ASSESSMENT OF SGD IN KARSTIC COASTAL MASSIF: AIGUADOLÇ BEACH (GARRAF)

Pau Navarro Maestro **Dídac Navarro Fernández**

Universitat Autònoma de Barcelona

geoWASU
Environmental and water surveys

Tutors:

Jordi Garcia Orellana
Mario Zarroca Hernández

Degrees:

Environmental Science and Geology

February 2019, Bellaterra

ABSTRACT

Submarine groundwater discharge (SGD) is an important source of freshwater and nutrients to Mediterranean Sea, but is also related with anthropic pollution. Since the last decades a new emerging and successful ways to trace SGD appeared, as they are natural radioactive isotopes (^{223}Ra, ^{224}Ra, ^{226}Ra, ^{228}Ra and ^{222}Rn) and electrical surveys (electrical resistivity tomography , ERT). Other methods have been less employed, but they have a great potential as electric induction (EI). This project describes and quantifies SGD and its nutrients driven input with these methods, never used before in Catalonia to asses SGD, in an anthropized coastal karstic massif. The study zone is Aiguadolç beach (Spain), the most southern beach in the Garraf massif, and the obtained SGD flows there were $9.7 \pm 2.0 \cdot 10^6$ $m^3 \cdot km^{-1} \cdot yr^{-1}$, with the associated fluxes of DSi, DIN and DIP, which were 63 ± 13 $mmol \cdot m^{-2} \cdot d^{-1}$, 78 ± 16 $mmol \cdot m^{-2} \cdot d^{-1}$, and 432 ± 91 $\mu mol \cdot m^{-2} \cdot d^{-1}$, respectively. A NH_4^+ flux of 74 ± 16 $mmol \cdot m^{-2}$-d^{-1} was also estimated due to a high concentration of NH_4^+ in groundwater. This concentration exceeds the legal limits of drinking water legislation. This high contamination suggests an anthropogenic influence of the aquifer which could be due to waste water leaking from urban, agricultural or livestock activity or the Garraf landfill itself. The study also evaluates the social conflict framed in Aiguadolç due to some issues that affect the beach in relation with SGD and outlet emergences, and propose some management actions that could improve the situation.

KEY WORDS: Submarine groundwater discharge, nutrients, geophysical surveys, radium, Garraf massif, karst, social conflict.

INDEX

FIGURE INDEX

TABLE INDEX

1. JUSTIFICATION

The Garraf massif is one of the most important karstic complexes in the Mediterranean basin. The massif is characterised by the well-developed karstic cavities and its permeable capacity, in terms of its natural dynamics. It is an important source of freshwater that discharges into the sea, as it is evidenced by satellite thermal images (*Figure 1*), where is possible to observe colder coastal waters with some identifiable thermal plumes. However, these natural dynamics have been highly modified by the human pressure and anthropogenic activities such as the presence of urban soils, crops and farms located inland, an old landfill placed in the same massif, the cement industry and the presence of several ports.

Figure 1: *Thermal satellite image of the seawater surface in Garraf from the Landsat 8 satellite in April, the showed temperature values are not contrasted with field measurements. Image code: RT_LC08_L1TP_198031_20180405_20180417_01_T1_B10. Personal communication: Sónia Jou.*

There are several studies that showed the existence of a leaching of waste from the landfill that has a direct and relevant impact on the terrestrial biota of El Garraf (Torres et al., 2006). The problem associated with those leachings is also known because in 2018, due to the significant rainfall that had taken place in the area, those leachings were transported by groundwater and discharged to the sea especially through one of the main coastal springs: La Falconera.

Related with this natural altered dynamics some beaches in Sitges present outlet emergencies. Concretely Aiguadolç beach has remarkable outlet emergences that become highly active at the beginning of this century. But at the same time this beach is suffering some issues related with the drainage processes, as they are erosion and waste of sand, small sinkholes under the sand, water stagnation and wet sand. These problematic facts are impacting the beach quality and becoming a social conflict in the municipality of Sitges, which main economic sector is the tourism.

On other hand the Garraf massif is a natural park protected by law, but its troubles related with human activities are evident. Not only the terrestrial biota is endangered, but the marine ecosystem is impacted too with the problematic consequences in the close *Posidonia oceanica* meadows. These processes could be an important ecological trouble for the Catalan coastal management, and can generate a range of possible impacts both in the ecological environments and the socioeconomical system.

Considering the existing evidence of contamination of the Garraf aquifer, the fact that this aquifer constantly unloads to the sea and the emergent controversy in Aiguadolç, we pretend to develop a research work in this beach, which is very accessible and easy to make a campaign. By doing this could be possible to have a notion about what is happening in Garraf massif which is a very environmental risky zone. By studying Aiguadolç may be possible to understand the social problems that could recreate in other coastal places with outlet emergences, and have a more accurate perception of the magnitude of Garraf water discharge; and how it could be related with the pollution. Is an objective of this study to provide solid data that could be employed in the future for other projects, entities, administrations and research groups. This information will be useful to establish management groundwater tools at local and regional scale, and serving as a precedent for future research projects, helping to develop integrated management of water resources, ecosystems and economic resources in coastal Mediterranean areas.

The main aim of this project is to describe and model this water flow from karst to the Mediterranean Sea, in mainland (beach) and sea, to relate it with fluxes of nutrients and pollutants, with beach erosion and with socioeconomical conflicts. With this final degree project (Treball Final de Grau; TFG) we intend to achieve several goals, trying not to fit the project in only one science modality, but in a confluence of them. We will try to accomplish this by using pioneering and modern methodologies never used before in Catalonia to trace SGD processes, and combining technologies to complement several environmental data sources. This is an attempt to present a multidisciplinary way to solve socioecological issues through mixing geology, physics, hydrology, analytic chemistry, geographic information systems (GIS) and social sciences.

As a double TFG framed in the double degree of Environmental Science and Geology in the Universitat Autònoma de Barcelona (UAB) this project wants to give a transversal approach, which faces the same issue from different modalities. The relevance of the integrator character reside in understanding the science as a whole, by using and interpreting the several results to give a more complete answer and solving problems in a practical way. This kind of multidisciplinary studies could help to improve environmental field studies that have multiple interactions of several variables. The geological matrix and the water flows are influenced by different environmental factors, and they have different environmental impacts, this must be understood since the two modalities to give a complete answer. Is essential to make this kind of joint projects to generate synergies between geology and other sciences and for enhance the potential of geosciences to solve practical problems in the society.

2. INTRODUCTION

The interface between sea and land is one of the most complex systems of study due to the huge quantity of variables that influence a large list of processes. The coastline is an essential factor in hydrological cycle, as it is the place where the water returns from mainland to ocean *via* rivers and aquifers. The riverine discharge is well documented around the world, but the groundwater discharge from coastal aquifers is more qualitatively described than quantitatively (Trezzi, 2016; Zektzer et al., 1973). The study and description of the Submarine Groundwater Discharge (SGD) process is one of the pending subjects to understand more accurately the water cycle (Burnett et al., 2003). Its impacts and implications, in different kind of natural and anthropogenic altered processes, are several and transcendent (Garcia-Solsona, 2009).

The beginning of SGD as a major issue in the scientific community did not happen until the mid-1990s, when the volumetric and chemical importance of this topic began to be observed and recognised (Garcia-Solsona, 2009). Indisputably the influence of SGD in the hydrological cycle may be one of the most important ways of water transport land to ocean and *vice versa*. These dynamics can be more noticeable in more susceptible and permeable geological environments, like karstic massifs or delta profiles. However, the significance of this process is the fact that this transport not only includes water, but also includes its diluted, suspended and colloidal components. Rodellas (2014) noticed that it "may represent an important pathway for material transport from land to the ocean, playing a relevant role in coastal ecology and geochemical cycles of several compounds" as nutrients, metals, carbon, pollutants, sediments and microorganisms. Because of this, SGD can be translated as an important source of freshwater into the marine water and may contain elevated concentrations of nutrients or contaminants (Garcia-Solsona, 2009). Different magnitude levels of impact could be observed, from a local point of view to large regional basins (Burnett et al., 2003).

Several techniques can be used for detecting, describing, quantifying and modelling these processes along the coastline. One of the most effectively methods is based on the natural environmental radioactivity. The use of the four natural occurring radium isotopes (the radium quartet ^{223}Ra, ^{224}Ra ^{226}Ra and ^{228}Ra), is useful to trace SGD processes at various time scales due to their different half-lives(Rama and Moore, 1996). Another of the most successful applied radionuclides used for tracing the flow paths of fresh water into the sea is the radon (^{222}Rn). But not only natural radioactivity methods are employed, also geophysical technics has been applied to study SGD. This is the case of electrical resistivity imaging (ERI) that consists in a direct current (DC) geoelectrical method, that generates a 2D/3D section of the resistivity subsurface patterns and has effectively been used to detect changes in the water composition and fresh/saltwater interfaces (Nowroozi et al., 1999; Zarroca et al., 2011).

2.1. SUBMARINE GROUNDWATER DISCHARGE

2.1.1. DEFINITION OF SGD

The Submarine Groundwater Discharge (SGD) is the flow of water through the continental margins to the ocean (*Figure 2*). This water flow is composed of freshwater and seawater recirculated through permeable materials and can be given through meters to kilometres (Rodellas et al., 2015). This process takes place in any coastal aquifer with a positive gradient relative to sea level and that is hydraulically connected to the sea through permeable rocks or sediments.

SGD can inflow to the coast as a mixture of three components: fresh groundwater generated in the continent, seawater circulating in the aquifer and groundwater whose salinity has increased due to the mixture of the two water masses.

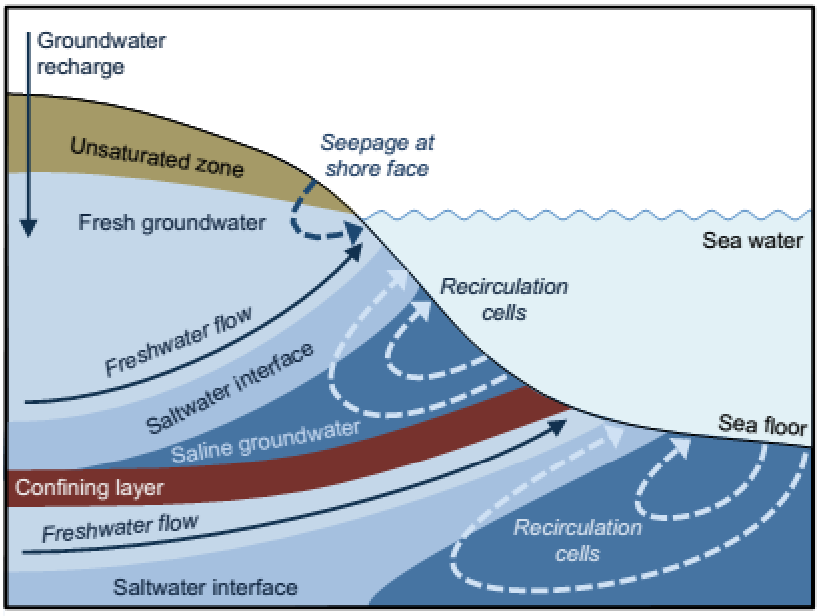


***Figure 2**: Schematic description of the SGD components in a section perpendicular to the coast. It shows the principal pathways for submarine groundwater discharge to the coastal ocean (Rodellas, 2014) based on Charette et al., 2008.*

The area where groundwater and seawater are mixed is called "subterranean estuary" (Moore, 1999) or mixing zone (saltwater interface in *Figure 2*), and they are characterized by being areas with many biogeochemical reactions, which transfer water, nutrients, metals, carbon and other elements to the coastal zone (Rodellas, 2014). In this zone the ionic strength fluctuates and the groundwater masses increases this strength. The inflow into the sea of fresh groundwater frequently have significantly higher concentrations of nutrients and trace elements than surface freshwater (Moore, 2010); the solute fluxes that discharge into the sea may represent a great contribution to the total flux of solutes to coastal ecosystems (Rodellas et al., 2015; Slomp and Van Cappellen, 2004).

The magnitude and location of the SGD depends on many factors related to the aquifer and the coast morphology (fractures, porosity, permeability, aquifer homogeneity, hydraulic conductivity, geomorphology, stream systems). The factors that influence the flow of groundwater by the coastal aquifer include the terrestrial hydraulic gradient (Alley et al., 2002) influenced by tides, waves, large storms and variations of sea levels (Moore, 1999) and according to the season (Michael et al., 2005), difference in water level through permeable barriers, convective movements due to water density and heating and ascension of groundwater due to geothermal heating (Moore, 1999).

Karstic environments and alluvial aquifers usually have high permeabilities and are expected to have the highest SGD values (Slomp and Van Cappellen, 2004). SGD in unconsolidated sedimentary coastal areas represents a small part of the water balance of the area; its volumetric contribution is relatively small compared to surface water, however in karst systems SGD can lead to a significant flow of water in the global water balance.

2.1.2. SIGNIFICANCE OF SGD FOR MARINE ECOSYSTEMS

Determining the behaviour of groundwater in a coastal aquifer is of great importance for coastal management. Fresh water from an underground aquifer can be extracted and used for human consumption at a lower cost than desalinating seawater. It can also be a profitable source of fresh water in those places where access to it is difficult. However, the use of water confined to aquifers can lead to problems related to overexploitation, such as the salinization of the aquifer, the sinking of coastal areas or the degradation of the aquifer (Rodellas et al., 2015). These problems affect society therefore it is worthwhile to take them into account to avoid possible conflicts.

Besides the flow of water, the SGD is also an important source of materials from the land to the sea (Moore, 1999). Groundwater usually has concentrations of nutrients, metals, carbon or salts higher than inland water (Rodellas et al., 2015). Knee and Paytan (2012) defined that these elements can be both natural (microorganisms, vegetation, soils) and anthropogenic (waste, mining, landfills, pesticides, organic compounds). In addition, if these waters are mixed with intruded seawater, the compositions vary, giving different fluids than groundwater and seawater (Moore, 1999).

Reactions occur such as ion desorption, dissolution and precipitation of carbonates, remineralisation of organic matter, redox reactions of metals and exchanges of nutrients and metals (Rodellas, 2014). The content in nutrients of groundwater can be several greater orders of magnitude than in surface waters. This input can be a factor to be taken into account in the eutrophication of coastal (Slomp and Van Cappellen, 2004), the entrances of water with high nitrate contents are related to algal blooms.

