms of the interferometric phase to improve and enlarge the coherent points with deformation measures.

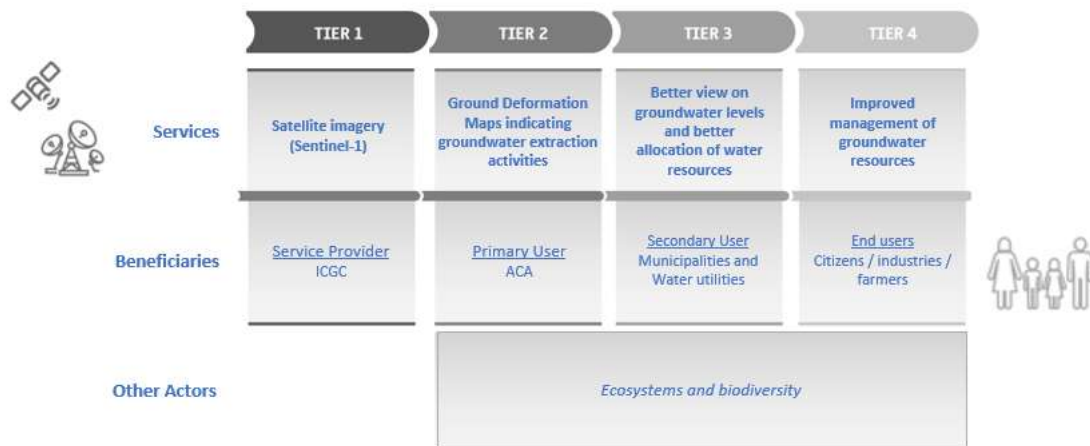
## 4 Understanding the Value Chain

The use of satellite data at the entry point of the value chain results in insights or improved operations that bring value for each link further down the chain. Ultimately, better groundwater management (both from an environmental and an economic point of view) results in benefits for our society at large. But before we dive into the individual links and attempt to quantify the benefits (in chapter 5), it is instructive to understand how the use of satellite data helps actors along the value chain to address the challenges that shape their own operational reality. Thus, in the following sections, we provide details on the interests and responsibilities of the stakeholders in each tier of the value chain.

### 4.1 Description of the Value Chain

The core value chain is shown in Figure 4-1. In the first tier, the **Cartographic and Geological Institute of Catalonia (ICGC) - the service provider** - is providing access to their maps and time-series data of the critical parameters indicating ground subsidence due to aquifer extraction.

The **Catalan Water Agency (ACA) - the primary user** - is using the information generated by ICGC for decision making and compile reports on underground water patterns in their region, so fulfilling their mission.



**Figure 4-1 The value chain for aquifer monitoring in Catalonia**

In tier 3, **the municipalities and water utilities** benefit from better water allocation at the Catalan region level. They also use information generated by the ACA to make decisions regarding water use and allocation.

These decisions, empowered by the information provided through ICGC, enable a host of benefits for **citizens and society** at large, occupying tier 4 of the value chain.

Outside the core value chain, there are also lots of benefits for biodiversity and ecosystems.

## 4.2 The Actors

### 4.2.1 Tier 1: ICGC

The ICGC, (Institut Cartogràfic i Geològic de Catalunya) is the Cartographic and Geological Institute of Catalonia. It is a public entity under the Catalan Government created in 2014 from a merger of the Cartographic Institute of Catalonia (ICC) and the Geological Institute of Catalonia (IGC). The ICGC's primary mission is to develop, disseminate, and manage geographic and geological data to support various governmental, societal, and environmental needs. The ICGC has 270 employees.<sup>51</sup>

The ICGC provides rigorous and quality information on the territory to address the challenges of our society such as climate change, risk and natural resource management, sustainable development or energy transition.

It is organized into several key departments: Cartography and Mapping, responsible for producing and updating various maps; Geodesy and Positioning, which manages geodetic networks and accurate positioning services; Geology and Natural Hazards, focused on assessing and mitigating geological risks; Data Management and Services, ensuring the storage and dissemination of geospatial data.

The ICGC is globally recognized for developing numerous innovative products and services - for which they won various awards. For example, one of their key projects, which started in the year 2008 is to manage **water resources and anticipate potential floods** using a combination of **LiDAR and aerial photography**. Such method allows to accurately measure snow thickness across large areas. This approach involves conducting flights over snow-free terrain to establish a reference model and subsequent flights over snow-covered terrain to calculate differences.<sup>52</sup>

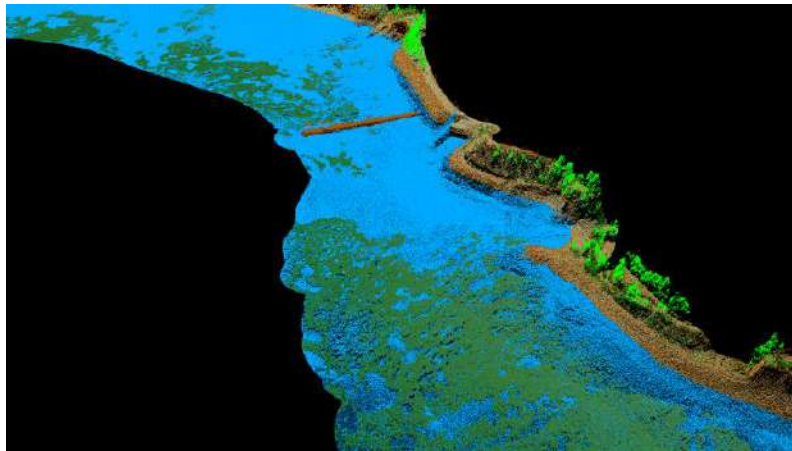
For another project, they are working on the **mapping the Catalan coast using airborne Lidar bathymetry**. As part of a Catalan government initiative to enhance marine environment management, the ICGC uses airborne Lidar bathymetry (ALB) to survey the Catalan coastal zone. This effort produced a precise and detailed topobathymetric elevation model, which serves as a foundational tool for effective coastal zone management (See Figure 4-2).<sup>53</sup>

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<sup>51</sup> Sourced from ICGC

<sup>52</sup> <https://www.icgc.cat/en/Innovation/Custom-projects/Water-resources>

<sup>53</sup> <https://www.hydro-international.com/content/article/mapping-the-catalan-coast-using-airborne-lidar-bathymetry>



**Figure 4-2 Topobathymetric elevation of the coastal zone in Catalonia<sup>54</sup>**

The ICGC has also developed its own interferometric processing chain to obtain ground motion measurements, with images from the **Sentinel-1A/B** satellites. These measures can be used in a wide range of cases, which include the maintenance of infrastructures, the monitoring of aquifers or the monitoring of landslides and underground mining.

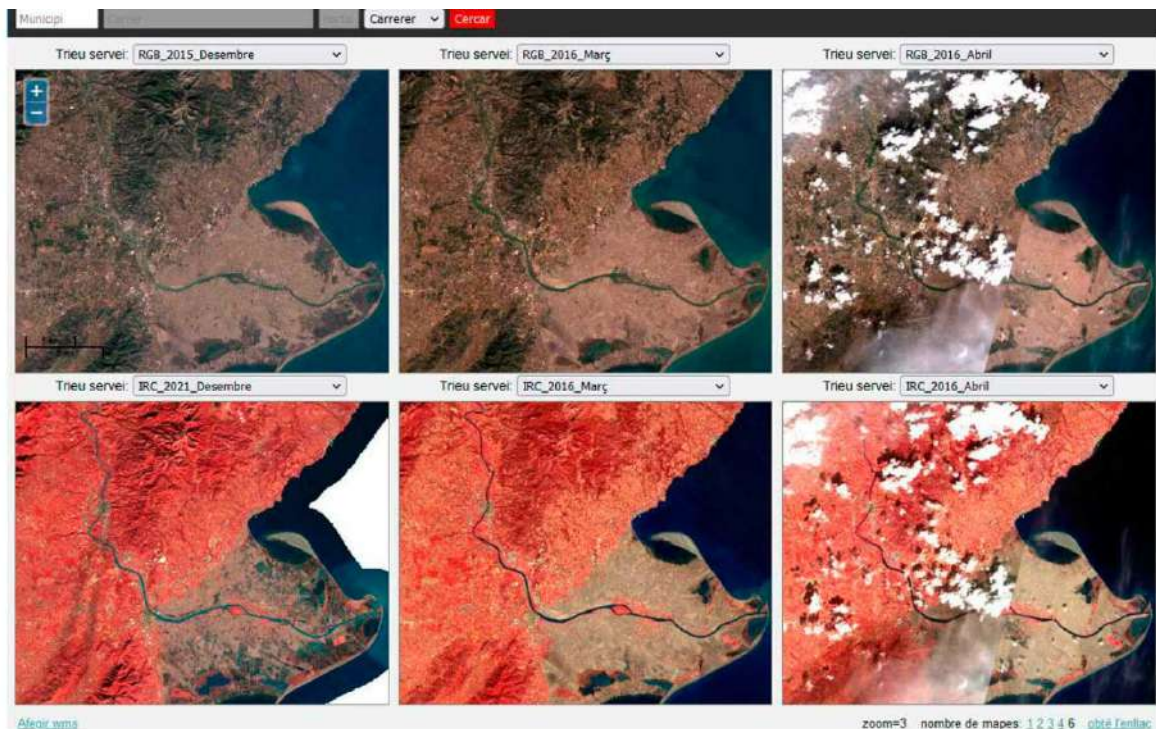
These measurements are also available in their new **Ground motion measurements service viewer (available on the ICGC website<sup>55</sup>)**. The viewer allows to choose the reference measurements, select the area in which people want to carry out the analysis by place name, load different background base maps, view time series of measured points and perform different visualization operations.

Earth Observation department of ICGC develop the DINSAR techniques to obtain temporal series of ground deformation (based on Sentinel-1), that will be analysed by the geologists of ICGC to determinate the risk equation associated. In case of deformations associated to groundwater exploitation, the analysis and assessment is done by ACA which can mitigate such risk.

They also develop many services and products based on Sentinel-2 which they share to the general public on their own website. As an example, monthly satellite image coverage of Catalonia is generated and published, which are continuous mosaics of monthly images captured by the Sentinel-2 satellite (See Figure 4-3).

<sup>54</sup> <https://www.hydro-international.com/content/article/mapping-the-catalan-coast-using-airborne-lidar-bathymetry>

<sup>55</sup> <https://www.icgc.cat/en/Thematic-areas/Territori-sostenible/Sostenibilitat-urbana/Observacio-de-la-Terra/Ground-movement-measurement-service>



**Figure 4-3 Orthoimages generated by ICGC from Sentinel-2 data<sup>56</sup>**

#### 4.2.2 Tier 2: ACA

The Catalan Water Agency (ACA) is the public company of the Government of Catalonia that is responsible for the planning and management of water in accordance with the basic principles of the Water Framework Directive. Created in 2000, the objective of the ACA is to guarantee, now and in the future, the supply, availability and quality of water at the source (groundwater and surface water). The Catalan Water Agency arose from the merger of three entities: the Sanitation Board, the Water Board and the General Directorate of Hydraulic Works.<sup>57</sup>

The ACA is financed through the water fee, a tax that is applied to the water bill. The tax accounts for approximately 30% of the water bill and contributes to more than €400 million/year to guarantee activities and investment, as well as the operation and replacement of water cycle infrastructure. Since 2011, the Agency has applied the social tariff of the water fee, a measure aimed at the most vulnerable groups. There is also an extension of the fee brackets, a measure to reduce the fee in homes with 4 or more members.<sup>58</sup>

To reach its objective, the ACA has several competencies. These include (for the internal basin):