2.1.3. SGD IDENTIFICATION AND QUANTIFICATION

There are different methods to identify and quantify Submarine Groundwater Discharge. Among the identification methods there are the thermal imaging methods (Johnson et al., 2008) that measure the temperature difference of the water masses form a satellite and geoelectrical techniques (Zarroca et al., 2014) that measure the resistivity of the materials. The methods used to quantify the SGD include direct measurements by seepage meters (Moore, 2010), hydrogeological models (Moore, 2010; Rodellas, 2014) and tracer techniques (Garcia-Orellana et al., 2014; Moore, 1999; Rodellas et al., 2017; Slomp and Van Cappellen, 2004) using nutrients, metals or radionuclides. The following techniques are used for first time in Catalonia to trace SGD processes. The present project could become a pioneering work in karstic systems in Catalonia to develop other studies in the same way and open some possibilities to water resources research.

2.1.3.1. GEOPHYSICAL TECHNIQUES

Geophysics uses non-destructive methods to investigate the terrain. The information it provides serves to correlate, extrapolate and verify geological information. The studied field needs to present a contrast between some physical properties to allow its delimitation. There are many geophysical methods that are based on different physical properties of rocks: electrical, magnetic or seismic among others (Escuder et al., 2009), but this study is focused on electrical methods.

2.1.3.1.1. VERTICAL ELECTRICAL SOUNDING (VES) AND ELECTRICAL RESISTIVITY TOMOGRAPHY (ERT)

Geophysics uses non-destructive methods to investigate the terrain. The information it provides serves to correlate, extrapolate and verify geological information. The studied field needs to present a contrast between some physical properties to allow its delimitation. There are many geophysical methods that are based on different physical properties of rocks: electrical, magnetic or seismic among others, but this study is focused on electrical methods (Escuder et al., 2009).

These methods are based on Ohm's law, which says that the resistivity (ρ) is the result of the quotient between the electric potential difference (V) by the electrical intensity (I) multiplied by a K factor that depends on the section of the cable and the length of it.

$$\rho = \frac{V}{I} \cdot K \qquad (1)$$

It consists of calculating the resistivity of the terrain by injecting a known electrical current through electrodes stuck in the ground (A, B) and measuring the potential difference between two intermediate electrodes (M, N; *Figure 3*). The value that is measured in this type of technique is the variation of resistivity in the terrain, measured in Ω·m. Sometimes the opposite of resistivity is used, which is conductivity. In a VES, resistivity in depth is measured under the point O, in the centre. Increasing the distance between electrodes A and B increases the depth of sounding. There are different ways to place the electrodes to perform a sounding. Each method allows measuring with a different depth or resolution.

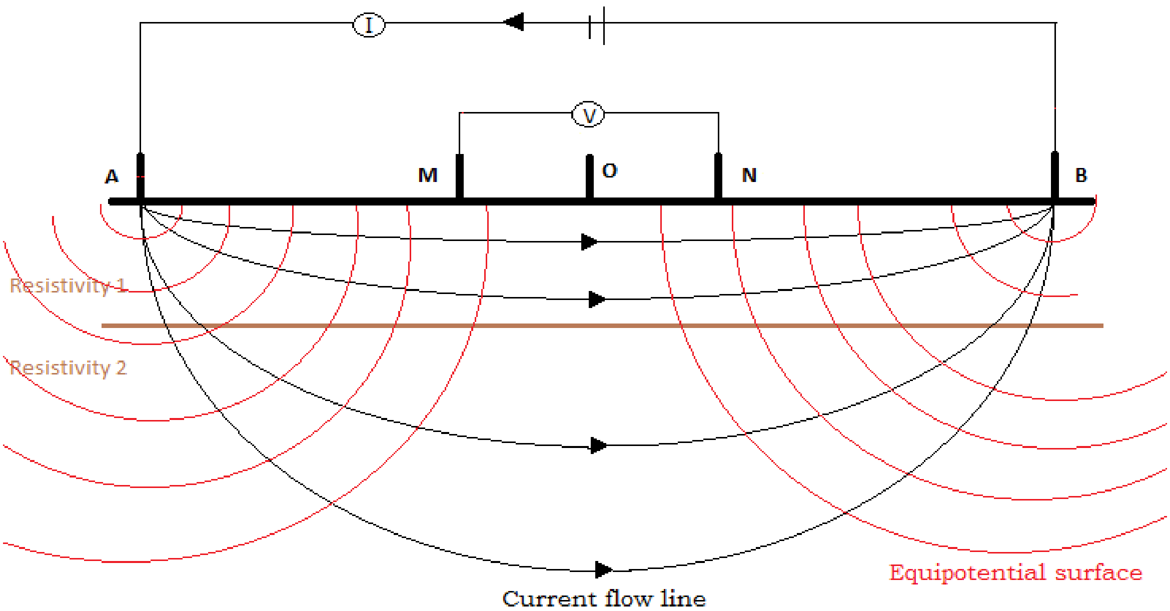


***Figure 3**: Schematic section of a Vertical Electrical Sounding (VES). Where A, M, N, B are the electrodes; O is the centre point; V is the voltmeter; I is the ammeter; the red lines represent the equipotential surface; the black arrows are the current flow lines.*

Resistivity of rocks depends on many factors: mineralogy, porosity, saturation, hydrochemistry, temperature, fracturing or metamorphism. For this reason it is difficult to attribute a cause of the resistivity to each type of rock. The fact that resistivity varies with water saturation and hydrochemistry makes possible to differentiate freshwater, seawater and mixing zone. Even so, geophysical studies are usually accompanied by other types of geological studies so that the causes can be interpreted.

Because of that, geophysical models are elaborated from the field data. The more this model adapts to the field data, the more reliable the probing will be. In an ERT the measurements are taken as in a vertical electric sounding (VES) but in this case the number of electrodes increases and measurements are made continuously. The ERT technique uses the values of apparent resistivity measured at the surface to generate images called pseudosections, which are necessary to solve the inverse problem and obtain a model of the subsoil. To adapt the data obtained to reality an inversion process is needed. In order to reach this, some software is needed to generate models that can adapt the interpretation to different variables that can be modified.

This method has been used to locate and identify fresh/saltwater interfaces, due to the fact that high-electroconductive fluid (saltwater) may produce a low-resistivity and a low-electroconductive fluid (freshwater) may produce high-resistivity (Zarroca et al., 2011, 2014). The saltwater high-electroconductive characteristics may generates a low-resistivity background masking the changes in resistivity on account of other variables as textural and porosity oscillations (Zarroca et al., 2011).

2.1.3.1.2. ELECTROMAGNETIC INDUCTION (EM)

EM is an electromagnetic induction survey, which its most relevant physical property the electrical conductivity, as in ERT and VES surveys, and it's sensed by means of a time varying magnetic and/or electric field. This method is based on the measurement of the change of conductivity between a pair of coils on or above earth's surface. There is a transmitter coil which is used to generate an electromagnetic field at specific frequency, known as the primary field. The primary field causes electrical currents to flow in conductive materials in the subsurface. This generates a secondary magnetic field which is sensed by the receiver coil. The magnitude of this secondary field depends on the type of material and its distribution. Both fields (primary and secondary) are detected at the receiver coil.

The EM methods can measure from the first meters of the subsoil to kilometres of depth. As in the electrical methods, an inversion process is also needed, with all the interpretative complications that this entails. The expected resistivity distribution, as in ERT, would consist of higher resistivity areas (freshwater) contrasting against low-resistivity background (saltwater). That method has been employed to some groundwater studies (Belaval, 2003).

2.1.3.2. PHYSICOCHEMICAL PARAMETERS

The water properties such as salinity or temperature can help to differentiate different water masses, since they do not mix due to their conditions. In the case of the SGD, salinity (fresh groundwater) and temperature (cold and with low variability during the seasons) are especially important, because these are the properties that contrast greatly from groundwater to seawater.

The contributions of SGD fresh water or brackish water modify salinity, making the coastal areas where these discharges occur have salinity lower than normal. The decrease in salinity influences other properties of seawater. For SGD studies it is especially interesting to study the different densities resulting from the different salinities. The waters of the SGD have lower salinity than sea water, making their density lower and therefore they are located in an upper layer of the water column. This arrangement of layered water creates a transition zone where water properties vary markedly. This layer receives different names according to the property that varies: Thermocline if the temperature variation is large, which can occur when the temperature of the SGD and the sea are very different; halocline if the variation is of salinity; pycnocline if the density varies, property dependent on the previous two, placing the waters of the SGD in the upper layer. These properties allow differentiating the mass of water discharged by the SGD and quantify its volume through the identification of the pycnocline.

2.1.3.3. RADIUM

Radium is a chemical element with symbol Ra and atomic number 88, it has 25 different known isotopes, but only four naturally occurring isotopes ^{223}Ra ($T_{1/2}$=11.4 d), ^{224}Ra ($T_{1/2}$=3.66 d), ^{226}Ra ($T_{1/2}$=1600 y) and ^{228}Ra ($T_{1/2}$=5.75 y). Due to the very differences between the half-lives of these isotopes, Ra-isotopes are commonly classified between: the short-lived isotopes (^{223}Ra and ^{224}Ra) and the long-lived isotopes (^{226}Ra and ^{228}Ra).

These isotopes are present in the nature in several matrices such as soils, rocks and in water (in both groundwater and surface water). The most naturally-occurring Ra isotope present in nature is the ^{226}Ra. The four mentioned isotopes conform the Ra quartet, which belongs to the ^{232}Th ($T_{1/2}$=$1.4 \cdot 10^{10}$ y), ^{235}U ($T_{1/2}$=$7 \cdot 10^{8}$ y) and ^{238}U ($T_{1/2}$=$4.5 \cdot 10^{9}$ y) decay series *(Figure 4)*. Thorium and Uranium are hardly linked to the geological matrices, some examples of the abundance in different materials and waters are given in the *Table 1*.

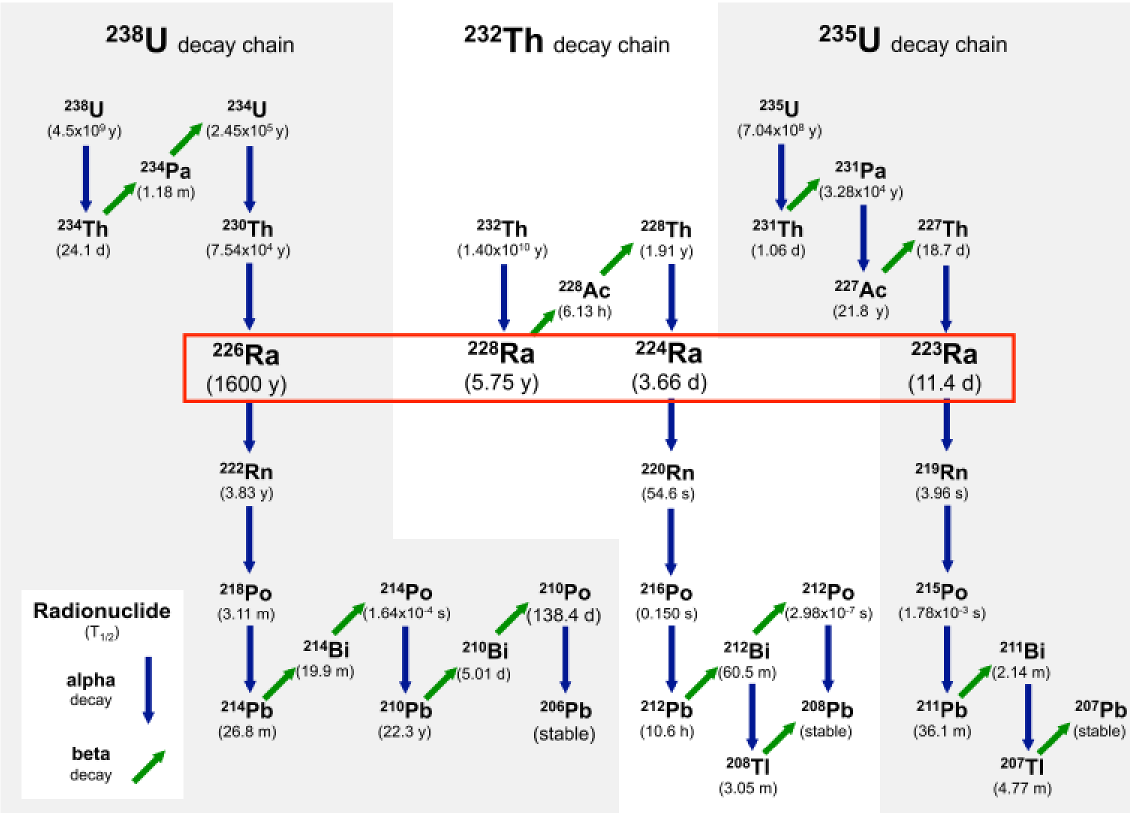


***Figure 4**: Uranium and thorium decay chains, the radium quartet is marked in red (Rodellas, 2014).*

Due to the differences in the physicochemical behaviour between parents and daughters and the biogeochemical processes in the aquatic system compartments, a radioactive disequilibrium and partitioning is produced (Garcia-Solsona, 2009). Ra isotopes are enriched in SGD, up to several orders of magnitude above seawater (Charette et al., 2008). In coastal sea Ra behaves conservatively, which means that its concentration is a function of only two variables: mixing and decay (Charette et al., 2008).

The enrichment in Ra depends on the aquifer (U-Th content of the geological matrix and transit time) and the ionic strength derived from the mixing of fresh groundwater and recirculated seawater in the subterranean estuary (Moore, 1999). Brackish groundwater is enriched in Ra between 1-2 orders of magnitude compared to the lower long-lived Ra isotopic activities and typically negligible short-lived Ra activities in seawater (Moore, 1996). Radium in SGD behaves conservatively in seawater (Garcia-Solsona, 2009). Radium is in secular equilibrium with its precursors (^{238}U and ^{232}Th), due to which the ^{228}Ra/^{226}Ra ratio in groundwater is usually similar to the ^{232}Th/^{238}U ratio in geological matrix. It is for this reason that, generally, the values of ^{228}Ra/^{226}Ra in groundwater may be associated with the primary source of radium.