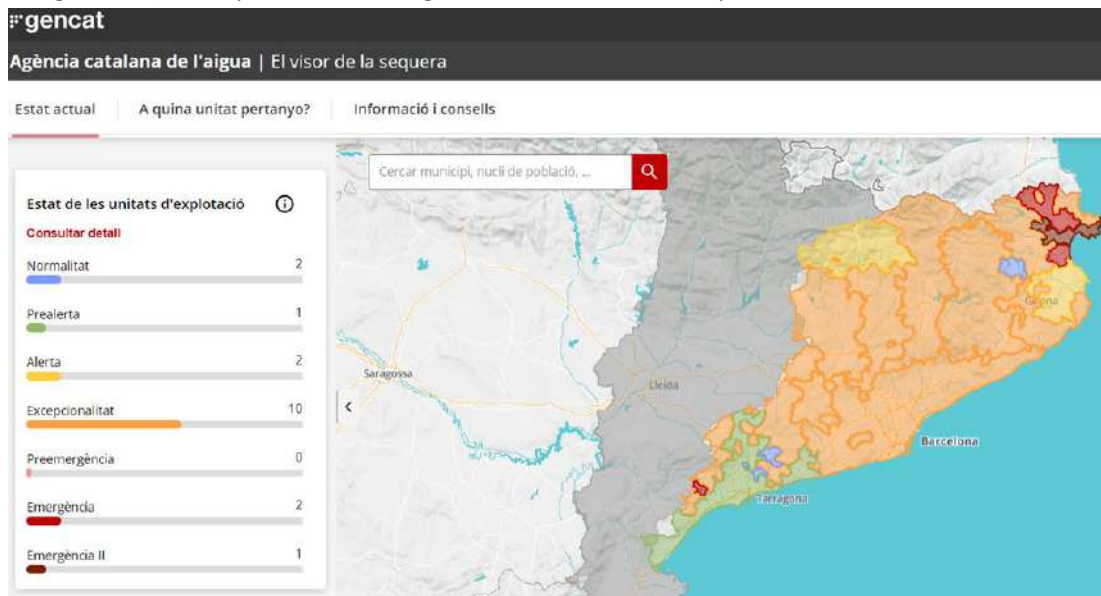
<sup>56</sup> <https://www.icgc.cat/ca/Ambits-tematics/Observacio-de-la-Terra/COPERNICUS-i-SENTINEL-2-Geoserveis-sobre-el-territori>

<sup>57</sup> <https://aca.gencat.cat/ca/laca/sobre-laca/>

<sup>58</sup> [https://aca.gencat.cat/web/.content/10\\_ACA/J\\_Publicacions/02-publicacions/02\\_fulleto\\_ACA\\_institucional.pdf](https://aca.gencat.cat/web/.content/10_ACA/J_Publicacions/02-publicacions/02_fulleto_ACA_institucional.pdf)

- Developing and revising hydrological plans and projects, as well as monitoring their progress.
- Facilitating the promotion, construction, and operation of hydraulic works under the regional jurisdiction.
- Wastewater treatment and water supply (outside the municipal scope).
- Ensuring the monitoring of both water quality and quantity.
- Managing and allocating financial resources in accordance with water legislation and budget preparation.
- Granting, managing, and overseeing water use concessions
- Enforcing the police authority over the “Hydraulic Public Domain” and its influence zones.
- Supervising, inspecting, and planning water distribution and allocation in the Ter-Llobregat network, collaborating with local entities.
- Administering and recording surface and groundwater abstractions.
- Promoting water-related entities and associations.
- Gathering necessary information from individuals and legal entities for exercising competencies.
- Determining flood zones areas and proposing limitations to ensure safety for people and property.<sup>59</sup>

The ACA has also a communication platform on its website<sup>60</sup> to inform citizens about the drought status and water availability in the region based on piezometric level of aquifer and reservoirs level (See Figure 4-4). It helps citizens to regulate their own consumption.



**Figure 4-4 Drought information on ACA website<sup>61</sup>**

<sup>59</sup> Sourced directly from the Catalan Water Agency

<sup>60</sup> <https://aplicacions.aca.gencat.cat/visseq/estat-actual>

<sup>61</sup> <https://aplicacions.aca.gencat.cat/visseq/estat-actual>

### The co-creation story between ACA and ICGC

The ICGC and the ACA are both keen to develop innovative approaches to monitor water quantity and quality. They also recognized the importance of modernizing conventional approaches by integrating satellite and other advanced technologies and understood the important impact such innovations could have on water management.

Being EO champions is not the only ingredient in such successful collaboration, as Jordi Corbera (ICGC) stated: *“we can achieve the greatest product in terms of technical feasibility and cost viability, but, if it is not useful to ACA due to time, regulation or other practical constraints, it won’t be of any use”*. Such statement highlights the importance of **creating and testing the product together** with the user.

In 2020, the two entities decided to develop four pioneering projects using EO technology. These initiatives span water quality monitoring in lakes, invasive species in rivers, coastal water surveillance and aquifer monitoring.

With regard to aquifer monitoring, the creation of the application encompasses five important steps. These five steps constitute a systematic and iterative process aimed at understanding, monitoring, and managing ground subsidence resulting from groundwater exploitation.

#### Step 1: Lithology Selection

This initial phase focus on identifying geological formations prone to subsidence as a result of groundwater exploitation. More specifically, sedimentary lithologies with low to medium hydraulic permeability are targeted (such as Neogene formations). These formations are subject to compaction and deformation when groundwater is extracted, leading to subsidence. Conversely, bedrock lithologies are excluded due to their inherent stability. Moreover, areas exhibiting significant downward piezometric pressure gradients are prioritized for further investigation. It ends up with the following selection below.

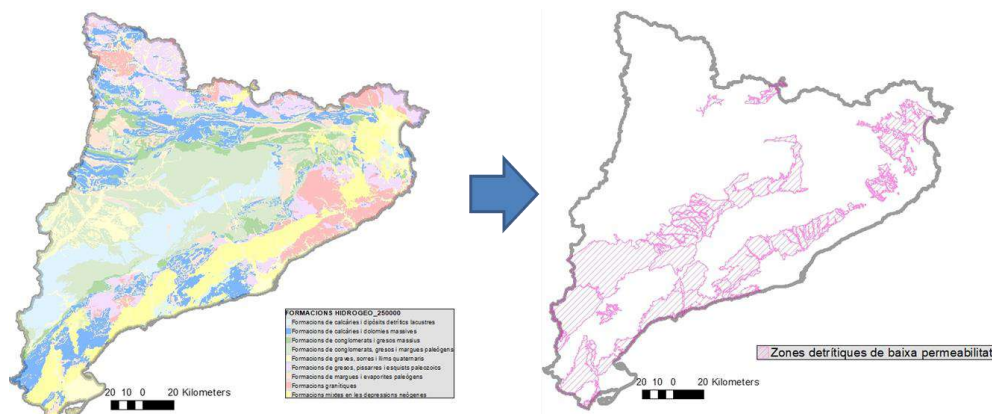


Figure 4-5 Lithology selection process<sup>62</sup>

#### Step 2: Active Deformation Areas’S SELECTION

<sup>62</sup> Figure sourced from the Catalan Water Agency

Building upon the lithological analysis, this step involves identifying regions experiencing active subsidence which are called Active Deformation Areas (ADAs). These areas show substantial decreases in ground levels, typically ranging from 20 to 50 centimetres, with observed interannual or seasonal fluctuations (which are usually good candidate for ground subsidence due to aquifer exploitation as the cyclical trend shows down lift movement during summer when more water is needed).



Figure 4-6 ADA's areas selection<sup>63</sup>

### Step 3: Groundwater Wells Selection

This step consists of identifying groundwater wells with the highest likelihood of contributing to subsidence. These wells are characterized by high-volume extraction as well as the ones exceeding certain depth thresholds. Drinking water wells, typically exceeding depths of 75 meters, along with industrial or agricultural wells going beyond 100 meters could lead to significant subsidence. Additionally, wells with depths exceeding 150 meters are also selected.

<sup>63</sup> Figure sourced from the Catalan Water Agency

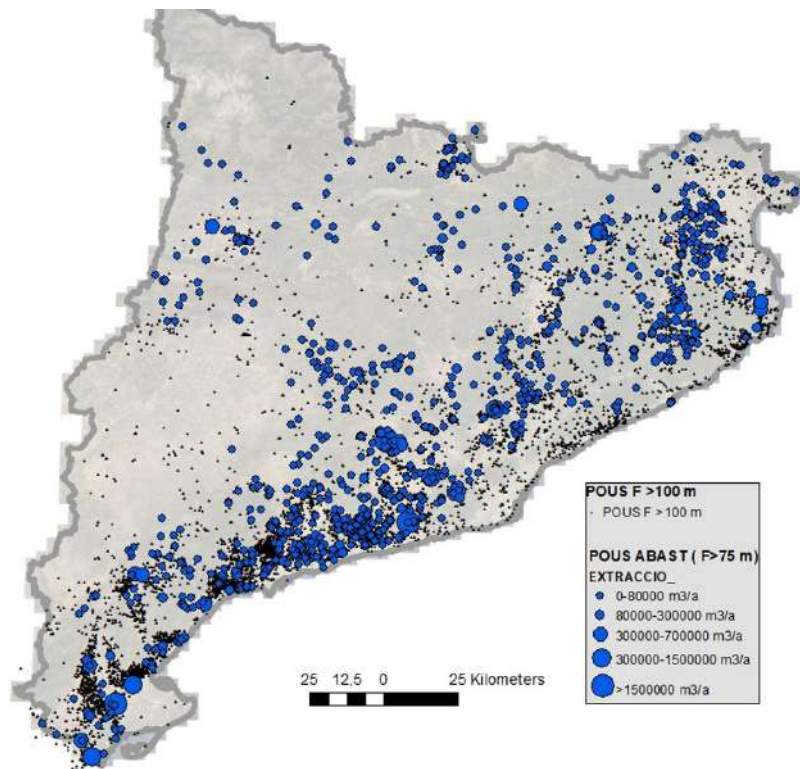
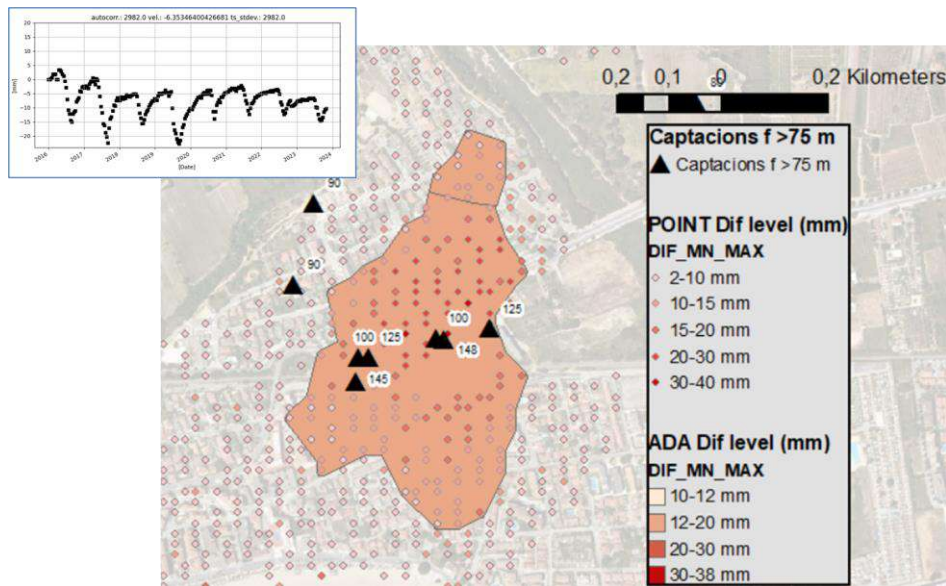


Figure 4-7 Groundwater wells selection<sup>64</sup>

*Step 4: Identification of Causal Factors of ground subsidence*

The phase integrates the information gathered from the preceding steps. By overlaying data on lithological susceptibility, identified ground subsidence (ADAs), and relevant groundwater wells, the ACA aims to discern patterns and correlations. In this framework, **seven cases** were identified and studied in dept in 2023.

<sup>64</sup> Figure sourced from the Catalan Water Agency



**Figure 4-8 Identification of causal factors of ground subsidence**

*Step 5: Inspection and Concessionary Tasks*

The final step involves **on-the-ground inspection** of concessional rights. This includes the identification of wells and the assessment of groundwater exploitation regimes (annual volume, seasonality of flow rates). Consequently, potential **modifications to concessionary rights** may be considered.

All in all, this collaboration has reached **successful outcomes** as a **strong correlation between subsidence (measured with Sentinel-1) and groundwater abstraction** has been detected. However, although this iterative process is promising, it is not always successful as there are some cases of subsidence that are not linked with groundwater abstraction and other cases where wells are not identified (e.g., illegal wells).

The next step is therefore to extend the process at a **larger scale** with many more cases.

In these case studies, Sentinel-1 data together with in-situ data allowed to (1) get information and **act on subsidence problems** that are due to groundwater exploitation, (2) **improve knowledge and management of concessional rights** (non-compliance, updates of rights, prevent from potentially harmful new concessions and detection of illegal wells) and (3) provide additional indicator for assessing the **quantitative status of groundwater bodies**, as outlined in Directive 2000/60/CE (Water Framework Directive).

Now that it has been shown successful for seven cases, the next step is to extend such process to many more cases in Catalonia.

It is also worth noting that such collaboration between ICGC and ACA has led to several other applications aiming at better monitoring water quality and water quantity in Catalonia.

One of these projects involves the quality of biophysical parameters in **coastal waters** along Catalonia's extensive and touristic coastline spanning 300 kilometres. Using Sentinel-2 satellite

imagery, the ICGC runs different models to analyse parameters such as chlorophyll-a (chl-a), turbidity, and transparency which allow to analyse surface/coastal water discharges and the consequences.

Another application involves analysing NDVI (Normalized Difference Vegetation Index) in relation to water quality in reservoirs and other water bodies, focusing on indicators like chlorophyll levels and algal blooms to maintain and improve water quality.

A last significant application derived from sentinels involves monitoring **invasive species in rivers**, particularly after heavy storms or river collapses. The ACA utilizes Sentinel-2 together with hyperspectral imagery from planes. This enables to locate invasive species and assess their impact on river ecosystems. The extensive coverage provided by Sentinel-2 is essential for monitoring large river systems. By employing techniques like Image Cross-Validation (ICV), the ACA can effectively identify and mitigate the impact of invasive species, which often disrupt river flow and degrade natural habitats.

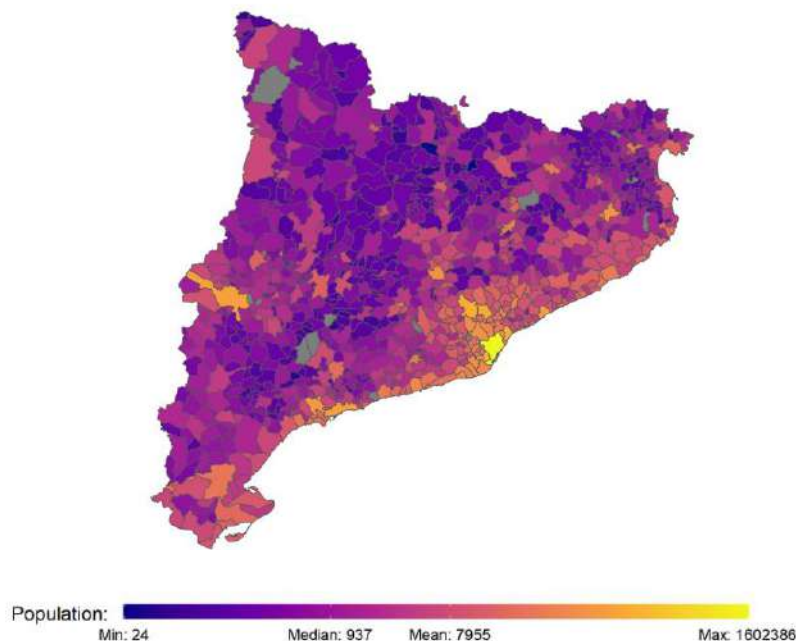
#### 4.2.3 Tier 3: Municipalities and water utilities

Since 2018, Catalonia is divided into 947 **municipalities**. Each municipality typically includes one main urban settlement, ranging in size from a village to a city, along with its surrounding land.<sup>65</sup> Municipalities are responsible for providing residents with access to clean and reliable drinking water. In some areas, excessive withdrawal of groundwater has led to a decline in water levels. Municipalities must manage demand and promote water-saving practices to mitigate this issue. Municipalities also need to implement strict pollution control measures and regular monitoring to protect water quality. There are also groups of municipalities on a same thematic such as the **Water Cycle Management Consortium (Consorci per a la Gestió del Cicle Integral de l'Aigua)** which includes multiple municipalities working together to manage water resources holistically, including groundwater.<sup>66</sup>

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<sup>65</sup> [https://en.wikipedia.org/wiki/Municipalities\\_of\\_Catalonia](https://en.wikipedia.org/wiki/Municipalities_of_Catalonia)

<sup>66</sup> <https://www.giacsa.com/>



**Figure 4-9 Municipalities in Catalonia<sup>67</sup>**

**Water utilities** are responsible for the distribution of water from the source (e.g., rivers, reservoirs, and pipelines) to end-users, including households, businesses, and industries. They operate under the water management plan set by the ACA, ensuring sustainable water use. ACA aggregates and analyses the data received from local water utilities and ensures that regional water management practices comply with both regional and national regulations, as well as with the Water Framework Directive (WFD). It then reports this aggregated data, along with its own findings and assessments, to the national authorities. There are several **water utilities** in Catalonia which operate within specific geographical areas or municipalities, often under long-term concession agreements or public service contracts.

Water utilities must efficiently manage water resources to meet the demand of households, businesses, and industries. This involves managing supply and demand. They must also comply with a range of regulations regarding water quality, environmental protection, and resource management. Compliance requires ongoing monitoring, reporting, and infrastructure investments. The largest one is Aigües de Barcelona covering 23 municipalities in the Barcelona metropolitan area, serving over 3 million people.<sup>68</sup>

In addition, **interregional committees** that manage water resources in the Ebro basin and its transfers to other regions often include a variety of stakeholders, such as water utilities and municipalities (as well as regional and national authorities), to ensure comprehensive and effective governance.

<sup>67</sup> [https://en.wikipedia.org/wiki/Municipalities\\_of\\_Catalonia](https://en.wikipedia.org/wiki/Municipalities_of_Catalonia)

<sup>68</sup> <https://www.aiguesdebarcelona.cat/ca/estat-actual-sequera>

#### 4.2.4 Tier 4: Citizens & Society

As seen many times in this study, agriculture, citizens and industry use groundwater in Catalonia. It is worth reminding the main figure showing the respective percentages of who uses groundwater in the inner basin (See Figure 4-10).

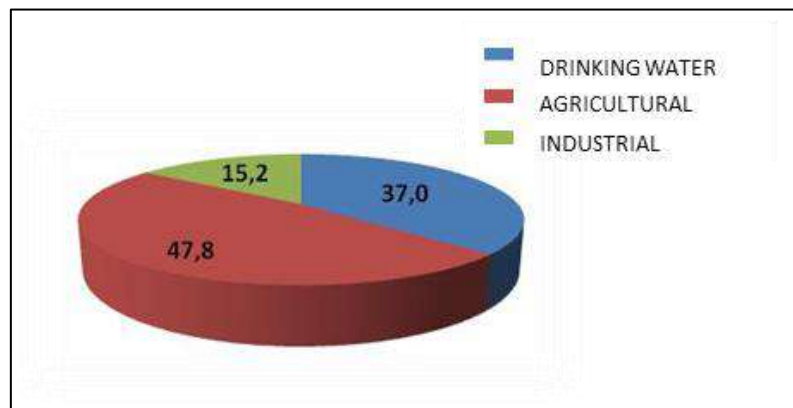


Figure 4-10 Groundwater use in the Inner Basin

**Citizens** are by nature dependent on the reliable and safe supply of water. First of all, the supply of drinking water is obviously an important aspect of water and aquifer management in the region. Secondly, the proper and sustainable management of the water resources and groundwater is indispensable for the wider economy in the region since tourism and other sectors generate important revenues and relies on a stable water supply.

On top of that, **citizens** and the wider public have an interest in the sustainable management of the aquifers since **land subsidence and ground deformation (causing damages, such as cracks, on buildings and other infrastructures)** associated to aquifer over-exploitation can cause considerable economic damage to the inhabitants.

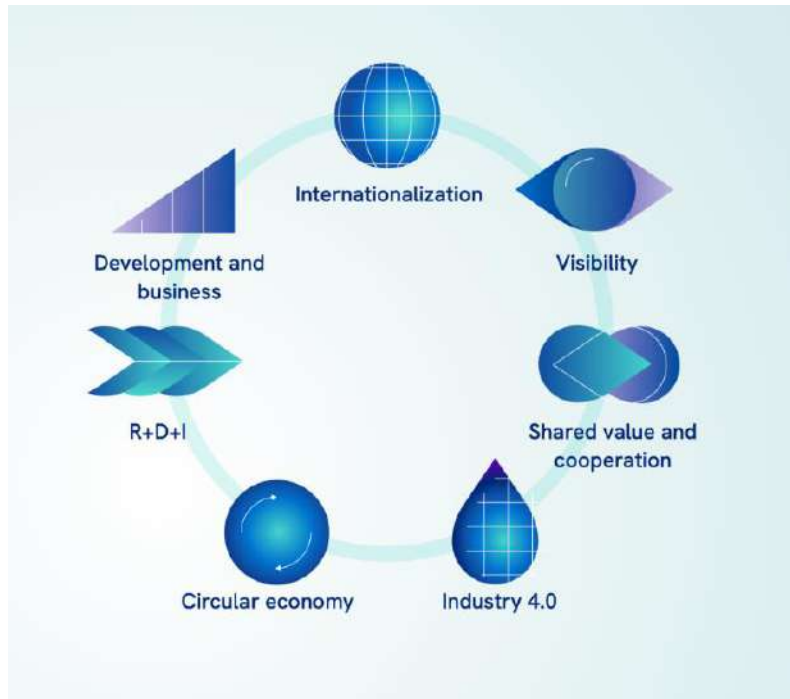
With regard to the **industry**, many businesses highly depend on water and some of them put water as the centre of their business. The **Catalan Water Partnership** represents such industries. It is a non-profit strategic association, formed by companies and knowledge centres that operate in the sector of sustainable water use, which has the mission of improving the global competitiveness of its associates. Some of their member associations are the [SMARTH2OTEL](https://cwp.cat/projectes/smarth2otel/)<sup>69</sup> project which aims to study and develop digital and innovative solutions for the efficient and sustainable management of the water cycle in tourist establishments. Meanwhile, the [ViWaTec](https://cwp.cat/en/projectes/viwaterc-3/)<sup>70</sup> project focuses on promoting technological solutions and other innovative strategies to improve water use efficiency in the wine sector. Additionally, the [Cosme Water Footprint](https://www.iagua.es/noticias/catalan-water-partnership/cosme-water-footprint-calculara-huella-hidrica-organizacional)<sup>71</sup> project, across its three phases, aims to develop

<sup>69</sup> <https://cwp.cat/projectes/smarth2otel/>

<sup>70</sup> <https://cwp.cat/en/projectes/viwaterc-3/>

<sup>71</sup> <https://www.iagua.es/noticias/catalan-water-partnership/cosme-water-footprint-calculara-huella-hidrica-organizacional>

a tool for calculating the organizational water footprint and the water footprint of products in the cosmetic sector.<sup>72</sup>



**Figure 4-11 Projects and activities of the Catalan Water Partnership**

Finally, the **agricultural sector**, which is the largest user of water globally and in Catalonia, represents an important part of the economic activities in Catalonia. Farmland corresponds to 36% of the Catalan territory, with nearly 61.000 farms<sup>73</sup> and agricultural exports representing 15.2% of the total of Catalan exports in 2023.<sup>74</sup> Below are some additional statistics about the agri-food sector in Catalonia.