Table 1: *Typical concentrations of U, Th and Ra (in mass and activity units) in various terrestrial rocks and water types (Eikenberg, 2002), applicable to the limestone of the Garraf massif.*

Type of sample		**^{238}U**		**^{232}Th**		**^{226}Ra $_{(1)}$**	
		ppm	**mBq·g^{-1}**	**ppm**	**mBq·g^{-1}**	**ppm**	**mBq·g^{-1}**
Igneous	Granite	2-10	25-120	5-30	20-120	0.5-4	25-120
	Gabbro	0.5-2	5-25	2-6	5-25	0.1-0.5	5-25
	Basalt	0.1-1	1-10	0.3-4	1-15	0.02-0.2	1-10
	Ultramafic	<0.02	<0.2	<0.05	<0.2	<0.01	<0.2
Sedimentary	Shales	2-4	25-50	5-15	20-120	0.5-1	25-50
	Limestone	1-3	10-40	0-3	0-10	0.2-1	10-40
	Coral	2-4	25-50	<0.01	<0.04	0.5-1	25-50
	Clay	1-4	10-50	1-15	5-60	0.2-1	10-50
Water $_{(2)}$	Seawater $_{(3)}$	3-4	40-50	<0.01	<0.05	0.01-0.1	0.5-5
	River water	0.1-1	1-10	<0.01	<0.05	0.01-0.1	0.5-5

(1) Values valid for secular equilibrium between all 238 U-series isotopes.

(2) Units for water samples [ppb] and [mBq·L-1].

(3) Range of values for 226Ra from Ivanovich and Harmon, 1992.

In freshwater, Ra transport depends on the adsorption/desorption processes. Radium is absorbed onto colloids and suspended particles (as clays and metal hydroxides), in the mixing zone the ionic strength varies and Ra is desorbed due to ionic exchange processes (Krest et al., 1999). Short-lived Ra isotopes are employed to estimate SGD fluxes and mixing times of near-shore waters, while long-lived Ra, which require a long time for regeneration, isotopes are employed to comprehend the Ra sources or fluxes (Moore, 2003). By determining all the sources and losses and establishing the radium concentration in the groundwater, the radium flux can be directly related to the SGD and quantified (Moore, 2003). The Ra excess calculated after defining the Ra inputs and losses is attributed to SGD (Garcia-Solsona, 2009).

In order to construct a mass balance is necessary to identify all the potential Ra sources (diffusion from fine-grained sediments, bio-irrigation, riverine discharge, ion exchange from suspended particles, atmospheric inputs, all the possible SGD sources and water recirculation) and sinks (radioactive decay, water outflow to deep waters, coastal groundwater discharge (CGD), and particle scavenging) that are shown in the *Figure 5* (Moore, 1999).

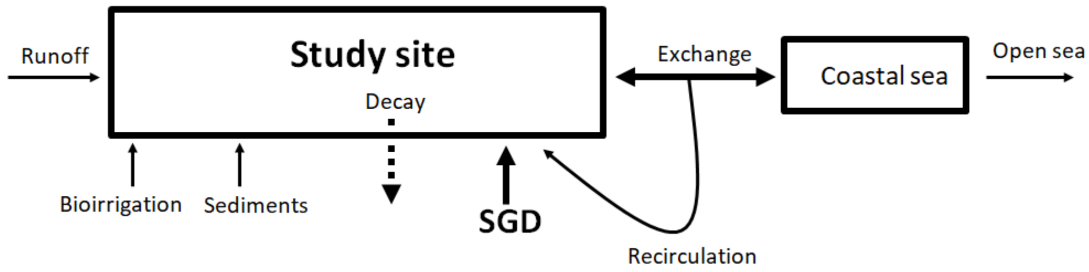


***Figure 5**: Box model scheme for the main radium inputs and outputs in Aiguadolç coastal area.*

The contribution of the internal ^{224}Ra, which is only available for exchange with porewater during weathering, to the adsorbed ^{224}Ra for sediments with particle size between 20-60 µm is negligible less than 2.25% (Sun and Torgersen, 1998). In muddy sediments, as in estuaries, the sediments flux of short-lived Ra isotopes may be significant, as in bioirrigation areas and particle mixing by the benthic fauna (Garcia-Orellana et al., 2014). But Aiguadolç beach is sandy, for that reason the sediments and bioturbation inputs are neglected. The diffusive input of radium from sediments is only a small fraction of the total radium flux (Charette et al., 2003). Summarizing, the most relevant sources of radium are the surface runoff and SGD, and the principal losses are the decay, the exchange with open sea and the water recirculation through coastal sediments.

The SGD estimation using Ra mass balances was first developed by Moore (1996), and widely used in several studies (Garcia-Orellana et al., 2014; Rama and Moore, 1996; Rodellas, 2014). If the groundwater is the dominant source of Ra in the study area, and the only sinks are ocean exchange and decay, is possible to assume that entrances are equal to the exits to calculate the groundwater flux for each portion of the coastal zone (at steady state):

$$SGD \cdot C_{RaEnd} = F_{Ra} - D_{Ra} \tag{2}$$

$$F_{Ra} - D_{Ra} = \frac{C_{exRaCW} \cdot V_{CW}}{t} - C_{exRaCW} \cdot \lambda_{Ra} \cdot V_{CW} \tag{3}$$

Where,

- SGD is the subterranean groundwater discharge flux (m^3·d^{-1}).
- C_{RaEnd} is the Ra endmember activity (dpm·m^{-3}).
- F_{Ra} is the Ra flux in the coastal water (dpm·d^{-1}).
- D_{Ra} is the Ra decay in the coastal water (dpm·d^{-1}).
- C_{exRaCW} is the coastal water Ra excess, which is equal to the observed Ra minus the offshore Ra measured (dpm·m^{-3}).
- V_{CW} is the whole volume of coastal water (m^{-3}).
- t is the residence or apparent time (d).
- λ_{Ra}: is the activity of the Ra isotope (d^{-1}).

Ratios between short-lived radium isotopes can be used to calculate water apparent ages/residence time of the water plume. This is the time elapsed since the water sample became enriched in Ra and was isolated from the source (Moore, 2000):

$$t = \frac{\ln\left(\frac{AR_{224/223End}}{AR_{224/223Cw}}\right)}{\lambda_{224}-\lambda_{223}} \quad (4)$$

Where,

- $AR_{224/223End}$ and $AR_{224/223Cw}$ are the activity ratios of ^{224}Ra and ^{223}Ra for the endmeber and for coastal water respectively.
- λ_{224} and λ_{223} are the ^{224}Ra and ^{223}Ra decay constants (d^{-1}).

2.1.3.4. RADON

Radon is a chemical element with symbol Rn and atomic number 86, is a noble gas, colourless, odourless and tasteless. Being a gas it has a great mobility and solubility in water, although it volatilizes quickly. Rn has multiple isotopes, natural and artificial, but ^{222}Rn ($T_{1/2}$=3.8 d) is the most stable of them, and it results of ^{226}Ra decay (*Figure 6*).

The Rn occurs naturally in the subsoil and emanates to the surface depending on the type of soil. The granitic zones are where the most radon is produced. The reason is that U and Th content in the granite is higher than in other types of rock such as sandstones or carbonates. The exhalation of radon occurs above all in porous soils, where the gas finds easy exit to outside. In very compact or clayey soils, less Rn is exhaled because they are less permeable. Very fractured granitic soils are also large emitters of Rn (El-Dine et al., 2001).

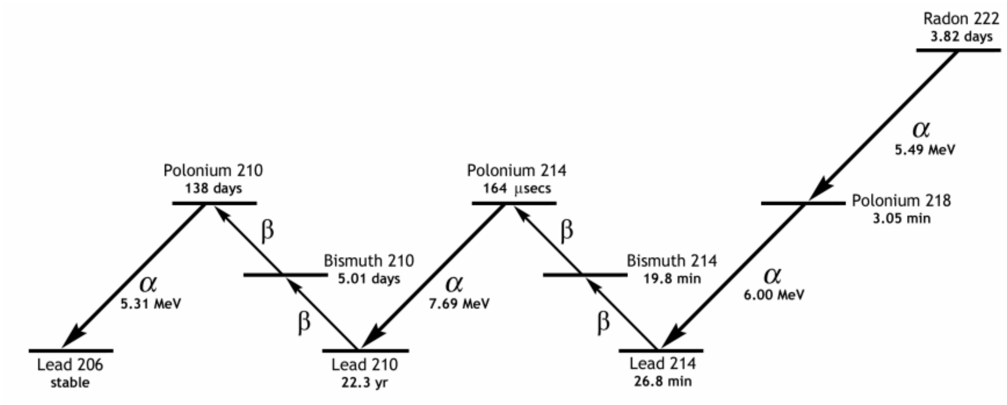


Figure 6: *^{222}Rn decay chain (Durridge, 2017).*

Meteorology also influences Rn levels. A most, permeable soil with a low atmospheric pressure and warm temperatures favours radon emanation while a dry soil, at high atmospheric pressure and very low temperatures inhibit the emanation of Rn. The isotopes of Radon ^{219}Rn (Actinon), ^{220}Rn (Thoron), and ^{222}Rn can be found in nature even though they have such a short life because they are constantly generated by their parents ^{223}Ra, ^{224}Ra, and ^{226}Ra, who are in secular equilibrium (situation in which the quantity of a radioactive isotope remains constant because of its production rate is equal to its decay rate) with long-lived isotopes 235.

2.1.3.5. NUTRIENTS

Nutrients are fundamental molecules in aquatic ecosystems, they are essential for live, but in excess could produce the dead of an ecosystem (thought eutrophication). The most important and necessary nutrients for live are phosphorous (P), nitrogen (N) and silicon (Si), because are limited in many marine environments. This limitation due to biological uptake and release generates a concentration variation, which is why nutrients are considered as non-conservative ions. Pinet (2016) described the near-surface nutrient concentrations in seawater for each nutrient element: P= 0.07 ppm, N= 0.5 ppm and Si= 3 ppm. Most organisms cannot use these nutrients in the elemental form and use the ionic forms as they are nitrite (NO_2^-), nitrate (NO_3^-), phosphate (PO_4^{3-}) and silicate (SiO_2).

The Mediterranean open sea has a strong oligotrophic character, these changes in coastal waters, due to continental waters influence from rivers and SGD. Even so, compared to other seas, Catalan coastal waters are poor in nutrients (Agència Catalana de l'Aigua, 2006). Nitrates have an important seasonal variation pattern, with maximum peaks that are reached from mid-autumn to late winter and minimum peaks during the summer; on the other hand, phosphorus does not have a clear variation pattern, but it is rapidly exhausted by phytoplankton when there is plenty of nitrogen (Agència Catalana de l'Aigua, 2006). The ACA (2006) confirm that in open areas and rocky coastlines such as the coast of La Selva or the Baix Empordà the annual average concentrations in surface water of these elements are low, usually less than 1 $\mu mol \cdot L^{-1}$ for nitrates and 0.1 $\mu mol \cdot L^{-1}$ for phosphates.

In karstic Systems the rainfall waters have a minimal filter and the transport of pollutants into the sea is usually fast. The water-rock interactions and the biogeochemical reactions that occur in the karstic aquifer (of calcium carbonate matrix) eliminates the greatest amount of nutrients in the form PO43- due to its mineral precipitation with Ca, Al or Fe in apatite training (Charette and Sholkovitz, 2002).

SGD is an important nutrient input into the ocean (Krest, 2000). Fresh groundwater is a major source of nutrients, which could be essential for the ecosystem. But the anthropization of the environment can impact into the leaching and in the drainage, modifying the natural nutrient fluxes. Agriculture, wastewaters and uncontrolled landfills, are some of the agents that could change the nutrient inputs among other SGD parameters. Because of the fact of being a source of nutrients in an oligotrophic environment, SGD could be detected through the nutrient analysis (Garcia-Solsona et al., 2010; Slomp and Van Cappellen, 2004) and the dissolved Si (DSi) can be used as a tracer.

3. INTRODUCTION TO STUDY AREA

3.1 REGIONAL GEOGRAPHY

Sitges is a municipality in Catalonia (Spain), located between Barcelona and Tarragona *(Figure 7*). The town has a population of 28.527 habitants, and belongs to the Garraf region which borders the Mediterranean Sea and the Baix Llobregat, Alt Penedés and Baix Penedés counties (Barcelona province).

The GDP per capita in the region is about 17.3K €, versus the 30,2K € in Catalonia, and the ratio of unoccupied population per active population is the 21%, less than the 25% in the autonomous community. The municipal district of Sitges, of 43,85 km^2, shares territory with a massif, a coastal plain located between sea level and height 100 m with a median slope of 2,5% and the sea. The most significant element of the region is the Garraf massif (Garraf Natural Park), due to the iconic of its landscape and its natural resources. The region has important natural spaces and landscapes, as well important socioeconomic development *(Figure 8*).

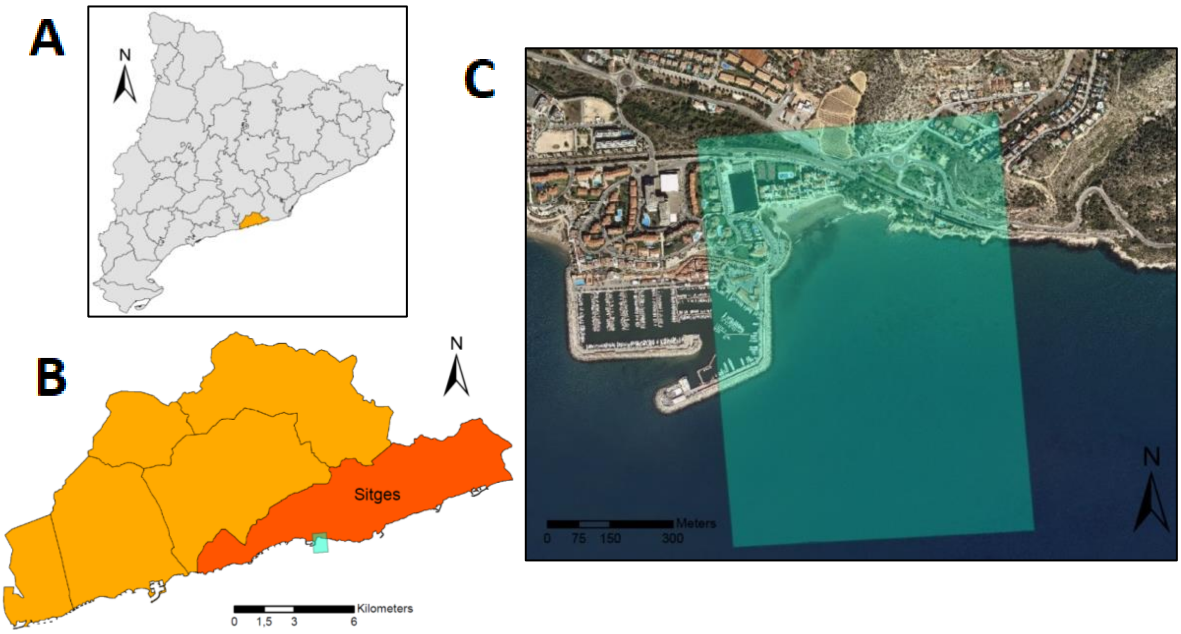


Figure 7*: Study zone location. Where: A) is the Location of Garraf in Catalonia autonomous community, B) is the location of Sitges in Garraf and C) is the location of Aiguadolç in Sitges (in blue, Aiguadolç beach studied zone).*