<sup>72</sup> <https://cwp.cat/en/home/>

<sup>73</sup> <https://www.accesstoland.eu/Background-Agriculture>

<sup>74</sup> <https://www.accio.gencat.cat/web/.content/banconeixement/documents/pindoles/ACCIO-el-sector-agroalimentari-a-catalunya-en.pdf>

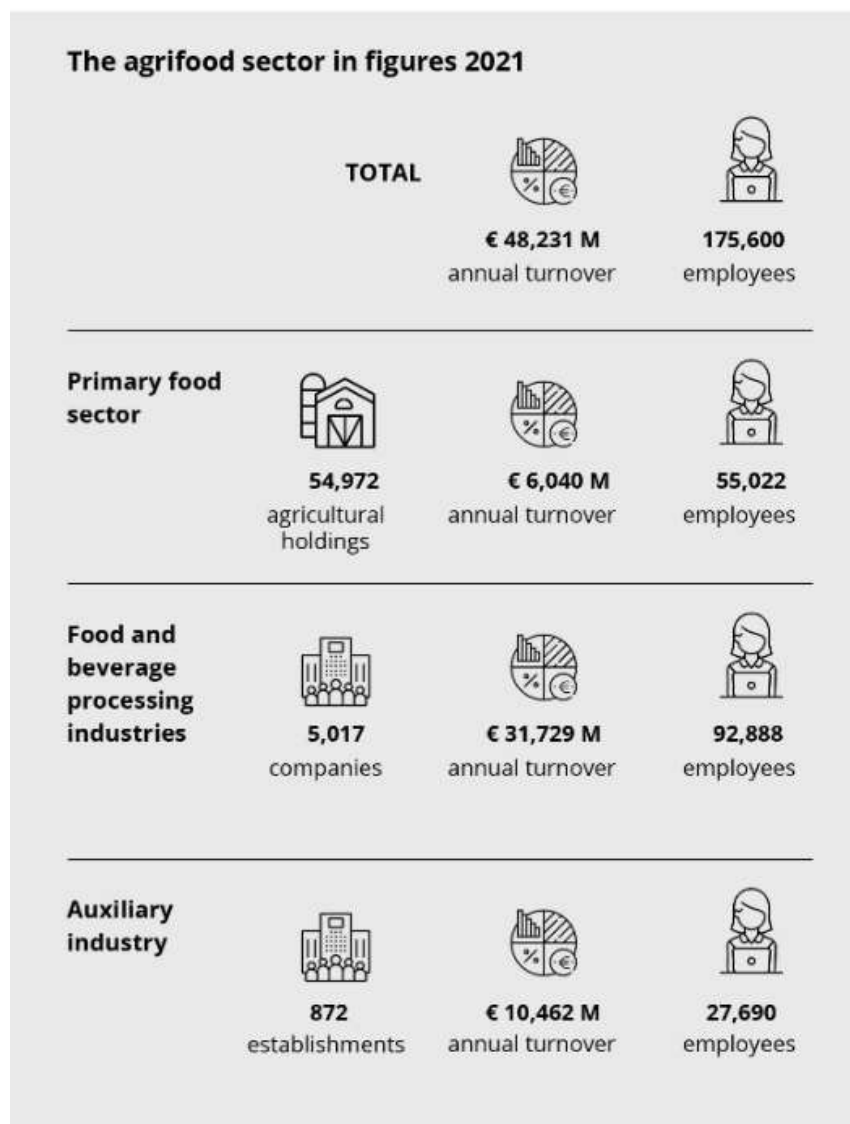


Figure 4-12 The agrifood sector in Catalonia<sup>75</sup>

The agricultural sector suffers from aquifer over-exploitation through salinization of the aquifer and water shortage. **Salinization** has important negative effects on crop yields, soil health, production costs and crop diversity. Addressing this issue requires sustainable water management practices, investment in technology to mitigate salinity, and policy measures to prevent overexploitation of groundwater resources. **Water stresses** resulting from aquifer overexploitation have more obvious consequences on agricultural productivity, leading to reduced crop yields, higher production costs, etc. Additionally, **overexploitation through illegal wells** during times of water shortage can exacerbate the above issues and **distort the market**, creating unfair competition. This issue has

<sup>75</sup> <https://www.prodeca.cat/en/sectors/the-catalan-agri-food-sector#:~:text=Catalonia%20in%20figures&text=The%20agri%2Dfood%20sector%20generates,and%20directly%20employs%20177%2C031%20people.>

significant societal and economic impacts and necessitates comprehensive regulatory measures to ensure equitable water distribution and market fairness.

#### 4.2.5 Other Beneficiaries

**Groundwater-Dependent Ecosystems** (or GDEs) are ecosystems that rely upon groundwater for their existence. These places include springs and seeps, caves and karst systems, and deep-rooted plant communities (phreatophytes). A large number of GDEs can be identified and classified as : (1) terrestrial vegetation and fauna that have seasonal dependence on groundwater; (2) ecosystems dependent on river streams that are eventually fed by groundwater; (3) aquifer and cave ecosystems; (4) wetlands and lakes that are mainly fed by aquifers' water; and (5) estuarine and coastal lagoons that depend on the discharge of groundwater floods.<sup>76</sup> **Many species** depend on habitats maintained by groundwater discharge. They add to the ecological diversity of a region and can be indicators of the overall biological health of a system. Some plants and animals that depend on groundwater are rare, unique, or threatened.<sup>77</sup>

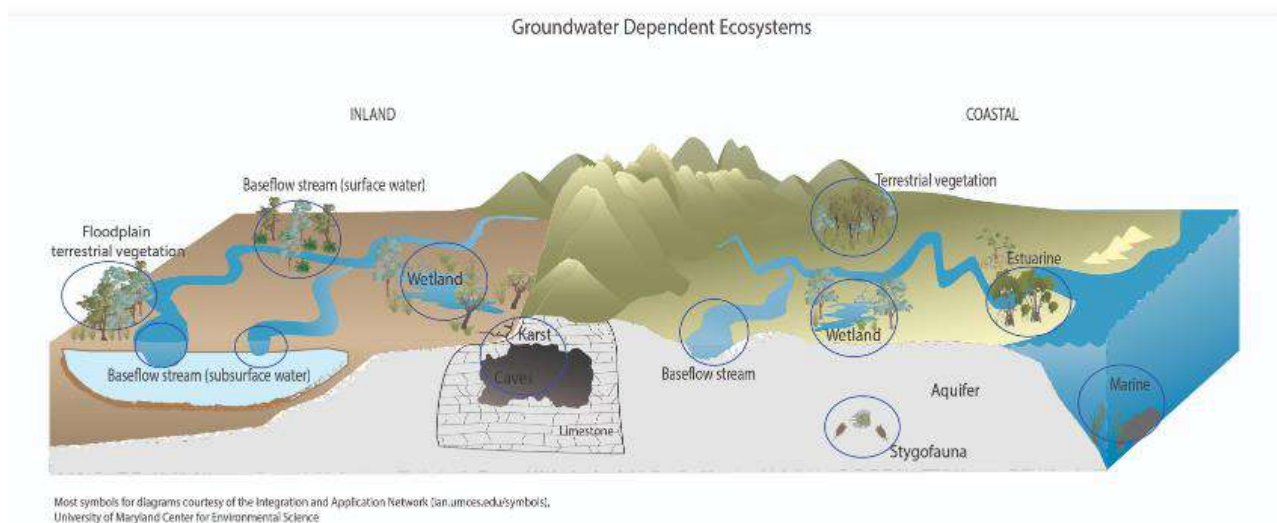


Figure 4-13 Groundwater dependent ecosystems<sup>78</sup>

<sup>76</sup><https://www.sciencedirect.com/science/article/pii/S0022169421009239>.

<sup>77</sup> <https://www.fs.usda.gov/managing-land/natural-resources/geology/groundwater/groundwater-dependent-ecosystems#:~:text=What%20are%20Groundwater%20Dependent%20Ecosystems,and%20lakes%20are%20also%20included.>

<sup>78</sup> <https://water.dpie.nsw.gov.au/our-work/science-data-and-modelling/surface-water/environmental-outcomes-monitoring-and-research-program/groundwater-dependent-ecosystems#:~:text=When%20large%20amounts%20of%20groundwater,of%20agriculture%20and%20urban%20development.>

## 5 Assessing the benefits

Having identified the effects of the Sentinel-enabled water monitoring service across subsequent tiers of the value chain, we can now delineate the various types of benefits generated through its utilization. This section seeks to quantify the financial value attributable to the availability of the service and to identify associated environmental and regulatory benefits. Additionally, we explore other potential social or scientific impacts that may be traceable as a result of the service's implementation. In this regard, it is useful to recall our value chain picture whilst adding the last two layers to it (See Figure 5-1).

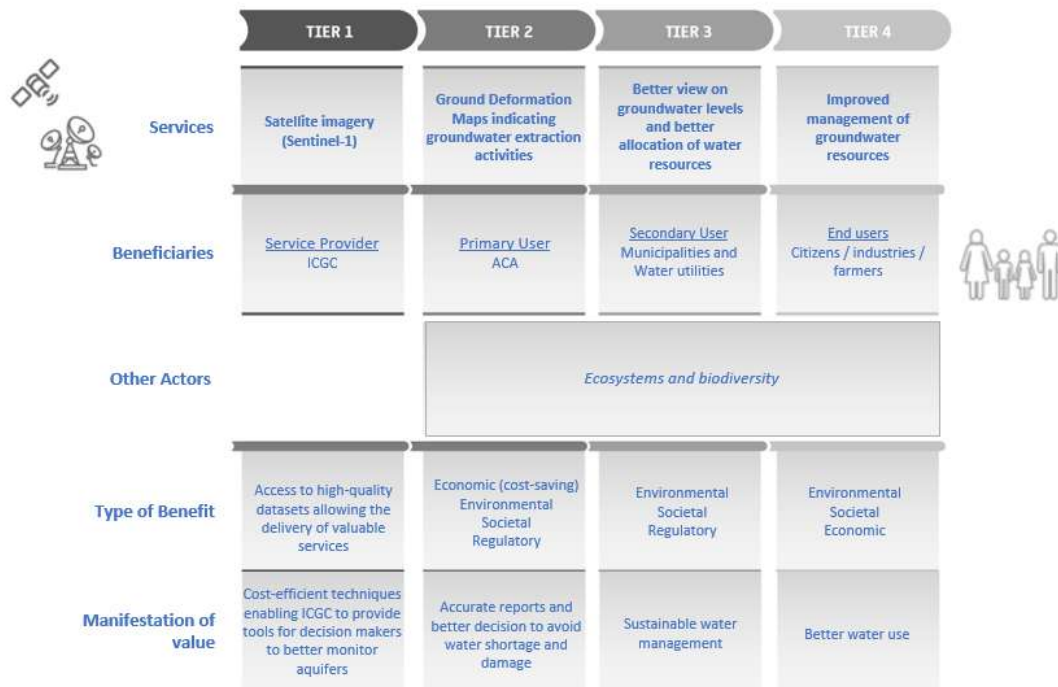


Figure 5-1 Benefits along the value chain

### 5.1 Overview

Before we dive into the discussion for each of the tiers it is instructive to make some high-level observations:

#### 1. Current benefits versus long term benefits of EO

Benefits deriving from the use of Sentinel EO data, are being seen today in a few cases but are likely to be much higher in the future. There are several reasons behind this:

- The strategy of the ACA and ICGC in this case is to start with a few trials and to extend the service in the future.

- Incorporating EO measurements for ground movement monitoring in the case of aquifer management requires significant resources and time. Although the ACA is interested in using new technologies, integrating EO data into daily operations is a long process.
- Additional tools, such as irrigation monitoring through Sentinel-2, currently in early stage of development, could be highly beneficial to water management in general.
- While water management becomes more efficient thanks to EO, actions for better water allocation (e.g. changing concession rights) also need to be taken afterward. When these actions are taken, it also takes time to observe the benefits.

## 2. Attribution to sentinel data

In most of the previous cases which have been analysed, we face the issue of attribution, i.e. how much of the economic benefit is due to the use of the data from Sentinel satellites. In the case of water monitoring in Catalonia, the ICGC service is based only on data only from Sentinels. Unlike previous cases where data from other Earth Observation platforms is also used as own airborne hyperspectral and LiDAR sensors, in this case, we shall take 100% of the benefits from EO as being due to the use of the data coming from the Sentinels.

## 3. Putting a Value on Nature

As this case refers to environmental factors, how much we should even attempt to place a monetary value on the benefits. In principle at least, every benefit can be translated into a financial one through different forms of analysis. In practice, it is often difficult to place a financial value on environmental benefits such as clean air or in this case water availability, maintaining a rich flora and fauna as well as good quality of life and culture.

These high-level observations will be echoed in discussion of the economic value and other types of benefits arising from the use of Sentinel data in each tier. These analyses have been generated thanks to the insights collected directly by the value chain actors and subsequent extensive research.