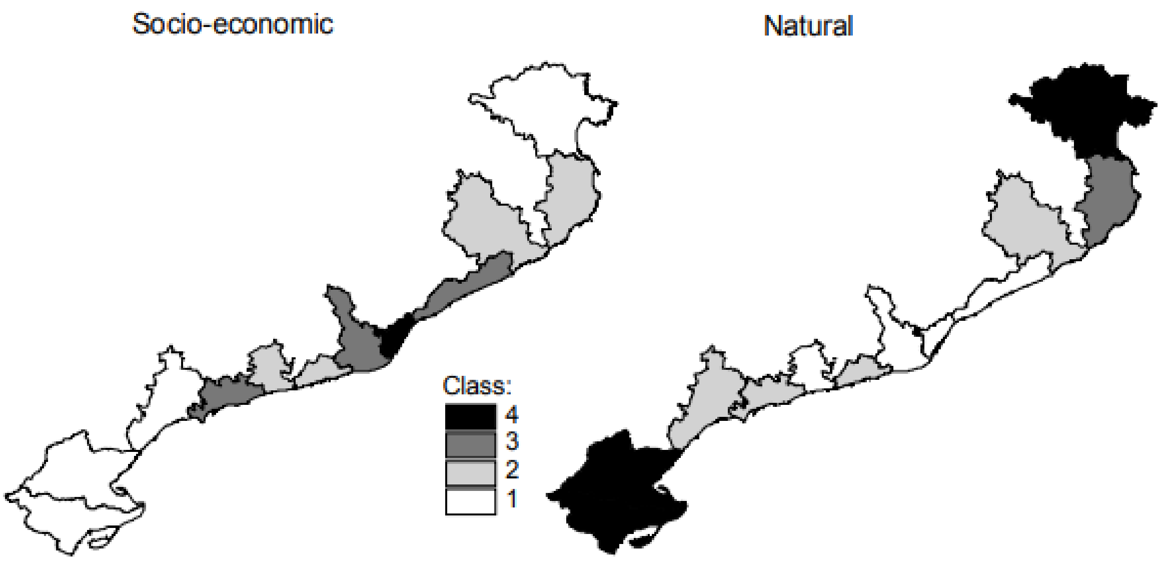


***Figure 8**: Socio-economic and natural regionalisation of the Catalan coast, values were generated by classifying Catalan coastal regions by using the Jenks method. The maximum value (four) indicates the highest relevance of the characteristic and the minimum (one) indicates the lowest relevance (Brenner, 2007).*

***Table 2:** Tourist accommodation in Sitges. Institut d'Estadística de Catalunya (https://www.idescat.cat/).*

Tourist accomodation, 2017	
Hotels	48
Places of hotels	4807
Campsites	2
Camping sites	2238

***Table 3:** Sitges population by place of birth, nationality and kind of population placement. Institut d'Estadística de Catalunya (https://www.idescat.cat/).*

Population	**Sitges population by place of birth (2017)**	**Sitges population by nationality (2017)**
Catalonia	16713	22675
Rest of Spain	4195	-
Foreign	7619	5852
Total	28527	28527
Population equivalent to full annual time (2016)		
Resident population	28478	
Seasonal population	2226	
Total	30704	

Socio-economic and natural regionalisation of the Catalan coast, the values were generate by classifying Catalan coastal regions by using the Jenks method. The maximum value (four) indicates the highest relevance of the characteristic and the minimum (one) indicates the lowest relevance (Brenner, 2007) and the Garraf is classified with a medium value for both factors. Sitges seafront is gifted with 3 sport harbours along 16.5 km, and some of the beaches have been awarded for their quality *(Figure 9)* becoming the 2nd municipality with more quality beaches in Catalonia. The exploitation of marine resources leaded traditionally to an important fishing activity, and currently a well-developed tourism sector as the main economic engine. Sitges is the European LGBT capital and it results in a very important factor for the tourism, the hotel industry sector of Sitges leads to Garraf with almost 73% of the places in the region with 48 hotels, most of four stars at least (*Table 2*).

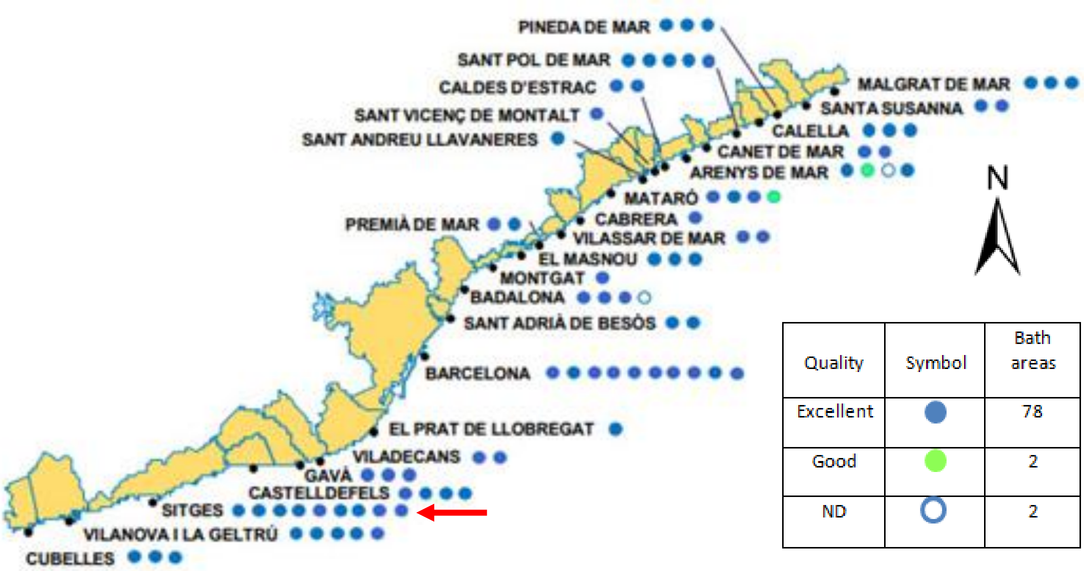


Figure 9: *Catalan beaches by quality, the red arrow indicate Sitges. Modified from Agència Caatlana de l'Aigua* (http:// http://aca.gencat.cat/).

This not only translates into hotel occupancy, but the tourism sector extends to the residential. Sitges abound in tourist residences; in fact an important part of the population is foreign. The population born outside of Catalonia (*Table 3*) represents 41% of the population, with a greater proportion than in the Garraf region (35%) and in Catalonia (22%). The seasonal population represents 7% of the total number of people who live in Sitges during the year.

There are other very important economic sectors as restoration, souvenirs, and boutiques. Principally the land uses are natural conservation, farming and urban. The most important part of the region can be categorized as natural vegetation, basically the massif's surface (*Figure 10).* The rest of the area is a combination of field crops and urban soil; these land usages are located in the coastal plain and represent 2/3 of the total area, in the *table 4* the surface uses dimensions are described. In addition, in the Garraf massif there are the cement industry and the old landfill where waste from the metropolitan area of Barcelona was accumulated at the ending of 20th century.

Table 4*: Land uses surface (Soler et al., 2012).*

Land uses		
Category	**Surface (ha)**	**%**
Natural Vegetation	12170,75	65,72
Crop fields	25781,98	13,89
Urban and urbanizable	2689,58	14,52
Anthropic	1087,69	5,87

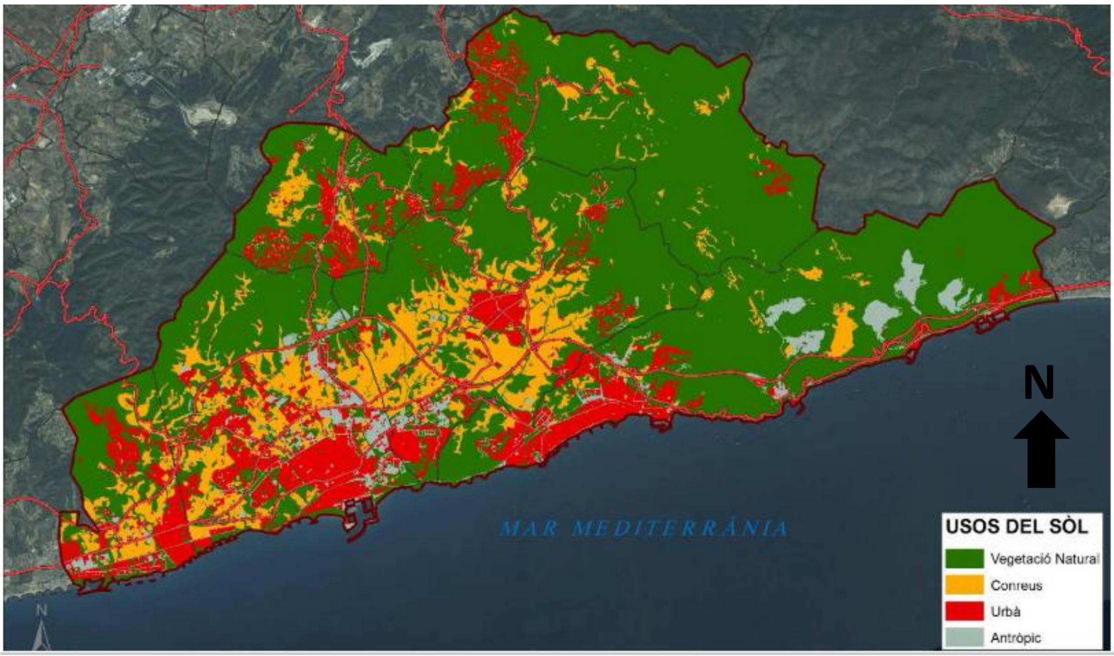


Figure 10: *Land uses map of Garraf. In green the natural vegetation, in yellow the crops, in red the urban soil and in grey the anthropogenic soil (Soler et al., 2012).*

3.2. ENVIRONMENT CHARACTERIZATION

3.2.1. FLORA AND FAUNA

Near Garraf coast a very rich ecosystem is present, in special for the 281 hectares of *Posidonia oceanica* meadows, shown in *Figure 11*, which are in front of Sitges (Palomino de Dios et al., 2012). This area is designated as SCI (Site of Community Importance). About 200 and 500 m offshore there are *Posidonia oceanica, Cymodonea nodosa and Corallina elongate* meadows, which start in front of Aiguadolç and extend to the South. The presence of these marine phanerogams is especially important because they serve as habitats for benthic and pelagic organisms and protect littoral zone from the effect of waves, and is also a clear indicator of good water quality.

The Garraf coast hosts a multitude of marine species, some of them in danger of extinction. Cetaceans are also frequent, such as sperm whales (*Physeter macrocephalus)*, dolphins, pilot whales (*Globicephala melas)*, turtles and numerous species of fishes, and others are less frequent as fin wale (*Balaenoptera physalus*) In the benthos of these waters live many species of bivalves, gastropods and cephalopods, specifically 68 species (Peñas et al., 2015) and several species of crustaceans. In addition, on the Garraf coast, live numerous species of seabirds that feed on marine fauna.

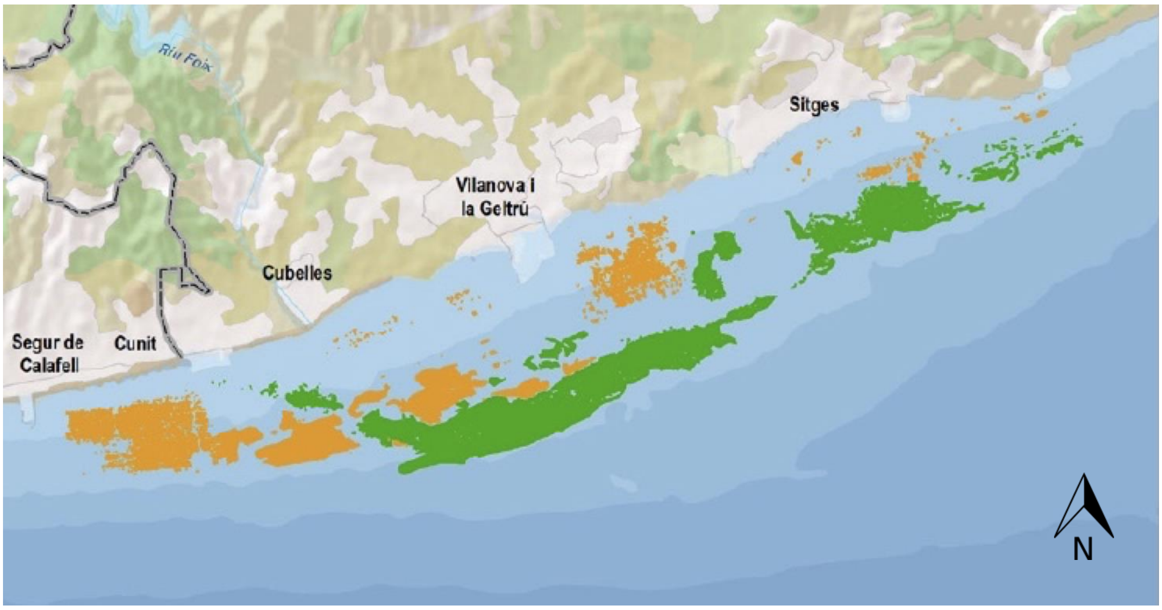


Figure 11: *Distribution of Posidonia oceanica (in green) and Cymodocea nodosa (in orange) meadows in Sitges coast and surroundings (Ruiz et al., 2015).*

3.2.2. CLIMATOLOGY AND METEOROLOGY

Garraf has a Mediterranean climate characterized by having dry, hot summers and temperate winters. Rainfall is scarce and concentrated in spring and autumn. In these times of the year the precipitations can be very intense, causing floods and erosion of the coasts, arriving to cause problems of lack of sand in the Catalan. Garraf is between sea and mainland, this location gives to the area a clear maritime influence, which is reflected in more moderate temperatures and a higher humidity than in the continental Mediterranean climate. The Garraf massif isolates Sitges from the cold winds of the interior such as *Tramuntana* (N) or *Llevant* (E) and makes the tempering effects of the sea more remarkable.

The maximum temperatures are in the months of July and August, reaching 30º C of maximum daily average. The minimum temperatures occur in the months of December, January and February, reaching the minimum daily average of 4 ºC (*Figure* 12). The average annual rainfall is around 600 mm. The highest average rainfall occurs in the spring and autumn months, reaching around 50 mm (*Figure 12*). In spite of this, the precipitations are very irregular, with years that exceed the 600 mm and other years in which it hardly rains.

The wind blows stronger in the spring arriving at average speeds of 19 $km \cdot h^{-1}$ and coinciding with a season where there are important rain episodes and most of the time it blows from south to north. These winds are characterized by being warm. In addition, these winds can bring particles of Sahara dust. As mentioned before, it can be seen how the north winds are weaker due to the barrier represented by the Garraf massif.

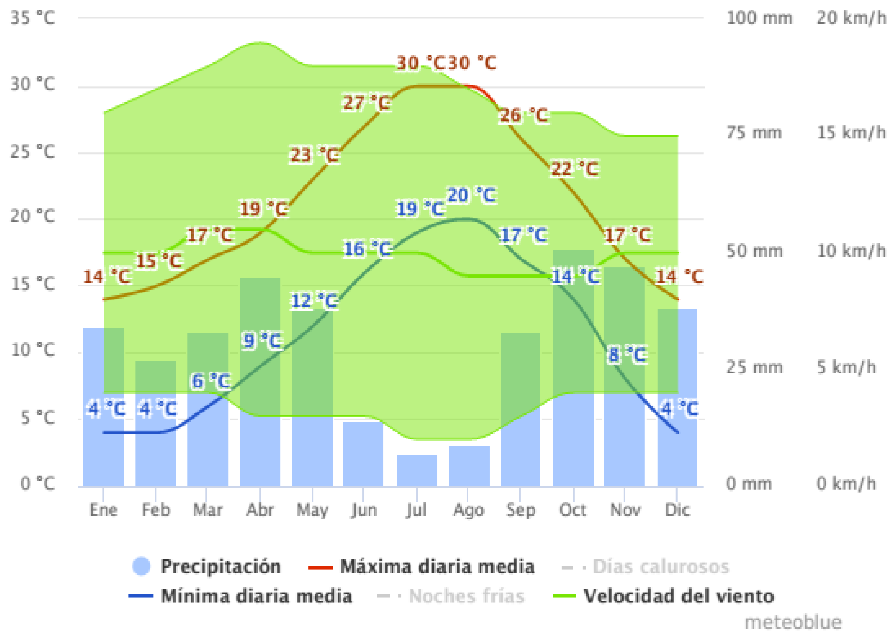


Figure 12: *Temperature, precipitation and average wind speed during the last 30 years (https://www.meteoblue.com).*

According to the INUNCAT (2010) graphics in Sitges can rain much more than the annual averages. In addition, the precipitations can be very intense, arriving to rain a lot of water in a few hours. These types of episodes are called cold blobs and are especially dangerous because of the damage they can cause. All of these precipitations produce material and human damages. For this work it is interesting, above all, the damage caused by erosion on the beaches. To appreciate the strength with which the spring and fall rains may have, the example of June 6, 2018 can be seen, when in just one hour it rained 45 mm. This amount is closer to the average monthly precipitation of the rainiest months of the last 30 years.

3.2.3. OCEANOGRAPHY AND COASTAL GEOMORPHOLOGY

The maximum tide does not reach 70 cm and the ordinary is approximately 30 cm. In the area, the most characteristic and predominant waves are those from the South-West and in second term those from the East. Waves are the exclusive agent of the sand drag along the coast, in NE-SO direction.

With respect to the marine currents, the predominant direction is the NE-SW direction but of little intensity. In open areas it does not go from 0,5 to 1 knot, and close to the coast is minimum (entorn and sitgesmodel XXI, 2008). The construction of the Sports harbours caused significant changes in the dynamics of coastal sediment transport, with significant regressions on the beaches located in the west of the harbours. Artificial breakwaters have been built along the coast, in order to solve these problems (Soler et al., 2012).

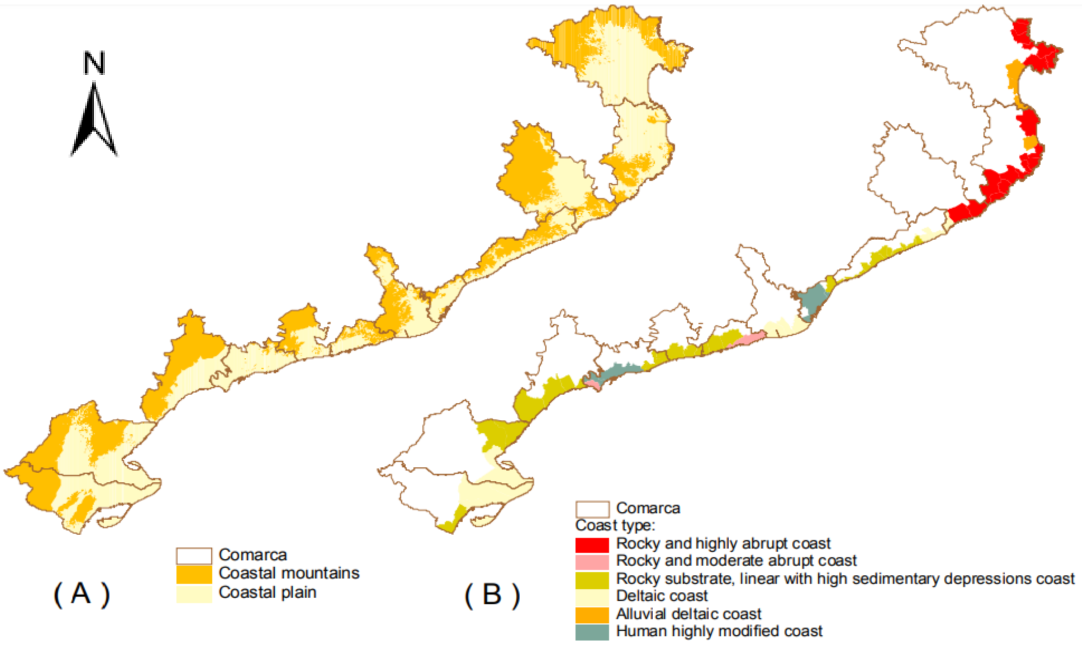


Figure 13: *Geomorphology along Catalan coast according to the type of materials (Brenner, 2007).*

The Garraf coast is as a transition from the Baix Llobregat beaches to the Costa Daurada beaches. It presents low cliffs with pocket beaches, some artificial ones, and the majority of these beaches present fine sands (*Figure 13*). Our study zone is the transition between a coastal plain (rocky substrate with recent sediments) and a coastal massif (rocky and moderate abrupt coast and cliffs).

3.2.4. ANTHROPOGENIC IMPACTS

Garraf coast has been very affected since the second half of the 20th century by the anthropic activities. These impacts have modified geological matrix and coastal ecosystems, partly damaging them. The reach of the karst is greatly influenced by the anthropic action (*Figure 14*): it is surrounded by urban soil; there are several open-cast quarries, a cement industry near the coast, four ports and the Vall d'en Joan dump (which present serious management problems). All these anthropitzations have their impacts in SGD, changing the fluxes and their composition and, therefore, having a direct impact on marine ecosystems and affecting the users of the beach and its surroundings.

These anthropic pressures can impact the massif in various ways and scales. The quarries become an important rainfall recharging points with high amounts of materials suitable for being transported by water action, these water contributions may contain cement industry materials that are incorporated directly into the sea and muddy the water. The cement industry generates a range of possible contamination of soils and waters due to the time that the industrial activity was developed, from the beginning of the last century until the 90s, as denounced entities such as DEPANA (League for the defense of the Heritage Natural). The crops located on the karst could also be contaminating the aquifer with the use of plant phytosanitary ware and the farms with the animal dropping.

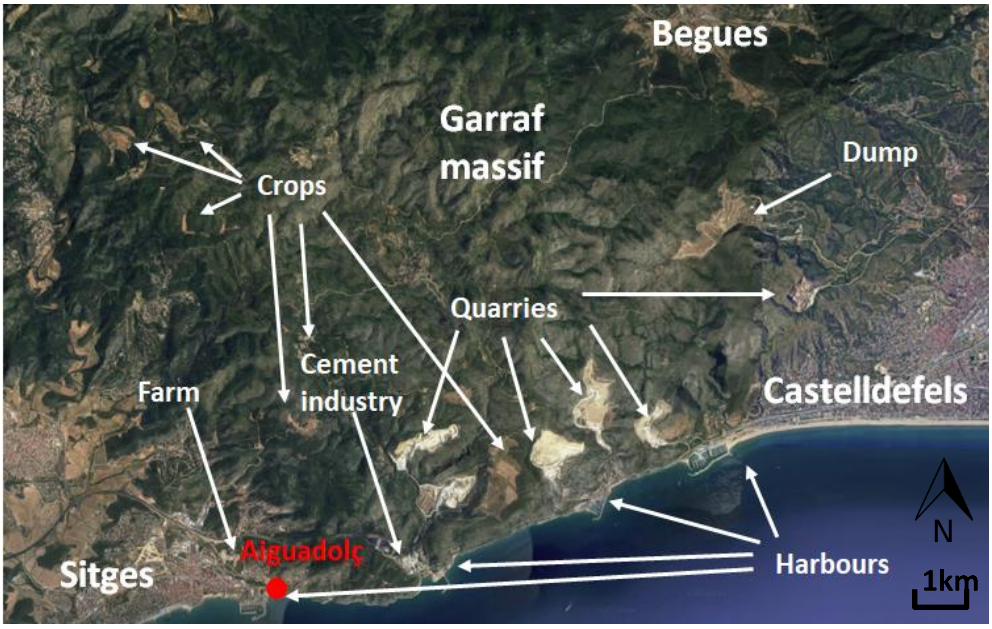


Figure 14: *Aerial image of the Garraf coast where the main zones of anthropic influence in the natural system are indicated.*

Until the end of the century, the Garraf landfill collected all kinds of waste from Barcelona, and the lack of resources for its management has led to the leachate of these waste that where infiltrated through the soil and the karst. The heavy metals and other pollutants adversely affect the terrestrial biota of Garraf (Sánchez-Chardi and Nadal, 2007; Sánchez-Chardi et al., 2009; Torres et al., 2006). De Lapuente et al. (2014) demonstrate that Garraf landfill produces more embryotoxic damage to the surroundings, due to its content in heavy metals, than other Catalan landfills (Can Mata and Montferrer-Castellbó). Several potentially toxic substances as Pb, Cd, Mg, Zn, Cu, and Cr indicate the harmful effect on wild terrestrial mammals (Sánchez-Chardi and Nadal, 2007; Sánchez-Chardi et al., 2009, 2007). But it seems that marine fauna and flora are also impacted, as it is described by the divers and speleologists who frequent the Falconera area. This location is well-known for being a subterranean river of importance, but now it is one of the biggest management problems in Sitges, due to the strong odors that it produces in the massif. According to the mayor of Sitges, the smells are so strong that some inhabitants have abandoned the urban center of Garraf. In some urbanization such as la Plana Novella they are suffering ammonium water pollution, disabling the use of water for human and animal consumption.

In addition, the fact that harbors urbanized soils and communication channels have made the functioning of the karstic system change, which already has a complex flow dynamics in itself. Aiguadolç beach surroundings are highly urbanized; in this case the buildings are residential and related with the tourism sector. Examples of this are the Punta Gavina urbanization, La Marina urbanization or Hotel Estela Barcelona among others, adding more anthropic pressure to the beach and the aquifer, because all are directly build on the aquifer unit. Not only the surroundings of Aiguadolç are urbanized, but also the entire Garraf massif is, surrounded by large population centers and crossed by major communication routes (C-31, C-32 and railroads among others). This can affect the components of the SGD contaminating the coastal waters and can also act like a barrier by redirecting the flow of the surface aquifer to specific points. All these facts are related with the bad conditions of Garraf groundwater in ammonium, sulphate and perchlorethylene (*Table 5*).

Table 5: *Garraf groundwater chemical status. Agència Catalana de l'Aigua (http://http://aca.gencat.cat/).*

Quality element	Nº sampling spots	Nº samples	Good quality water mass (%)	Diagnosis
Ammonium (%)	32	36	69	Bad
Arsenic (%)	32	52	100	Good
Cadmium (%)	32	52	100	Good
Lead (%)	26	52	100	Good
Chloride (%)	32	61	51,5	Bad
Conductivity (%)	32	69	60,3	Bad
Sulphate (%)	26	61	69	Bad
Nitrate (%)	32	64	91,3	Good
Chloroethylene	8	21	99,9	Good
Perchlorethylene	8	21	36,9	Bad

The extraction of fresh water from the aquifers caused that for a few years the SGD process was interrupted and these aquifers were salinized due to marine intrusions (*Table 5;* Soler Bartomeus, 1983). In addition, humans have changed the beach geomorphology to make it more attractive for the tourism, as Aiguadolç, which now is a sandy beach when it used to be a pebble/rocky beach. For some years fresh water discharges have been reactivated with the inconvenient facts that are criticized by the neighbors.

As it can be noticeable in the *Figure 15* the construction of the Aiguadolç harbor (1983) has radically changed the geomorphology of the beach, varying the rates of sedimentation-erosion and possibly modifying the SGD paths. In addition, coastal morphology evolution of the coast in Aiguadolç is evident. From 45 to 86, substantial changes are observed with respect to the coastline modifying the land landscape, mainly due to changes in land use and the edification of infrastructures. The Aiguadolç harbor infrastructure is the most significant change in the beach. There are many pools and gardens of grasses around the beach since 94. The land uses pass from agriculture and forestry use to communication channels, the port and urbanizations dispersed tied to it from the 80s. In 90's some dispersed urbanizations at the first line of the coast and businesses related to the tourist exploitation of the beach where build.