## 5.2 Benefits along the Value-Chain

### 5.2.1 Tier 1: ICGC

There are two ways in which we can quantify the economic added value at the service provider level as a direct result of using Sentinel data:

- 1) Quantifying the economic added value associated with the number of workers employed by ICGC and whose employment can be directly tied to the utilisation of Sentinel data in monitoring underground water monitoring in Catalonia. In this regard, ICGC development currently provides work for two part-time personnels.<sup>79</sup>

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<sup>79</sup> For confidentiality reasons, we will not develop further in monetary terms.

- 2) Additional resources received by the Department of Research & Development projects linked to groundwater monitoring (e.g., Horizon 2020, HEU, ESA and other national R&D fundings). As an example, external funding available for 2023 represented about 250 hours of expert time for underground water quality related projects and budget funding.

Beyond the economic aspects, it is important to note that ICGC contributes greatly to the EU's **innovation** and entrepreneurial landscape thanks to their innovative use of Sentinel data to develop highly valuable and cutting-edge software and services. Other EU stakeholders might be inspired to develop such projects in their own country, a process further supported through ICGC's participation in R&I projects.

Furthermore, by having access to such rich data, ICGC together with other researchers can improve their **research**. ICGC is deeply involved on the use of EO data, from satellite or airborne sensors, especially through the use of innovative Artificial Intelligence architectures. As key researchers in that domain, they contribute to the global research by publishing scientific papers. For example, one of their last works involved an **innovative approach on the use of active sensors**: "*Effective Training and Inference Strategies for Point Classification in LiDAR Scenes*"<sup>80</sup> published in the *Remote Sensing* journal. With regard to the use of Sentinel data, the ICGC is deeply involved in the monitoring of forest status and evolution of resilience landscape by using Sentinel-2 in the context of the European Green Deal project FIRE-RES.<sup>81</sup>

### 5.2.2 Tier 2: ACA

The primary user of ICGC's service, the Catalan Water Agency, obtains a host of free data and observations which are very useful for their groundwater monitoring process. ICGC data offers quantitative status assessment which covers the entire territory with observations every six days on average. It also enables the monitoring of much more surface than would be possible using traditional in-situ measurements. Additionally, EO data allows for historical analysis of ground movement trends, providing valuable insights into groundwater extraction patterns.

This availability of free data from earth observation represents a great source of information **complementing the in-situ monitoring network** (see figure 2-14). In the near future, when the service reaches full-scale deployment, it will allow the ACA to have a better view on the exploitation of groundwater as well as subsidence problems due to extraction. It in turn allows the ACA to prioritize and optimize its monitoring efforts more effectively, which may consequently lead to better allocations of these groundwater resources.

Currently, ACA monitors groundwater levels at 500 sites, with an annual budget of approximately €500K for monitoring groundwater quantity and quality, including chemical parameters. The cost specifically for monitoring groundwater quantity is €250-270K/year, broken down as follows: **data acquisition**: €120K/year, **construction of new piezometric control levels**: €100K/year, **sensor level**

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<sup>80</sup> <https://www.mdpi.com/2072-4292/16/12/2153>

<sup>81</sup> <https://fire-res.eu/>

**data transmission:** €30-50K/year (including sensor price annual amortization, maintenance, and data transmission).<sup>82</sup>

While Sentinel data cannot directly measure groundwater levels, it can provide indirect indicators that help prioritize areas for more intensive monitoring. More specifically, ground movement data from EO can identify areas with potential subsidence problems, allowing ACA to optimize its in-situ monitoring efforts by focusing on critical areas. The ACA may then increase the frequency of groundwater level measurements or construct new piezometric sites in identified areas of concern.

Despite ACA's extensive network of 500 sites for groundwater levels monitoring, climate change and increasing droughts require better monitoring tools. We hypothesize that this gap could be filled either by using EO tools or adding more piezometric stations. Assuming no EO tools are used in this context of climate change, ACA might need 50 to 150 new monitoring sites, representing 10% to 30% of the current network. Each site costs €500 annually, requiring an additional budget of **€25K to €75K per year**. By using Sentinel data, these costs could be offset through efficiency gains, allowing ACA to monitor more critical areas without significantly increasing the budget.

In addition, by better managing water resources thank to Sentinels data, the ACA could **save cost from investing less in alternative water sources** such as recycled water and desalination plants.

Beside the above costs, the ACA also experiences **regulatory benefit** as Sentinel-based observations offer additional proof of adherence to the relevant provisions under the EU WFD. These benefits could increase in the future, when EO measurements will enter into regulatory frameworks.

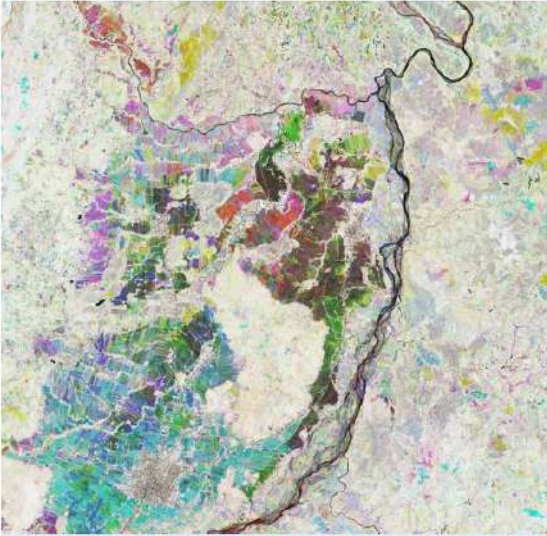
Ultimately, such innovative product provides more **visibility to ACA** activities which in turns impacts positively the general public awareness on water use (and reduce its consumption) which allows the ACA to better manage the overall water quantity. It also leads to other non-economic benefits such as a better reputation or improved trust through transparency. Furthermore, with this innovation, ACA is increasing its knowledge which may produce further benefits in due course. Overall, it improves ACA's capability to be recognised as a true centre of excellence. Below is an example of article enhancing ACA's reputation and visibility.

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<sup>82</sup> Information sourced from the ACA

**Catalonia presents a success story on the use of satellite data at the European Parliament**

Oct 26, 2023



**Caption:** This Copernicus Sentinel-2 false-colour image shows the Nueva Vizcaya Province in the Philippines.  
**Credits:** ESA (CC BY-SA 3.0 IGO)

The [‘Copernicus4regions’](#) debate on the European Union’s Earth observation programme [Copernicus](#) was held yesterday at the European Parliament in Brussels. Organised by [NEREUS](#) (the network of European regions promoting the use of space technologies), the European Commission and the [European Space Agency](#) (ESA), the aim of the session was to highlight the value of the [Copernicus programme for green policies related to climate change adaptation](#).

**Catalonia was one of the three regions chosen to present a success story** in the use of Copernicus data. The delegation from the [Cartographic and Geological Institute of Catalonia](#) (ICGC), headed by its director, **Ms Miriam Moysset**, presented the collaboration that is being carried out with the [Catalan Water Agency](#) (ACA), and that allows for better management and control of aquifers and their exploitation through the detection of ground movements with radar satellite data.

**Mr Josep Colomé**, director of the Area for the Promotion of the Space Sector of Catalonia (APEC), within the [Institute of Space Studies of Catalonia](#) (IEEC — Institut d’Estudis Espacials de Catalunya), participated as a member of NEREUS management board. The IEEC participates in this network on behalf of Catalonia, by delegation of the Generalitat, in the framework of the [NewSpace Strategy of Catalonia](#). The NewSpace Strategy is promoted by the Government of Catalonia with the collaboration of the IEEC, the [i2Cat Foundation](#) and the ICGC.

**Figure 5-2 Article on the website of the *Institute of Space Studies of Catalonia* <sup>83</sup>**

### 5.2.3 Tier 3: Municipalities and water utilities

Thanks to the InSAR measurements and the follow up work done by the ACA and other higher authorities – i.e. ministries, especially the Ministry for the Ecological Transition and the Demographic Challenge who oversees water policy and management at the national level - on water use, municipalities can mitigate damage caused by subsidence due to excessive groundwater extraction. In practice, this means that if a certain well seems to produce too much displacement, it could be shut down or more closely controlled by the ACA. By this means, municipalities are ensured that no damages occur in buildings – a benefit enabled in Tier 3 with the help of the ACA but “felt” in Tier 4 (Citizens and Society).

Additionally, efficient water management done by ACA inevitably helps municipalities to fulfil better their objective of managing demand and promoting water-saving practices. Looking ahead, we can also expect the ACA to share their EO data/imagery with water utilities in order to help water utilities to communicate better to the general public as well as their partners in inter-regional committees about water sustainable use.

<sup>83</sup> <https://www.ieec.cat/en/catalonia-presents-a-success-story-on-the-use-of-satellite-data-at-the-european-parliament/>

Water utilities also benefit from better groundwater management enabled by the ACA’s use of EO data. Improved monitoring and management at the top (from the ACA) inevitably helps water utilities in doing a better work, which translates into optimization of the distribution processes, leading to reduced waste and increased operational efficiency.

#### 5.2.4 Tier 4: Citizens & Society

Sentinel-1 data together with in-situ data allows to

1. Avoid **subsidence problems** that are due to groundwater exploitation. It helps mitigating societal impacts by reducing the risk of fractures in buildings and other infrastructures.
2. **Improve water allocation** by prioritizing essential uses and reducing non-essential ones<sup>84</sup>. This approach supports sustainable water use and quantity through better concessional rights and the avoidance of illegal wells. Maintaining sustainable water levels in aquifers helps prevent saltwater intrusion, which can make water unusable for citizens, industries, and agriculture, and avoids compaction, which reduces the aquifer's overall capacity and long-term groundwater availability.

**Sustainable use of groundwater** resources on the one hand presents many direct and long-term benefits for citizens, farmers and industries as they are all important **consumers** of ground water (as observed on the figure below).

On the other hand, by better managing water resources, fundamental societal aspects of **fairness** and **social cohesion** are addressed. Ensuring that water is distributed fairly helps prevent conflicts and promotes social harmony, as all stakeholders—farmers, businesses, and citizens—have their needs met in a balanced manner.

hm <sup>3</sup> /year	Drinking Water	Agriculture	Industrial	TOTAL
Catalan Inner Basins	175	226	72	473
Ebro Catalan Basins	27	93	8	128
<b>Total</b>	<b>202</b> (34 %)	<b>319</b> (53 %)	<b>80</b> (13 %)	<b>601</b>
<b>% GROUNDWATER OVER TOTAL WATER DEMAND</b>	40 %	15%	30%	21%

**Table 5-1 Different uses of groundwater in Catalonia**

#### Citizens and industry

**Water taxes** are applied to each water bill to finance ACA activities. It represents a total of €400 million/year. Because of last drought, water bills rose by 11.5 %<sup>85</sup>. As Sentinel data allows the ACA

<sup>84</sup> Non-essential uses are for example private swimming pools, golf courses, decorative fountains, illegal wells, etc.).