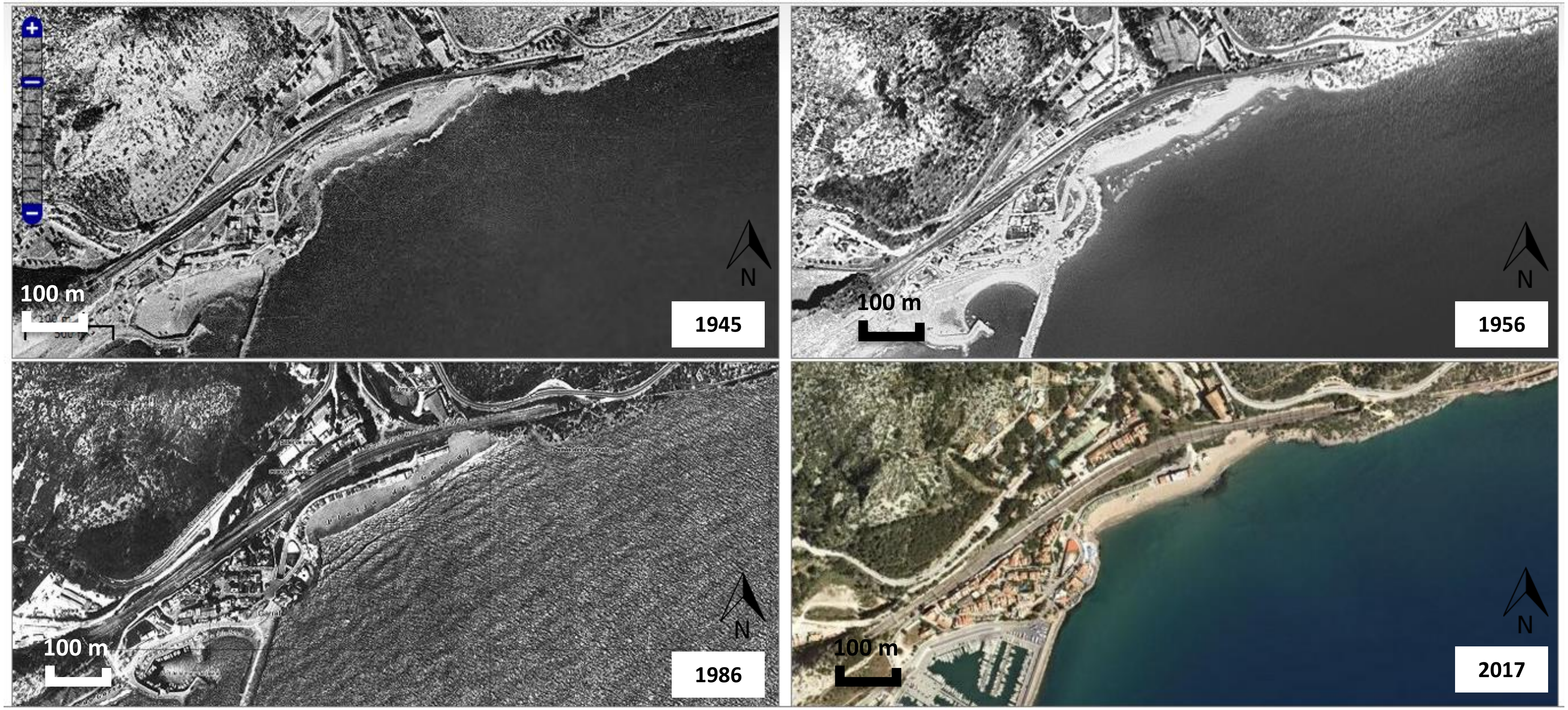


Figure 15: *Ortophotos from Aiguadolç beach in different time intervals 1945, 1956, 1963 and 2017. Institut Cartogràfic i Geològic de Catalunya (http://betaportal.icgc.cat/canurb/).*

3.3. TERRITORIAL PLANNING AND LEGAL FRAMEWORK

The following laws and legal framework are the most suitable to have some kind of influence in the project proposal. The actual Spanish coasts regulation framework is the *Law 2/2013, of May 29, on the protection and sustainable coast use and the modification of Law 22/1988, of July 28, of coasts*. The main aim of this law is the protection of the coastal environment, including; adaptive measures to climate change, measures for monitoring the sustainability of the economy, restrictive building measures to protect some spaces, and the study zone is a competence of this law. This law depends on the *Ministerio de Medio Ambiente, y Medio Rural y Marino* and it is a state competence.

In terms of local scale, the management and planning is implemented with different documents plans. The *Pla d'Ordenació Urbanística Municipal de Sitges* (POUM) of 2006, which is an integrated urban planning tool of the municipality's territory, and the most important and basic framework. Its functions are: to classify the soil and establish the legal framework; to define urban implementation and urban development strategies; to generate a program for the development and execution of the corresponding forecasts.

The *Pla director urbanístic del sistema costaner* (PDUSC) and the *Pla director urbanístic dels àmbits del sistema costaner integrats per sectors de sòl urbanitzable delimitat sense pla parcial* (PDUSC-2), are from 2005 (but were modified in 2014).These documents are processed and approved in order to protect open spaces and guide the development of soils which are located less than 500 meters from the coast. The PDUSC regulates two types of land: the urbanizable and the non-urbanizable, from a territory of supramunicipal scope.

Finally, in the closest level to the area of study, the *Pla Especial Urbanístic del sector B-5 Port d'Aiguadolç*, which is a derived urban planning subordinated to the POUM. It attempts to order the uses related to the port infrastructure, nautical activities and services.

With respect to water management, the most important law is the Directive 2000/60/EC, *Directiva Marc de l'Aigua*. The Agency is working on the progressive implementation of the Directive 2000/60/EC thought the Management Plan for the River Basin District of Catalonia (PGDCFC; November 23, 2010) is the new instrument for water planning for the period 2010-2015 in the territorial area competence of the *Generalitat de Catalunya*. PGDCFC is the tool that will determine the necessary actions and measures to develop the objectives of hydrological planning for the internal watersheds of Catalonia and the associated groundwater and coastal waters.

In 2006, the Consortium the Colls and Miralpeix-Coasts of Garraf was created, as an organization for the integrated management of coastal zones, with the objective of managing in a sustainable and integrated way the coastal area (marine and terrestrial) of the Garraf region, favouring the biological connectivity of this area. The Consortium promoted the elaboration of the Integrated Management Plan of the coastal areas of Garraf, as the territorial planning tool that establishes the guidelines for action and planning. The main objective of the Plan is to preserve the free spaces of interest on the Garraf coastline, and on a higher scale, to guarantee the recovery of potentially connecting areas and the continuity of the coastal areas with the protected interior areas.

Due to the ecological importance of the Garraf coast, zones of ecological importance have been delimited. The Garraf massif has its own regulation framework, is one of the areas that were included in the Special Plan of Natural Interest (PEIN) of Catalonia in 1992, and it is also part of the Natura 2000

Network, a special conservation areas network at European level created by the Habitats Directive, and place of community importance (LIC) and also a zone of special protection for birds (ZEPA).

3.4. AIGUADOLÇ BEACH

One of the Sitges' awarded beaches is the main scope of this study, Aiguadolç beach (coordinates 41°14'11.3"N 1°49'41.1"E), which is located between Garraf massif and the urban core on the plain. This beach of 145 m length and 20 m width, is communicated with an entirely urbanization (La Marina d'Aiguadolç) to the NW, with a harbour (Port d'Aiguadolç) to the SW and with the Garraf massif to the E. The limits of the beach are to the west a breakwater and the access road to the harbour and to the east a rocky cliff.

At the E of the Aiguadolç harbor there is the torrent (intermittent channel) of the same name that drains into the sea in the beach of Aiguadolç. This torrent has a length of 5 km and is integrated into the urban plot. There is another smaller torrent in the W side of the beach. The beach has a highly anthropic modifications, its original soil was calcareous rocky, composted by boulders and the limestone bedrock; but it was covered by sand for the tourism.

There is a freshwater outlet that gives the name of Aiguadolç and there are notable freshwater layers that emerge from the subsoil rivers in the middle of the sea and near the coast (Muntaner, 1986), the submarine emergence is also recognized by the terriginal spots that leave in the marine water (Custodio et al., 2017). Is historically registered that water flows intermittently between the stones of the beach and that probably in the antiquity it was place of water supply to the ships of step. Muntaner appoint different outlet emergences from 1609 and notable sorrows 1822, 1869 and 1953, reaching flows of 1440L·min^{-1}, but the general behaviour tended to decrease since the middle 90s. This is due to the railroad construction, which runes partially covered the exit hole; but in the beginning of the 21th century the emergences started to work another time.

In 2014 the local newspaper L'Eco de Sitges publishes a new: Fresh water floods five beaches. In this article it is affirmed that salinity of the sea in Aiguadolç decreases five points due to the freshwater inflow (*Figure 16*), and that 'Two streams flow through the sand. Alongside and leaving between the same sand, small springs flood the area by expelling cold water that comes from the ground and which, thanks to the pressure, form small fountains'. Geologists from the Col·legi de Geologia de Catalunya (COLGEOCAT) visited the freshwater emanation of the beach of Aiguadolç (*Figure 17*) with the intention of verifying if it is a natural water emergence. They confirmed that there are not dangerous pollutants for human health.

But for the beach users this become a problem for its own enjoy of Aiguadolç. Some issues are described by the local citizens are about the beach's state. The freshwater is rich in nutrients, and can stay stagnated for a few time in the sand, contributing to the appearance of algae. When the upwelling of fresh water becomes important it could result in a difficult beach for stay or walk around. There are some sinkholes, and they could drain the wet sand and sink objects or people's feet when they are above it.

Figure 16*: Water outlet emergences produce a warning in Sitges, the council takes some actions to guarantee the citizens safety (http://lecodesitges.cat/laigua-dolca-inunda-cinc-platges).*

This beach has an entire urbanization and hotel complex behind, and it is one of area’s attractions with greater added value. There is a surf school and a beach bar in Aiguadolç beach that can be affected too. And the Aiguadolç’ harbour could be impacted in different ways as the proliferation of planktonic blooms, and the consequent management problems.

Figure 17: *Freshwater emanations in Aiguadolç (COLGEOCAT).*

4. THE GEOLOGY OF EL GARRAF

The Garraf massif is a calcareous and high-rise rectilinear cliff, with scarce and small coves. From the village of Garraf, the cliff is ended by the dragging of the detritic materials of the Llobregat delta, and retreats progressively towards interior, connecting to the south with the low coasts of Penedès. At cliffs base, a marine platform extends up to 100 m, where the slope becomes more accused and the continental slope begins appearing some submarine bumps and canyons. The coast line and the extension of the platform have changed following the eustatic movements, ascent and descent from the sea level. About 25,000 years ago the level was 120 m below the current one and the coast had been about 20 km away inside.

This massif is a horst that occupies an area of 500 km^2. It forms low mountainous reliefs with a maximum height of 600m due to a gentle tilting. The central part of the massif is dominated by Cretaceous carbonate rocks, where most of the karstic morphologies have been developed (Daura et al., 2014). The karstification of this massif is concentrated in the fractures of the carbonate rocks, reaching to form structures such as dolines, shafts, and caves containing Pleistocene sedimentary (Daura et al., 2014). During the alpine orogeny, a northeast-southwest compression resulted in an antiform structure (Daura et al., 2014), with fractures in the same directions (Guimerà, 1988). The development of shafts in this massif is controlled by fractures following two directions: NE-SW and NW-SE (Daura et al., 2014). The springs sprout along the coast, from Punta Ginesta to the Aiguadolç Creek. The most important in the Garraf massif is the Falconera, which constitutes a true underground river.

From a geological point of view the Garraf massif is a tectosedimentary unit, consequently the materials that shape this massif are a function of structure and the tectonic moment at the time of deposition of the different materials over time (Instituto Tecnológico Geominero de España, 1989). Tectonically, the Garraf mountain range and the basin have been controlled by late Hercynian faults at the socle level, which have allowed the differential subsidence between the different units; but in general lines the deposition in the basin corresponds to a series of pits, with semigrabben structure within, which different kinds of sedimentation originated, and which underwent stages of compression and distension, result of the reactivation of the faults of the socket (Instituto Tecnológico Geominero de España, 1989).

Aiguadolç beach is the most southern beach of the Garraf massif. According to *Figures 18* and *19* and *Appendix 1* and *2*, Aiguadolç is located in the transition between the Miocene-quaternary detritic basin and Cretaceous carbonate massif, resulting in a complicated aquifer complex. In the *Figure 19* can be seen how the carbonates have direct contact with the sea water and therefore the SGD could flow through this aquifer directly to the sea. Structurally it is located in the Catalan Coastal Range, marking the interface between Neogene basin and coastal mantles or if we speak of relief, in the interphase between Prelitoral depression and Serralada Litoral (Garraf massif).