<sup>85</sup> [https://www.europarl.europa.eu/doceo/document/E-9-2024-000083\\_EN.html](https://www.europarl.europa.eu/doceo/document/E-9-2024-000083_EN.html)

to be more efficient in estimating groundwater quantity in Catalonia, it should inevitably impact the water taxes. While it would be hazardous to precisely quantify the benefits of integrating Sentinel data, we can provide an illustrative example. If the use of Sentinel data allows water bills to lower the rise to 11.4% instead of 11.5% (thanks to better groundwater monitoring and hence better water resources management), **the overall water bill would see a reduction of approximately €400K for the year.**

Additionally, during **drought periods, water use is limited** (see section 2), a better allocation of water resources (thanks to Sentinel data) may help in improving **climate change resilience** as well as **avoiding radical measures** to limit the use - which have important economic and societal impact on the whole population. As an example, in May 2024, the ACA activated the state of *exceptionality* (which is better than the emergency status before, see chapter 2). The exceptional situation makes it possible to have a water supply per inhabitant per day of 230 (vs the 200 litres in emergency situation). The following savings measures are still enforced at the time of writing this study:

- 15% reduction in water consumption by industrial users (in an emergency it was 25%).
- Reduction of water consumption in recreational uses (15% in urban uses and 50% in irrigation).
- The use of water for the irrigation of gardens and green areas of a public or private nature is prohibited (except for the survival irrigation of trees or plants which will be done drop by drop or with a watering can). Municipal irrigation with ground water is allowed only if it does not reduce the availability of water for domestic supply.
- Lawn irrigation is prohibited in all cases, except on surfaces intended for federated sports practice, or that irrigation that is done by reusing rainwater collected from roofs or regenerated water from sewage treatment plants.
- It is forbidden to clean streets, sewers, pavements, facades or buildings with drinking water.<sup>86</sup>

Such water restrictions during drought periods can lead to **significant psychological and societal impacts**. For citizens, these restrictions – especially when combined to extreme heats - can lead to increased stress, anxiety, and social tension. Limited access to water affects daily routines, hygiene practices, and overall quality of life, contributing to mental health issues.<sup>87</sup>

A striking example of social tension provoked by water restrictions and shortages is the conflict between Barcelona citizens and tourists. When local populations face more severe water restrictions than those applied to the tourism industry, resentment inevitably grows. This disparity can exacerbate social tensions, as residents struggle with daily limitations while tourists continue to use water for leisure and comfort (for more details on this issue, see Chapter 2).<sup>88</sup> In addition,

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<sup>86</sup> <https://www.aiguesdebarcelona.cat/ca/estat-actual-sequera>

<sup>87</sup> Mental health in water scarce cities: an unrecognized climate change pressure point - The BMJ

<sup>88</sup> <https://www.euronews.com/travel/2024/07/08/fake-signs-and-hunger-strikes-whats-behind-europes-backlash-against-overtourism>

such tension impacts the tourism industry which has repercussions on economic activities in the region.



Figure 5-3 Thousands of Barcelona residents have taken the streets to protest overtourism<sup>89</sup>

Industries as well, particularly those heavily reliant on water, also face production slowdowns and financial instability due to water restrictions, which can lead to job losses and economic issues.

### Agriculture

According to the World Bank, **groundwater can mitigate up to 50% of agricultural productivity losses** due to rainfall variability.<sup>90</sup> It is therefore very important to have an efficient management of such important resources to avoid losses in non-essential uses and illegal wells while having more water for agricultural use. It is also important to preserve quality of groundwater by avoiding salt intrusion and the long-term quantity by avoiding compaction.

Catalonia's agricultural sector, which is the greatest groundwater consumer (see figure above) could see important increase in revenue with improved crop yields and reduced water stress thanks to EO data. The latest example is rather strong as the amount of water that the agricultural sector could use to irrigate crops was cut by up to 80 % during the drought of 2024. At the time of writing this report (June 2024) it is still cut by 40%. There is also a reduction of 30% in livestock uses (in emergency situation, it was 50%).<sup>91</sup>

<sup>89</sup> <https://www.euronews.com/travel/2024/07/08/fake-signs-and-hunger-strikes-whats-behind-europes-backlash-against-overtourism>

<sup>90</sup> <https://documents1.worldbank.org/curated/en/099257006142358468/pdf/IDU0fb2550de013100434708d920a3e3bec6afb1.pdf>

<sup>91</sup> <https://www.aiguesdebarcelona.cat/ca/estat-actual-sequera>

The EU estimated **losses from last drought in the agricultural sector to 700 million in Catalonia<sup>92</sup>** - the agricultural sector total turnover being estimated at more than €6 Bn/year (see figure 4-11 above). Knowing that groundwater could mitigate such loss by 50% (see above), it means that €350 million could potentially be saved thanks to enough groundwater resources used for agriculture during drought periods. To estimate the benefits of Sentinel data in such case, we make the hypothesis that the use of EO data (which improves water allocation efficiency<sup>93</sup> and long-term overall quantity of quality water by avoiding compaction and intrusion of saltwater) could participate in 0,5 to 1 %<sup>94</sup> of the savings above, it means the agricultural sector in Catalonia could save **€1,75 to €3,5 million** thanks to Sentinel data.

### 5.2.5 Other beneficiaries

One of the most important roles of groundwater is its support for ecosystems that serve as crucial links between nature and society. When large amounts of groundwater are extracted for agriculture or industry use, less water may be available for **Groundwater-Dependent Ecosystems** (or GDEs) causing springs, wells, and other water sources to dry up. This affects plants, animals, and human communities that depend on these sources. These GDEs also provide a wide range of benefits (the ecosystem services) to society, including flood risk reduction, carbon sequestration, climate regulation, and recreational opportunities. When groundwater management decisions impact GDEs, these benefits may also be affected.<sup>95</sup>

## 5.3 Summary of Benefits

In this section, we draw together the different benefits to the stakeholders identified along the value chain, grouping them by six dimensions of value-chain analysis. A summary of the degree of the benefits -based on the ratings on the sub-sections below - as applicable to this case, taking into account previously studied cases, is shown in tables 5-2. The assessment is subjective; the basis for it is given in Annex 2.

Economic	Environmental	Societal	Regulatory	Innovation & Entrepreneurship	Scientific & Technological
★★★★★	★★★★	★★★★★	★★★★	★★★★	★★★★★

**Table 5-2 Benefits Assessment by Category**

<sup>92</sup> [https://www.europarl.europa.eu/doceo/document/E-9-2024-000083\\_EN.html](https://www.europarl.europa.eu/doceo/document/E-9-2024-000083_EN.html)

<sup>93</sup> Better allocation efficiency would inevitably mean less loss of water for non-essential use (e.g. private swimming pools, golf courses, decorative fountains, illegal wells, etc.) and more water for critical agricultural needs.

<sup>94</sup> It is a conservative hypothesis based on knowledge of previous SeBS cases which are all in the same ranges.

<sup>95</sup> <https://www.frontiersin.org/journals/water/articles/10.3389/frwa.2023.1115416/full>

### 5.3.1 Economic

The main objective of this study is to compile the significant benefits that demonstrate the potential impact of Sentinel data on water resources management. Additionally, this section aims to quantify these benefits. While we recognize that the product is not yet fully operational and these estimates are preliminary, Sentinel data has already shown some impact on monitoring efficiency, agricultural production, and other areas.

While the economic benefits have so far been calculated specifically for Catalonia, it's useful to consider what these benefits might look **like if Sentinel satellites were used for aquifer management across all of Spain.**

Water scarcity and its importance to local communities (households, businesses, and agriculture) are in fact issues that affect many other regions in Spain. For example, the European Environment Agency reports water supply problems in the Guadiana, Guadalquivir, Segura River Basin, and Sur Basins.<sup>96</sup> Other sources also list the Jucar region, which is heavily irrigated and suffers from droughts. Furthermore, the last SeBS case in Murcia<sup>97</sup> also refers to important subsidence issues due to groundwater extraction in the same region. Additionally, the same report states that the Upper Tajo basin suffers from the same issue, particularly in Madrid.

Given these widespread water issues, we can scale the results from Catalonia to Spain. To do so, we need to adapt the process compared to the case of Murcia, which focused more on damage from ground movement caused by aquifer exploitation. Since “more efficient water management” is the primary source of benefits in this case, we should scale the benefits from Catalonia to Spain based on variables directly linked to **water demand** and **resource availability**.

Spain is 15.6 times the size of Catalonia in terms of **surface** area, but it also has 5.5 times Catalonia's **GDP**, 5.5 times Catalonia's **agricultural production** (in terms of turnover), and 6.2 times Catalonia's **population**—key factors influencing water demand. In terms of water resources, Catalonia is mid-range, not as abundant as Galicia and Asturias but not as scarce as Murcia and Valencia. This means that it is unnecessary to apply a different weighting coefficient for water resources.

We may also note that the **lithology** of the region also influences the efficiency of the Sentinel-based tools which inevitably influences the benefits of the use of such tool. In fact, in the case of a region with bedrock lithologies – which are less prone to subsidence, using ground subsidence as a proxy for groundwater extraction might be less efficient or even useless (see section 4.2.2 for more explanation). Therefore, the effectiveness and benefits of using Sentinel satellites for monitoring groundwater extraction and subsidence should vary across Spain, depending on the predominant lithology of each region. Catalonia's diverse lithology, with both sedimentary and bedrock formations, makes it comparable to many other regions with similar sedimentary issues, though regions with predominant bedrock lithologies like Galicia and Asturias will see different outcomes.<sup>98</sup>

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<sup>96</sup> <https://www.eea.europa.eu/en/analysis/indicators/use-of-freshwater-resources-in-europe-1>

<sup>97</sup> <https://ears.org/sebs/aquifer-management-in-spain/>

<sup>98</sup> [https://en.wikipedia.org/wiki/Geology\\_of\\_the\\_Iberian\\_Peninsula](https://en.wikipedia.org/wiki/Geology_of_the_Iberian_Peninsula)

To be conservative, we decided to scale the results from Catalonia to Spain using the population coefficient (6.2), which is moderate compared to the surface area coefficient (15.6) but still a bit higher than GDP and agricultural production coefficient (5.5).



Figure 5-4 Map of Spanish River Basin districts

Tier	Benefits identified	Catalonia		Spain	
		Min	Max	Min	Max
Tier 1 (ECGC)	Job creation Research fundings	N/A	N/A	N/A	N/A
Tier 2 (ACA)	Improved allocation of the monitoring budget	€25k	€75k	€155k	€465k
Tier 3 (Municipalities and water utilities)	Reduced damages from subsidence, Better	N/A	N/A	N/A	N/A


	groundwater management				
<b>Tier 4 (Citizens and Society)</b>	Efficient agricultural water use	<b>€1,75m</b>	<b>€3,50m</b>	<b>€10,85m</b>	<b>€21,70m</b>
<b>TOTAL</b>		<b>€1,775m</b>	<b>€3,575 m</b>	<b>€11,005m</b>	<b>€22,165m</b>

**Table 5-3 Summary of economic benefits**

What this table tells us is the following: if ACA and ECGC and their counterparts in the other river basins (where it would make sense to deploy InSAR monitoring for aquifer management) were not using the service, the less efficient exploitation of the aquifer could generate water stresses inequalities in consumption and unsustainable use corresponding **to annual costs valued at 11 to 22,16 million Euros in Spain**. This shows that whilst our projection is very modest, it still yields significant benefits thanks to Sentinel 1-based InSAR. We note that this number is hypothetical because the service is not yet fully operational, although it is already improving the situation in Catalonia.

As discussed in previous sections, there are undoubtedly many additional economic benefits manifested in each tier of the value chain that have not been quantified within this table due to the many unknowns and complexity involved in performing this analysis. Therefore, it should be noted that the figures in the table are what could be more objectively quantified within this report and are considered quite conservative in terms of the actual total economic value Sentinels are bringing in this case. Beyond the benefits listed in the table, we can also consider the improvement in the **tourism industry** resulting from decreased social tension between citizens and tourists. Efficient water management also supports **industries reliant on water**, contributing to **economic stability** and job creation.

We classify the contribution to economic benefits as 4 stars, mainly coming from savings in irrigation due to better groundwater resources management.



- Improved allocation of the monitoring budget (tier 2)
- Reduced damages from subsidence and better management (tier 3)
- Efficient agricultural water use (tier 4)



### 5.3.2 Environmental

As discussed in the previous sections, the Sentinel-enabled service supports the monitoring of groundwater in Catalonia, giving rise to significant environmental actions and benefits. This includes:

- **Sustainable Water Management:** better monitoring leads to better water allocation, avoiding over-extraction and preserving groundwater levels.

- **Preservation of Groundwater-Dependent Ecosystems (GDEs):** effective groundwater management supports GDE, providing flood risk reduction, carbon sequestration, climate regulation, and recreational benefits.

All these benefits feed into the discussion of ecosystem services presented in section 5.2. Whilst the full realisation of these benefits relies on the actions taken by the competent authorities, there is strong evidence that the Sentinel-enabled information provided by ICGC empowers these authorities. Thus, 3 stars have been assigned for the environmental benefits in this case; we expect this to become 4 stars in the near future when further measures based on Sentinel data will be taken.






- Sustainable Water Management (Tier 4)
- Preservation of Groundwater-Dependent Ecosystems

### 5.3.3 Regulatory

Sentinel-based observations help the ACA comply with EU Water Framework Directive provisions, ensuring regulatory adherence. Currently, EO measurements are not used for reporting, but their future use is a possibility. If implemented, these benefits are expected to increase significantly. In addition, EO measurement helps in **improving public services** (e.g. municipalities can do a better job) and **improving policy enforcement**.

We classify the contribution to the regulatory benefits as 3 stars. We do not assign a 4 since the full potential of regulatory benefits is not yet realized.



- Better monitoring for regulatory compliance (tier 2)
- Improved policy enforcement (tier 2)

### 5.3.4 Innovation & Entrepreneurship

The development of the new product combining artificial intelligence and remote sensing have strong impact for ICGC and the ACA. We also expect important spillovers in Spain, the EU and potentially the world. Articles, papers but also this “Sentinel Benefits Study” will also increase the spillovers effects.

Furthermore, ICGC's innovative use of Sentinel data fosters the development of advanced software and services, inspiring similar projects across the EU.

On balance, we classify the contribution to innovation benefits as 3 stars on our qualitative scale as a product is still at Technology Readiness Level (TRL)-8 stage of development, we expect it to increase very soon.

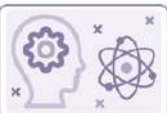




- Creation of innovative services (tier 1)
- Championing of innovative services and changing of operational practices (tier 2)

### 5.3.5 Science and Technology

There is a great deal of research on aquifer management and monitoring as well as environmental effects of groundwater and there is a great potential for EO in general to enrich such studies. In this respect, access to rich Sentinel data enables ICGC and other researchers to improve their studies on groundwater management. Research findings are also shared globally, advancing scientific understanding and practical applications of EO data.

We classify the contribution to scientific and technological research as 4 stars.

- Wide-scale nature of the measurements possible with Sentinel data is enabling research projects into ecosystems services.
- Research on new methods for groundwater measurement.

### 5.3.6 Societal

The benefits to citizens and to society are possibly the most important ones deriving from this case – and naturally, there is also an overlap with the environmental benefits. This highlights the circular nature that a case with environmental benefits has, as these benefits are further reflected into societal and regulatory benefits. This is because environmental benefits are being increasingly recognized by the public and, similarly, the impact of activities on the environment is usually subject to legislation. The other societal benefits are the following:

- Municipalities benefit from Sentinel data to prevent **subsidence** and related damages, enhancing public **safety**.
- Better managing water resources helps in addressing fundamental societal aspects of **fairness** and **social cohesion**. Ensuring that water is distributed fairly helps prevent conflicts and promotes social harmony while maintaining and ecosystem services to citizens.
- Better water management helps avoid **drastic drought measures**, which helps avoiding stress amongst citizens while maintaining agricultural productivity and stability for farmers.
- Increased visibility and transparency in water management improve **public trust** and awareness, encouraging water conservation.

We classify the contribution to societal benefits as 4 stars, with the anticipation that it will rise to 5 stars in the near future as EO services continue to evolve and their impact on water quantity becomes more clearly and significantly demonstrable. Water is essential, affecting the daily lives of all citizens and the economy. Easy access to water preserves social cohesion, enhances quality of life, and promotes overall well-being. Even a modest improvement in water management can lead

to substantial positive changes, showing the importance of the utilization of EO in water management.



- Improved ecosystem services (tier 4)
- Better quality of life (tier 4)
- Fairness and social cohesion (tier 4)

## 5.4 Synoptic Overview

Having looked at the different types of benefits and before proceeding to the conclusions extracted in this study it is instructive to provide a synoptic overview in the table below.

Tier	Benefits identified	Type	Value where economic (annual)
Tier 1 (ICGC)	Employment	Economic	
	Funding for R&D projects	Economic	
	Improved allocation of the monitoring budget	Economic	
	Innovative software and services	Entrepreneurship and innovation	
	Scientific research and publications	Science	
	Better work for environmental mission.	Environmental	
Tier 2 (ACA)	Improved allocation of the monitoring budget	Economic	€165-465 k
	Cost savings in avoiding finding/creating alternative water sources	Economic	
	Regulatory compliance	Regulatory	
	Improved water allocation and management	Environmental	
	Improved policy enforcement	Regulatory	
Tier 3 (Municipalities and water utilities)	Damage mitigation from subsidence	Economic	
	Optimized distribution from water utilities	Economic	
	Improved public services and policy enforcement	Regulatory	
Tier 4 (Citizens and Society)	Efficient agricultural water use	Economic	€ 10,85-21,70 m
	Fairness and social cohesion	Societal	
		Economic	

	Savings on water bills due to efficient water management		
	Avoiding drastic water usage limitations	Societal	
	Environmental benefits for groundwater-dependent ecosystems	Environmental	
	Avoided permanent deterioration of aquifer (compaction)	Environmental	
<b>TOTALS</b>			<b>€11,00-22,16m</b>

**Table 5-4 Summary of benefits for each Tier**

## 6 Key Findings and Final Thoughts

### 6.1 Key Findings

The benefits from using Sentinel-1 data to provide measurements over groundwater exploitation are significant. This technology provides measurements of several parameters linked to the groundwater extraction over a large geographical area. Its utilization complements other methods to measure the groundwater quantity (in-situ analysis, e.g. piezometric level) and provides and offers cost-effective information that would otherwise be expensive to obtain. The impact of Sentinel-1 data is evident as other regions, such as Murcia (e.g. Murcia, see SeBS case<sup>99</sup>), have increased their budgets for Sentinel-enabled services to enhance aquifer management.

Such services are especially relevant in a country like Spain which suffer a lot from droughts and water stresses, where the economy relies strongly on agricultural activities, industry and tourism. Last drought in Catalonia in 2024 illustrates very well the importance of using effective technologies supporting efficient water management.

Like the previous case in Murcia, we observe a significant contribution to value that is being generated across the full range of dimensions although the economic return is the most striking one. These economic benefits have been calculated based on a realistic current and future scenario. They are based largely on ACA saving monitoring costs in the current context of climate change and sustainable agriculture water use.

Another noteworthy aspect of this case is that the advantages will significantly expand in the coming years, given that Spain is currently in the early stages of transitioning toward more use of EO for groundwater sustainable management but also in the future for all water resources. In this regard, we expect EO tools to improve while they will be extended over the full territory.

Such evolution is particularly relevant in the context of climate change, which may exacerbate water scarcity and increase the need for more efficient water management tools. As such, the implementation of EO will be key in addressing these challenges and ensuring sustainable water resources management.

### 6.2 The Impact of Sentinel Data

The case of aquifer management in Spain provides a perfect example of how Sentinel-1 data can enable innovative solutions (InSAR services) that meet direct user needs.

In most cases analysed under the *Sentinel Benefits Study*, the question of attribution arises, i.e. what percentage of the produced benefit can be attributed to the use of Sentinel data versus other satellite programs? In this case, however, this question can be very easily answered: 100%.

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<sup>99</sup> <https://earsc.org/sebs/aquifer-management-in-spain/>

## 6.3 Widening the Perspective

### Geographic Extension

Given the widespread water issues, the successful use of EO in Catalonia can be scaled to the (almost) rest of Spain as well as the rest of the world.

The ICGC provides various services in Spain, Europe, and internationally, although its current groundwater monitoring activities are limited to Catalonia. However, their experience in international projects positions them well for future expansions. Once the service for detecting aquifer exploitation through ground movement monitoring demonstrates strong results, it is expected to be naturally adopted in other regions of Spain and Europe (and even further away). As demonstrated in Chapter 5 and the previous SeBS case in Murcia, this service is crucial for regions suffering from droughts and groundwater over-exploitation. Whether the service will be extended by DARES, which offers similar services in Murcia, or by ICGC, or by any other service provider, we can anticipate **significant extensions**. Subsidence due to groundwater extraction is in fact a common issue globally, **particularly in areas experiencing droughts**. This problem is prevalent across the Mediterranean basin, affecting countries with intensive groundwater use for agriculture, such as Spain, Italy, Greece, Turkey, Israel, Jordan, Egypt, and Morocco.<sup>100</sup> The scalability and adaptability of this service highlight its potential for widespread application and impact.

An additional important variable in expanding the service is the **lithology** of the region. More specifically, sedimentary lithologies with low to medium hydraulic permeability are subject to compaction and deformation when groundwater is extracted, leading to subsidence. Conversely, bedrock lithologies (in mountainous regions) are more stable and much less prone to subsidence. Catalonia's diverse lithology, with both sedimentary and bedrock formations, is comparable to many regions in Spain, though regions with predominant bedrock lithologies, like Galicia and Asturias, will see lower added value from the implementation of EO in groundwater monitoring. In addition, these two regions experience fewer water shortages and more rainfall, making them less likely candidates for the implementation of such technology.

### Increased Market Penetration

There is strong potential to increase the uptake of ICGC services within Catalonia and Spain as stated above. The service was tested for 7 spots in Catalonia and proved to be very useful. It will therefore very soon be extended for many more groundwater spots in Catalonia.

In addition, although it is not yet in the ACA agenda, we believe there could be strong potential in merging the EO application for aquifer monitoring with the ACA website<sup>101</sup> on droughts monitoring (for illustration, see figure 4.3) as well as the current communication on drought measures in each municipality (see figure 6-2 below), water saving guides and tips, communication material, etc.

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<sup>100</sup> See <https://earsc.org/sebs/aquifer-management-in-spain/>

<sup>101</sup> <https://aplicacions.aca.gencat.cat/visseq/estat-actual>

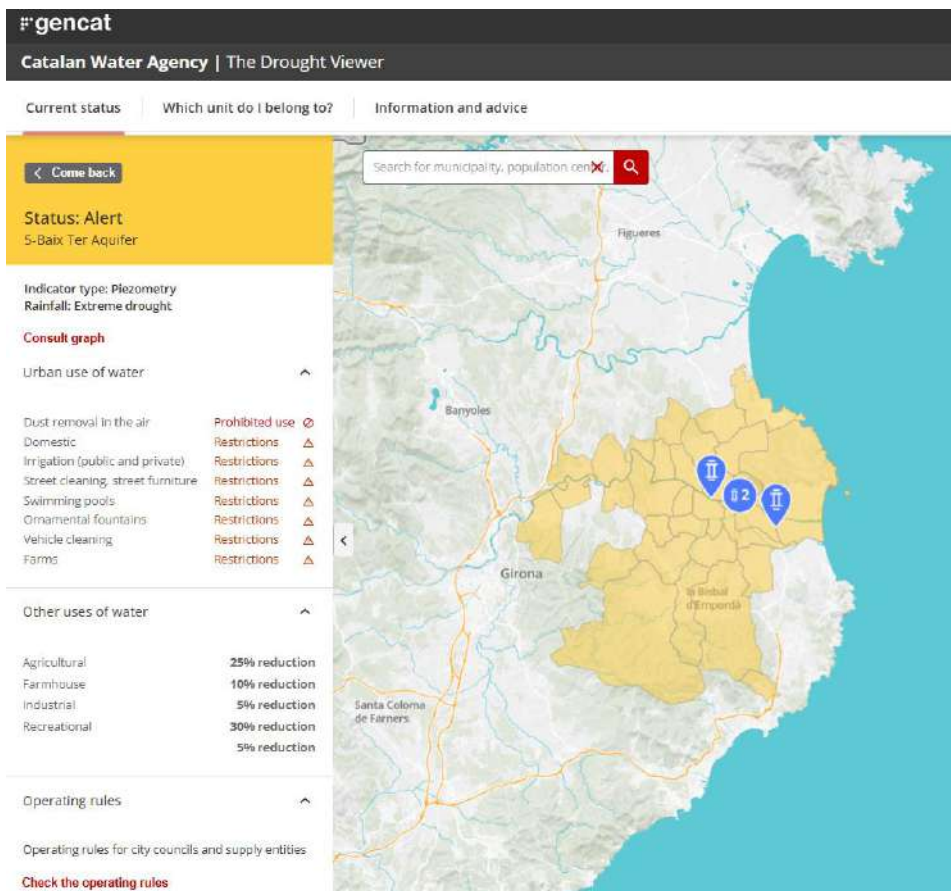


Figure 6-1 Drought status and restrictions in 5-Baix Ter Aquifer (near Girona on 22/07/2024)<sup>102</sup>



Figure 6-2 Water saving guides and tips + communication material in Catalonia<sup>103</sup>

<sup>102</sup> <https://aplicacions.aca.gencat.cat/visseq/estat-actual>

<sup>103</sup> <https://sequera.gencat.cat/ca/accions/estalvi-daigua/>

There are also potential synergies with the ICGC website<sup>104</sup> on ground movement monitoring (for illustration, see figure 3.3). All these synergies should help to mainstream such service through the population for a larger use base.