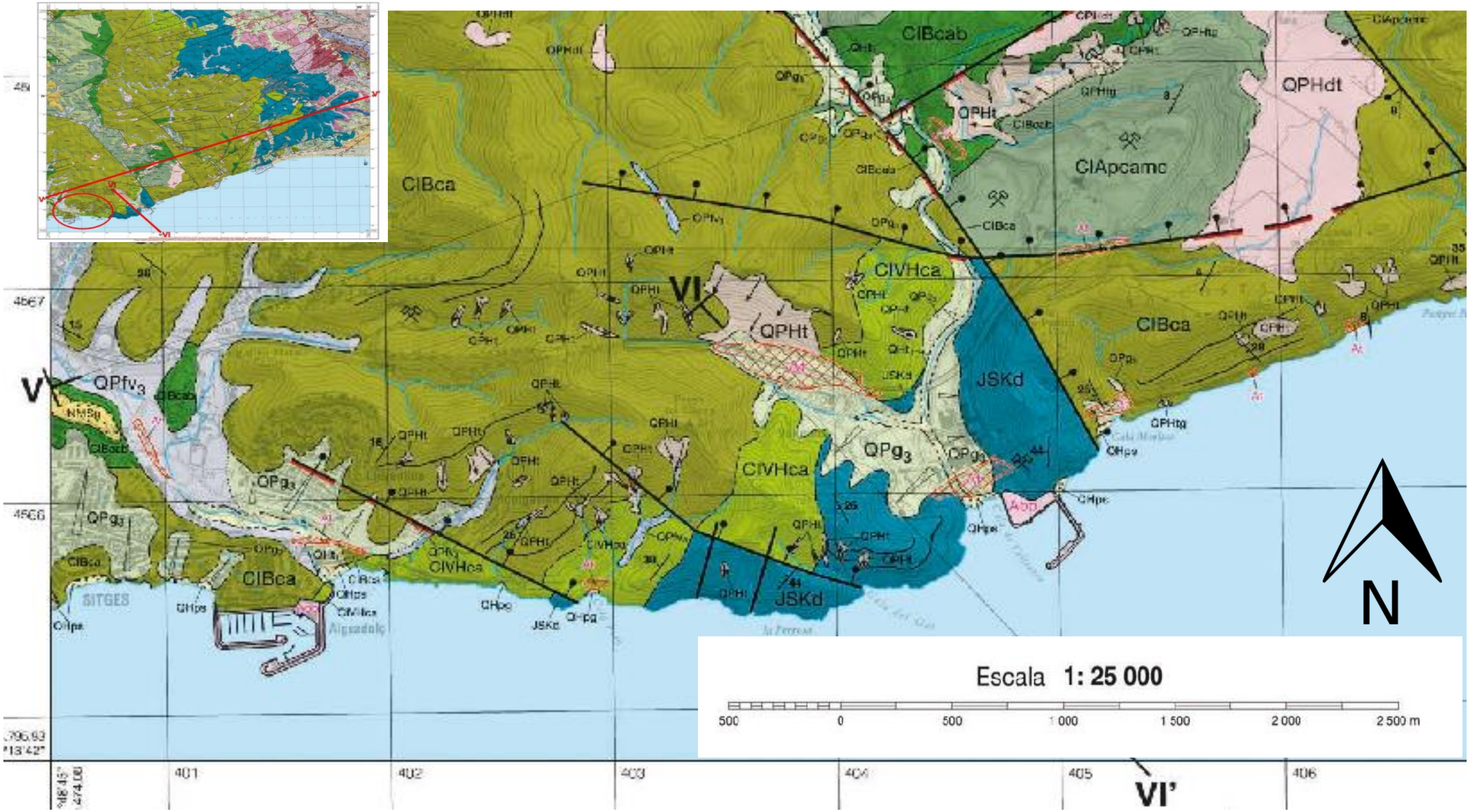


Figure 18*: Geological map of Catalonia Castelldefels-Vallcarca 1:25.000.ICGC*

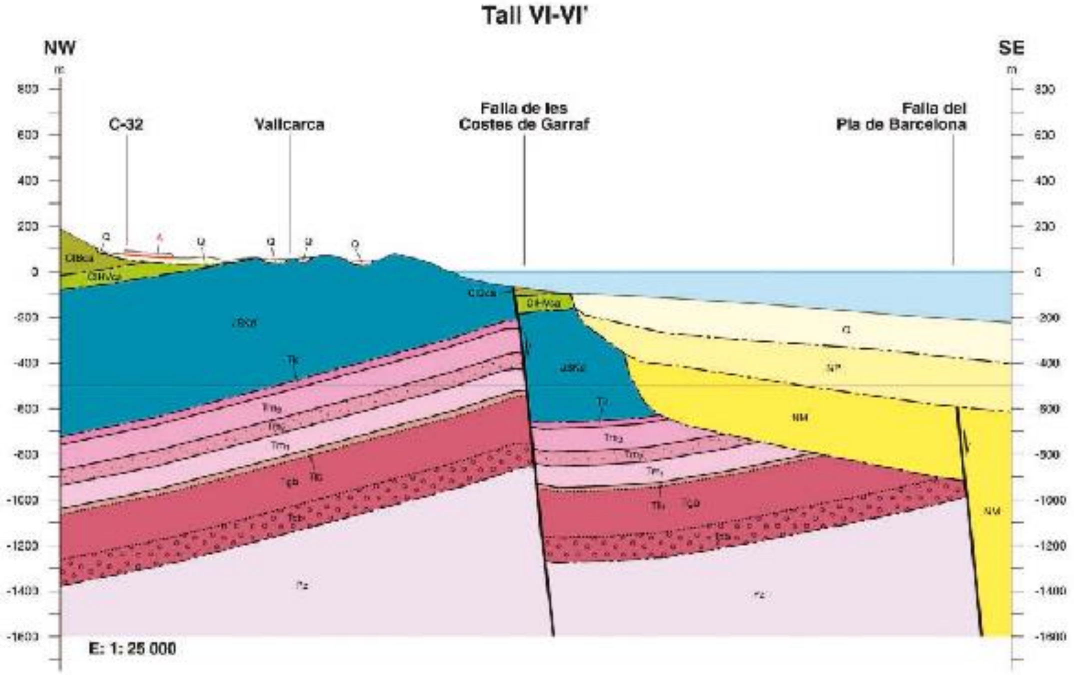


Figure 19: *Cut VI-VI' (Geological map of Catalonia Castelldefels-Vallcarca 1:25.000.ICGC).*

According to *Figure 18* the materials of the beach are the following:

- **QHps**: Quaternary well-selected sands with medium-thick granulometries. Forming small Garraf beaches. Its cementation grade is zero. Its morphology is conditioned to anthropic conditions.

- **QHt1**: Quaternary gravels and blocks with sandy matrix with clay levels of carbonaceous composition. Correspond to levels of swamps and beach sands. Its cementation grade is zero. They correspond to materials deposited in bottoms of streams with a maximum thickness of 5 meters. Water circulates through these detrital materials (also QHps) through primary porosity derived from the physical properties of these materials.

- **CIBca**: Cretaceous micritical and bioclastic carbonates. They contain bivalves, gasteropods, algae and orbitolines. Sediments deposited on shallow marine platform. Locally breccias levels are observed. The thickness of these carbonates can vary between 200m and 750m grouped in massive strata. They are discordant on the CIVHca materials. These materials have a secondary porosity derived from karstification, which causes water to circulate through it. It is possible that while water circulates through these limestone it is enriched in radioactive isotopes such as Ra and Rn.

- **CIVHca**: Cretaceous micritical and bioclastic carbonates with intercalations of ocher shales. They contain bivalves, gasteropods, algae and orbitolines. Sediments deposited on shallow marine platform. They are arranged in well-stratified metric or decimetric levels, with small levels of interbedded marls, with a total thickness of 30m-150m. Locally breccias layers appear without much lateral continuity. The fracture planes are dolomitized. These materials also have a secondary porosity so water can circulate through it and be enriched in radioactive isotopes.

All these materials can contain different fractures, cementation level, empty spaces, certain minerals or water. These characteristics will affect the resistivity typical of the materials surrounding Aiguadolç, shown in *Table 6*.

Table 6*: Resistivities of different types of materials and fluids (Sheets, 1995).*

Material:	Carbonates	Non-cemented sands	Sea water	Fresh water
Resistivity:	10^3-10^4 Ω·m	10-10^3 Ω·m	0.1 Ω·m	10-100 Ω·m

4.1. KARST DEVELOPMENT IN EL GARRAF

The term Karst refers to a type of relief resulting from chemical dissolution, by natural processes related to water, carbonates, limestone rocks, dolomites, gypsum, halite, marble and other soluble rocks. This landscape is characterized by a specific morphology such as dolines, karren, caves, canyons and very particular hydrological patterns where water runs mostly underground.

Calcium Carbonate ($CaCO_3$) is the main constituent of carbonates. In pure water, $CaCO_3$ is slightly soluble but natural waters have a certain amount of carbon dioxide (CO_2) and carbon dioxide (H_2CO_3). Thanks to H_2CO_3, carbonates increase their solubility, forming bicarbonate (HCO_3^-) and calcium (Ca^{2+}) ions. In groundwater the balance chemical equation is the following:

$$CO_2 + H_2O + CaCO_3 \leftrightarrow Ca^{2+} + 2\ HCO_3^- \quad (5)$$

This balance shows how the CO_2 enriched waters favour the dissolution of the carbonates and, on the contrary, the waters enriched in Ca^{2+} will favour the precipitation and formation of calcareous rocks. The Garraf massif is essentially calcareous so the karstic processes are very important. These karstic processes have led to the formation of karstic geomorphology like the following:

- **Lapiaz**: Forms characterized by presenting channels and sharp grooves in the rock. These forms are present throughout the whole Garraf massif but they are concentrated above all in the Pla del Campgràs. In this location, the lapiaz fields have the particularity that they are not oriented following the diaclases or fractures but they follow the stratification, sometimes due to the dip of the layers (Al, 1948).

- **Cylindrical perforations:** Small holes that are formed in the lapiaz fields and that can reach depths of 0.7 with widths of 0.3 meters. They are formed by purely chemical erosion. They need prolonged periods of rain since the water that accumulates inside and dissolves the rock is saturated in bicarbonates and needs a water renewal, otherwise it would precipitate the carbonate. So when it rains continuously these cylinders fill up and the water overflows, renewing its contents.

- **Doline:** Depressions produced by the effect of the carbonate dissolution under the ground. They may have different morphologies, some narrow and deep and others broad and shallow. Garraf dolines are usually found in Cretaceous rocks and have a scarce development, but there are several, most located between Campgràs and La Morella (*Figure 20*).

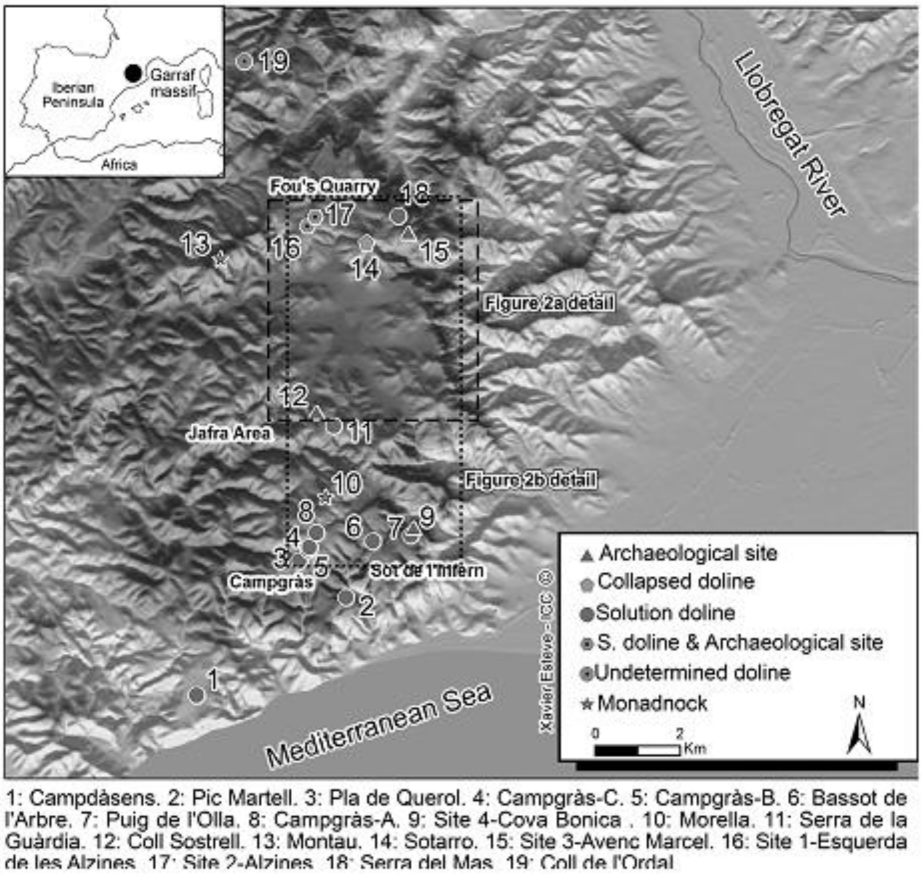


Figure 20: *Location of the main dolines (Daura et al., 2014)*

- **Poljé:** Closed depression with abrupt edges, flat bottom and generally large dimensions. They are originated by the union of sinkholes, caving subsidence or tectonic subsidence. In the Garraf we find that the Begues valley is a large Poljé
- **Wells, chasms and caverns:** Underground cavities were formed by intense dissolution over the years. In Garraf massif there are different wells and caverns such as Cova Bonica, l'avenc Marcel or les Alzines. The most famous is the Falconera.

The karst developed in Garraf is polycyclic, that is it has been formed along different cycles. There were three karstification cycles during the Pliocene and Quaternary. The first cycle took place in an immediately post Messinian age (Upper Miocene); the second, at the end of the Pliocene and the beginning of the Pleistocene, and the third, in full Quaternary. From the first cycle we find numerous residual chasms that are currently hanging and decapitated by surface erosion (Pla de les Basses chasm and Pla de les Agulles chasm). In the second cycle, deeper chasms were formed. Some have been reactivated like the Ferla i l'Esquerrà In the third cycle we find the chasms that have not yet reached their maximum and are currently active. They are located in the bottom of well-preserved sinkholes (Pla de Campgràs), lapiaz fields or bottoms of streams.

In the Garraf there are large cavities near the coast although water circulation is poor. These cavities have not suffered the abrasive influence of the sea due to their disposition towards the continent or protected by the topography. It has been observed that this is due to physicochemical changes that affect the solubility of carbonates (Montoriol, n.d.). It has been seen that the water circulating inside these caverns is slightly brackish. The cause of this is found in the contribution of salt made by the waves, when they hit the cliffs, on the surface and roof of these. Amounts of salt have been found filling sinkholes and cracks in these cliffs that contain cavities. It has been proven that the presence of accessory salts in a solution (in this case sodium chloride) increases the solubility of carbonates with respect to that which would be present with pure water. In this case, the greater aggressiveness of the water compensates for the lower water supply that these Garraf areas have (Montoriol, n.d.).

4.2. HYDROLOGY AND HYDROGEOLOGY

4.2.1. SURFACE HIDROLOGY

Aiguadolç beach belongs to the Garraf streams basin (Conca de les Rieres del Garraf, *Figure 21*), which its total surface is 339 km with an average rainfall of 574 mm·yr^{-1}. The surface circulation of Garraf's surface water in permanent courses is avoided due to the karstic characteristics and it relief. The valleys and main courses that collect water from the massif and end up in the Garraf Coasts are Vallbona stream, Garraf stream, Falconera stream, Vallcarca stream and Aiguadolç stream. These valleys are formed by the union of numerous torrents and funds, which are practically dry all year round. Water only runs during and shortly after heavy rains (Soler et al., 2012). The nature of the land makes this region very poor in water, with little sources or spots of water rising thought karstic cavities or fractures.