In the longer term, we could also expect some expansion of such EO services and data to **the whole market of water, including reservoirs, lakes and rivers, water rights enforcement, crop irrigation, drought management, water transfers, hydraulic centrals, etc.**

### Improved Technological Maturity

The product is currently at Technology Readiness Level (TRL) 8, demonstrating its efficiency and reliability in real-world applications. Moving forward, the process will be automated and further refined to enhance its performance and scalability.

In addition, as explained in Section 1.3, one key future development is also the analysis of NDVI (Normalized Difference Vegetation Index) in conjunction with LAI (Leaf Area Index) to assess agricultural water extraction and predict potential subsidence (as some models can estimate water use through irrigation patterns which in turn could predict subsidence). By understanding vegetation health and water usage patterns, this analysis can help optimize irrigation practices and detect early signs of ground subsidence due to excessive water extraction as well as detect illegal water abstraction (and potentially close wells).

Furthermore, the forthcoming ROSE-L (Radar Observing System for Europe in L-band, with data on soil moisture, geohazards and surface motion) and LSTM (Land Surface Temperature Monitoring, with data on land surface temperature and evapotranspiration at high resolution) missions could enhance the current capabilities of EO data for a better management and knowledge of groundwater resources.

## 6.4 Final Thoughts

A comparison with the SeBS cases in Murcia is instructive. Both regions utilize Sentinel-1 satellite data to monitor ground deformation linked to groundwater extraction. However, their core objectives differ significantly. **In Murcia, the primary goal is to prevent damage caused by such deformations**, focusing mainly on safeguarding infrastructure and buildings. Consequently, the economic benefits in Murcia are largely tied to the cost savings from avoiding structural damages.

In contrast, **Catalonia's** approach aims to **sustainable water management**. By tracking ground deformation, they use it as an indicator of aquifer exploitation, aiming to reduce water stress through more effective resource management.

Additionally, it is essential to highlight that Sentinel-derived services have been providing, in the two cases, a rich source of information generating significant economic and environmental sustainability impact.

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<sup>104</sup> <https://www.icgc.cat/en/Thematic-areas/Territori-sostenible/Sostenibilitat-urbana/Observacio-de-la-Terra/Ground-movement-measurement-service>

In this specific case, the benefits are expected to greatly grow in the future. This can serve as inspiration for the roll out of similar services in Spain and in other countries that are – or will be – facing similar challenges, especially in the context of climate change.

A last final comment worth to emphasis is the perspective of **holistic use of EO data** for overall water management, encompassing aquifer management, water right enforcement, crops irrigation, overall drought management, water transfers, production of hydroelectric power plant, etc. Integrating the detailed and real-time data provided by Sentinels into water management practices could significantly enhance the efficiency and sustainability of water use across various sectors. We believe that **such beneficial practices should be explored and further developed on a larger scale**. Additionally, this development could be inspired from the current siloed practices from different agencies or stakeholders managing various aspects of water resources independently (such as the ones explained in various SeBS cases on water quantity and quality management).

## Annex 1: References and Sources

Bateson, L., Cigna, F., Boon, D., & Sowter, A. (2015). DInSAR-based monitoring of land subsidence related to groundwater over-exploitation: Example from developing urban center of Nairobi, Kenya. *Hydrogeology Journal*.

Catalan Water Agency. (2022). *Management Plan for the River Basin District of Catalonia and Programme of Measures. 2022-2027 Synthesis document*.

Forero-Ortiz, E. Gandíanez-Gomariz, & R. Monjo. (2020). Climate Change Implications for Water Availability: A Case Study of Barcelona City.

Foster, T., Brozović, N., & Butler, A. P. (2017). Effects of initial aquifer conditions on economic benefits from groundwater conservation. *Water Resources Research*, 53, 744-762.

Howard, J. K., Dooley, K., Brauman, K. A., Klausmeyer, K. R., & Rohde, M. M. (2024). Ecosystem services produced by groundwater dependent ecosystems: A framework and case study in California. *Frontiers in Water*.

World Bank. (2024). *The Economics of Groundwater in Times of Climate Change*. DOI: <https://www.worldbank.org/en/topic/water/publication/the-hidden-wealth-of-nations-groundwater-in-times-of-climate-change#:~:text=Groundwater%20is%20nature's%20insurance%2C%20serving,security%20and%20reduces%20child%20malnutrition>.

Note: The reader can find more references in the form of footnotes throughout the report.

## Annex 2: General Approach and Methodology

This case has been analysed as a part of the Sentinel Benefits Study (SeBS), which looks at the value being created by the use of Sentinel data. It follows a [methodology](#)<sup>105</sup>, established during a previous study, looking at a value chain for the use of a single EO service.

For each case, a value chain is established with a service provider and a primary user. The value-chain is validated with these two key players. Through a combination of desk and field research, we develop our understanding of all the actors in the value chain, the role that they play and how they may benefit through the use of the satellite-derived products.

The value-chain is divided into a number of tiers where the supplier is Tier 1, and the primary user is Tier 2. The last Tier is always “Citizens and Society”. The number may vary according to the complexity of the value-chain. The benefits are then analysed against each of these tiers.

Once written, the draft report is then shared with all the persons with whom we have spoken, and their comments are incorporated, or a further discussion is held to establish a common understanding. Note that we are not asking these experts to endorse our findings but to indicate any gross errors or sensitivities which may have been introduced. At the end of this process, the report is made public.

As work has proceeded and more cases analysed, some modifications have been made to the methodology described in reference 105. The first of these has been to expand from the two dimensions used earlier, namely economic and environmental benefits, to add those connected to societal, regulatory, innovation and entrepreneurship and scientific and technological. These six dimensions are described in the table A2-1 below.

Dimension	Definition
<b>ECONOMIC</b>	Impacts related to the production of goods or services, or impacts on monetary flow or volume, such as revenue, profit, capital and (indirectly, through turnover generation) employment.
<b>ENVIRONMENTAL</b>	Impacts related to the state and health of the environment, particularly as regards the ecosystem services on which human societies depend.
<b>SOCIETAL</b>	Impacts related to societal aspects such as increased trust in authorities, better public health or secured geostrategic position.
<b>REGULATORY</b>	Impacts linked to the development, enactment or enforcement of regulations, directives and other legal instruments by policymakers.

<sup>105</sup> SeBS Methodology; June 2017 and The Six Dimensions of Value Associated to the use of Copernicus Sentinel Data: Key Findings From the Sentinel Benefits Study (<https://www.frontiersin.org/articles/10.3389/fenvs.2022.804862/full>)

<b>INNOVATION- ENTREPRENEURSHIP</b>	Impacts linked to the development of new enterprise and/or the introduction of technological innovation into the market.
<b>SCIENCE- TECHNOLOGY</b>	Impacts linked to academic, scientific or technological research and development, the advancement of the state of knowledge in a particular domain.

Table A2-1: Definitions for the benefit dimensions

For each of these, a ranking has been introduced to give an immediate, visual impression of the scale of the benefits under each dimension. To aid in the quantification of these, a guide has been introduced which is shown in Table A2-2.

Rank	Benefit status	Criteria
<b>0</b>	<b>Null</b>	The case presents no perceivable benefits in this dimension, and no potential for such benefits to emerge is anticipated.
<b>1</b>	<b>Latent</b>	The value chain described in the case may, in general, present potential benefits in this dimension, but none have been identified or described in this particular instance.
<b>2</b>	<b>Manifest:</b>  At least one benefit in this dimension has been identified through the value chain within the case. Its significance in the context of the case overall is judged to be:	<b>Low</b>
<b>3</b>		<b>Moderate</b>
<b>4</b>		<b>High</b>
<b>5</b>		<b>Exceptional</b>

Table A2-2: The ranking of the benefits.

In order to introduce further basis for comparison, a systematic approach has been developed for the analysis of the benefits. A series of indicators have been defined for each of the benefit dimensions against which each case can be considered.

The indicators used in the case are listed in chapter 5, and a full list of all indicators considered is provided in Table A2-3.

Dimension	Indicator	What it can mean.
Economic	Avoided costs	Alternative means to gather data
	Increased Revenues	Increased production/sales
	Reduced Inputs	Less time spent or material saved

	Improved Efficiency	Better use of resources
	Employment	Increased employment in the service provider
	Reduction of risk	Reduction of risk and consequential costs
Environmental	Reduced pollution	Reduced amounts of pollutants in key resources e.g. water, air
	Reduced impact on natural resources	Reduced environmental impact e.g erosion, habitats/biodiversity.
Societal	Improved public health	Less toxicological risk
	Common Understanding	Better control and communication of remedial efforts i.e through common maps.
	Increased trust and better transparency	Improved preparedness / response
	Strategic Value	Common societal value to a country or region.
Regulatory	Improved policy / regulation design/drafting	Better information (scale, accuracy) leading to better regulation
	Improved efficiency in policy/regulation monitoring	Better information available to monitor adherence to regulations.
Innovation & Entrepreneurship	Innovative products	Sentinel data leads to creation of new products / services
	New Business models	New ways to generate income.
	New markets	Global nature of sentinel data enables international business development
	New businesses	Creation of new companies; start-ups
Science & technology	Academic output	
	Research exploitation	Applied science to operational services
	Research contribution	New product enabling scientific research

Table A2-3: Complete list of indicators considered within SeBS analyses.

## Annex 3: About the Authors



*Lauriane Dewulf, PhD in Economics*

Lauriane is a consultant with the Brussels-based consultancy Evenflow, who work in collaboration with EARSC on the Sentinel Benefits Study (SeBS). She has more than 10 years' experience as project manager, lecturer, researcher, data scientist and economic advisor. She has led various projects linked to EO applications in water management, including SeBS cases. Previously, during her PhD, she made rigorous economic and analytical studies on various topics linked to R&D and Innovation.

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## The SeBS Study Team

The SeBS study is conducted by a team of experts under the direction of ESA (the European Space Agency) and led by EARSC (the European Association of Remote Sensing Companies). The team is of a variable geometry and different experts work together on the different cases. The full team and the organisations for whom they work, is shown below.



*Geoff Sawyer, BSc (Electronics), MBA*

Geoff is the former Secretary General of EARSC having held senior management positions in the space industry and numerous representative positions in the UK and Europe. Geoff was the radar systems engineer responsible for the ERS-1 synthetic aperture radar and after many steps was, until 2011, EADS Vice President Corporate Strategist for Space. In addition to his extensive industrial experience, Geoff spent three years working for the European Commission where he was responsible for supporting the creation of the GMES initiative (now Copernicus). Geoff is now Strategic Advisor to EARSC. [geoff.sawyer@earsc.org](mailto:geoff.sawyer@earsc.org).



*Dimitrios Papadakis, M.Sc. Research Methods*

Dimitrios is a strategy consultant and communication/dissemination expert with over ten years of experience in the commercialisation, uptake and exploitation of space-based data and applications, primarily as concerns the Copernicus programme and its services. He has provided expertise on a range of major market, cost-benefit and user uptake studies in the EO domain, for clients including the EC, ESA, EEA and the SatCen.

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His expertise is mathematical modelling and optimization under uncertainty. Dr. Khabarov joined [IIASA](http://iiasa.ac.at) to strengthen the team in charge of quantifying benefits of improved Earth observations. Since then, he has been a principal investigator and contributor to a range of research projects focusing on economics of adaptation, estimation of the value of information, disasters modelling, reduction of risks through innovative financial tools. [khabarov@iiasa.ac.at](mailto:khabarov@iiasa.ac.at)



*Lefteris Mamais, MSc in Theoretical Physics*

Lefteris is a strategy consultant with solid knowledge of programmatic, strategic and business aspects of EU Space Programmes (Copernicus and Galileo). For more than a decade, Lefteris has been extensively involved in various studies and projects related to the development, market uptake and exploitation of EO downstream applications. He has been advising clients and partners across the full spectrum of the EO value chain, including EU institutions (EC, EEA, SatCen, ESA, EUSPA), universities and private companies.

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