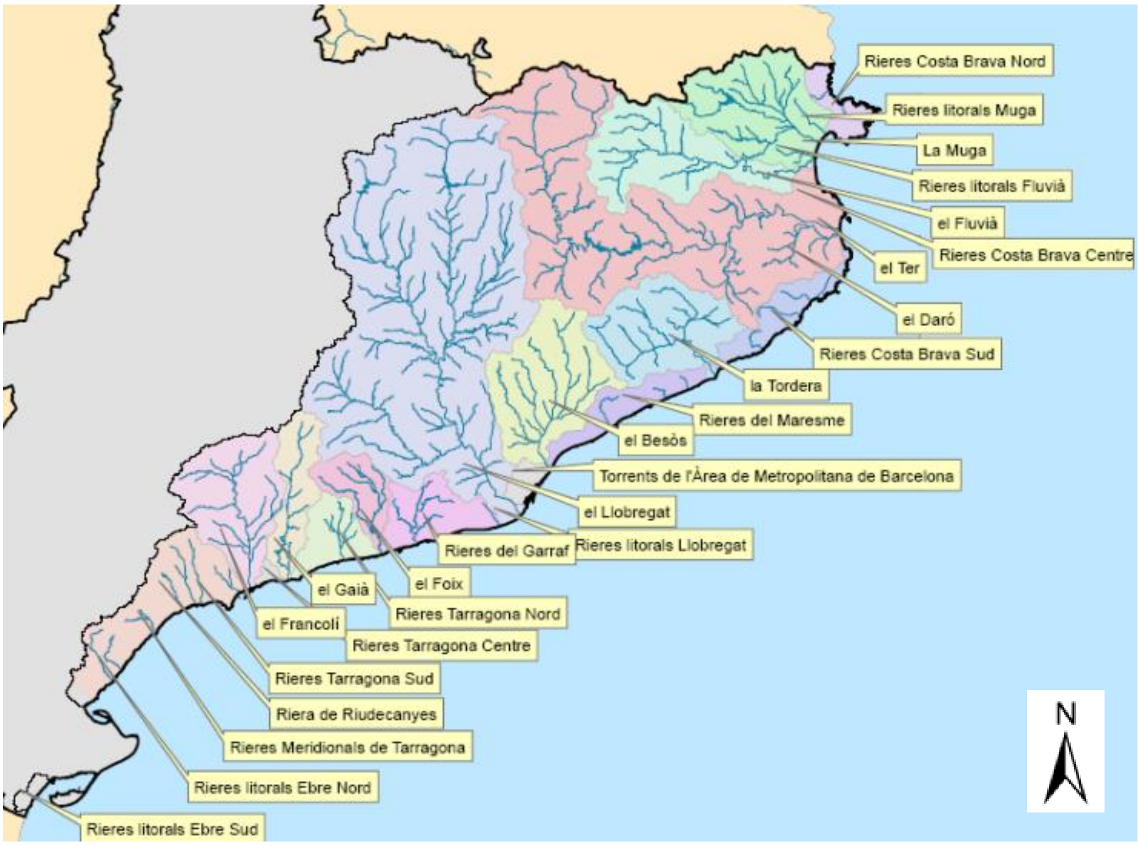


Figure 21*: Catalan hydrography basins (ACA, 2014).*

4.2.2. HYDROGEOLOGY

The study zone is found between the calcareous unit of the Massif del Garraf (Cretaceous) and another unit that corresponds to a tectonic cuvette (Miocene-quaternary) originated in the last distant phases of the Alpine Orogeny, which begins precisely in the municipality of Sant Pere de Ribes and opens south-west to the sea. Thus, the materials that emerge in the area are from the Cretaceous and Miocene period, with the presence of a weak Quaternary (alluvial and colluvial) coverage at the bottom of the valleys and the plain.

The main aquiferous unit in Garraf and sorroundings is the Garraf aquifer (*Figure 22)*. This aquifer is conformed by several lithologies that give differents hidraulic beahaviours and physicochemical propierties, but the similarities are more significant and all of them can be encompassed in this regional unit.

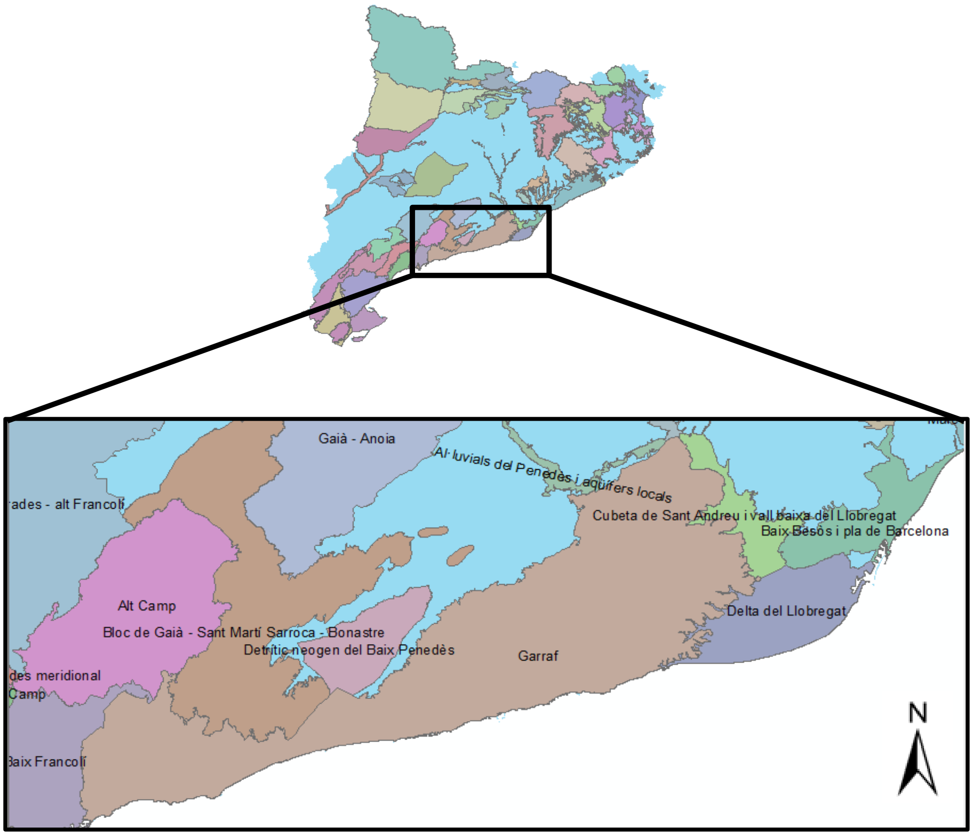


Figure 22: *Garraf aquifer unit.*

The main processes that impact the Garraf groundwater are the saline intrusion and the landfill leaching. As regards to salinization, breaching chlorides indicator shows that the 51.53% of the mass achieve this indicator, although default on the chloride parameter, it is considered in good quantitative state due to uncertainties regarding the anthropic influence of salinity. The exploitation index (extractions/resource) and the density of coastal exploitation index are low. The evolution of piezometric levels shows a general stable trend, but locally descending in some spots with measurements below the sea level, which indicate problems in supply wells. With regard to the chemical status, the aquifer water mass has some quality elements in bad conditions; as ammonium, sulphates and salinity (*Table 5*).

Aiguadolç is framed in the Garraf-Bonastre Mesozoic and Tertiary hydrogeological area (*Figure 23*). It most abundant aquifer subunits are consolidated with a well-developed permeability, due to its calcareous materials fracturing and karstification. Bartomeus (1983) described the subterranean hydrology specifying the presence of two main hydrogeological units in El Garraf: Garraf Jurassic-Cretaceous limestone aquifer and Garraf-Bonastre Miocene-quaternary aquifer, these units were identified and characterized by using geological criteria

The hydrogeological edges coincide with the geological contacts and structures. The different aquifers has different hydraulic potentials, but looks like they are regionally linked (Soler Bartomeus, 1983). The permeable capacity increased as we approach to the coast (*Figure 24).* The Mediterranean Sea is characterized by the abundance in submarine springs (Zektzer et al., 1973), and the Garraf aquifer discharge is a major example, Bartomeus (1983) described the intermittence of these springs as a result of siphon like behaviour of the karstic aquifers. The section between Punta Ginesta to Aiguadolç has a total of 17 coastal or submerged springs detected (*Figure 25*), with the Falconera as the main coastal spring, at the west of the town of Garraf (entorn and sitgesmodel XXI, 2008).

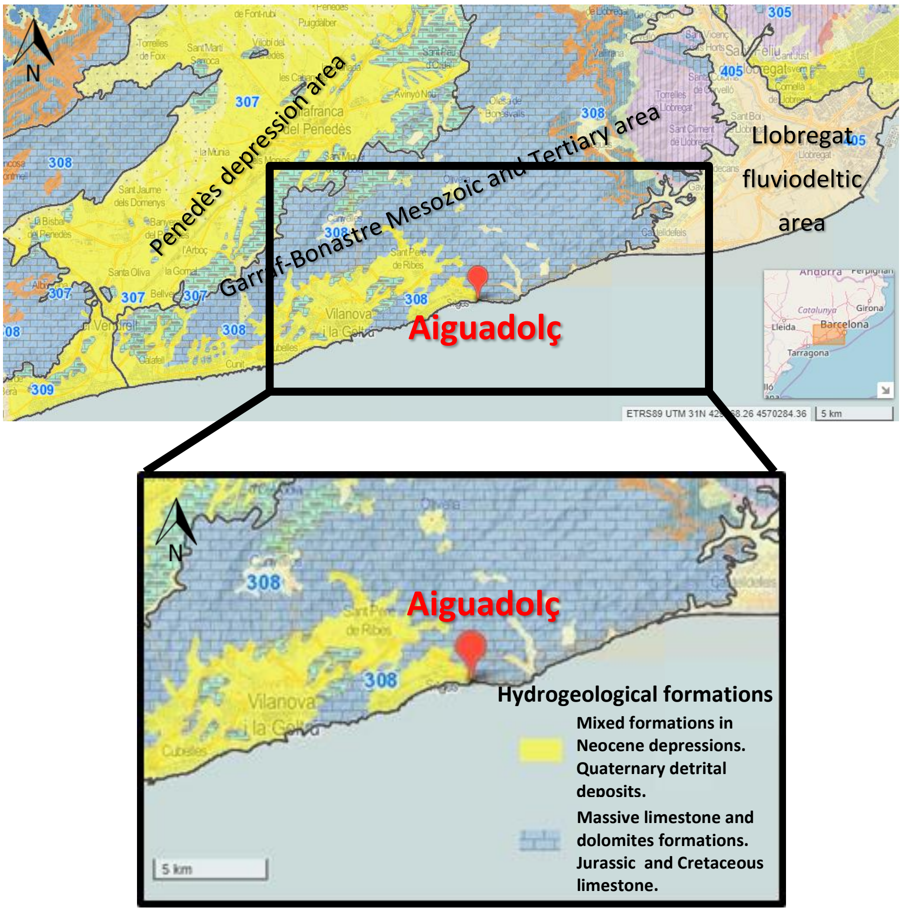


Figure 23: *Hydrogeological areas in Aiguadolç domain. Adapted from Mapa d'Àrees Hidrogeològiques de Catalunya 1:250.000 (MAH250M v1.0, 2017).*

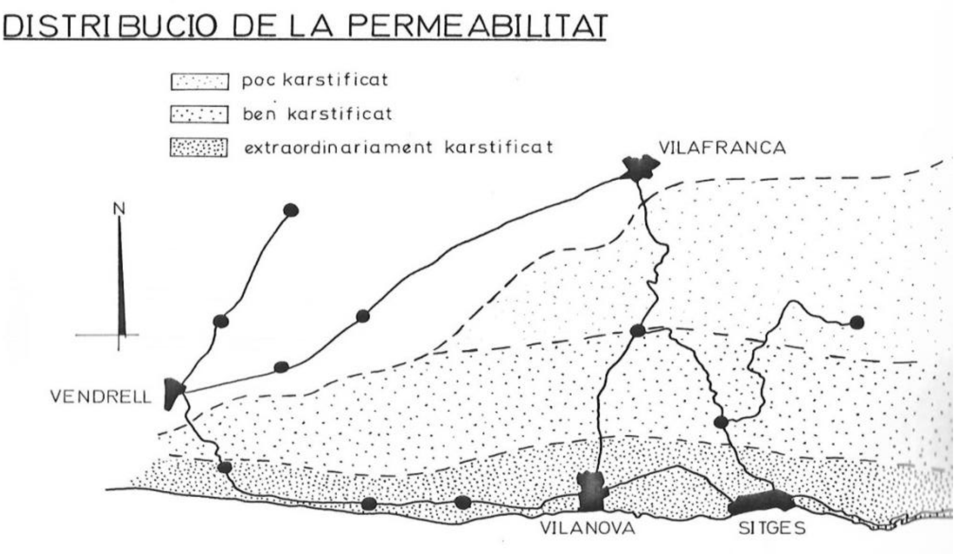


Figure 24: *Permeability distribution in Garraf region (Soler Bartomeus, 1983).*

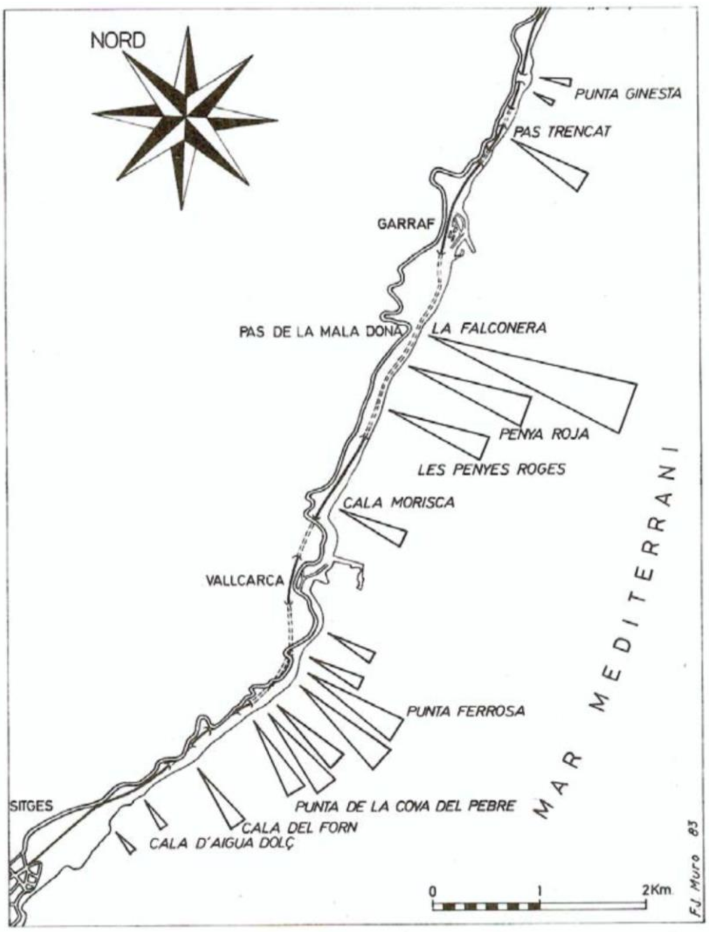


Figure 25: *Map of the Garraf massif marine springs according to Ll. Astier, established according to Garraf-70 campaign (Panareda, 1986).*

Garraf-Bonastre Miocene-quaternary aquifer

The Miocene-quaternary aquifer (*Figure 26)* is composed by all the detritic Neocene materials that are filling Vilanova depression, due to the lutitic character of the sediments, this aquifer unit capacity is very limited. The lithology is shaped by conglomerates, sandstones, clays and marls. Specifically, in the very close coastline, the lithology is composed by Quaternary beach sediments (sand). Due to this composition its porosity is primary and intergranular (Agència Catalana de l'Aigua, 2011b). These materials are located on the Cretaceous limestone basement. The aquifer recharge is done through the direct infiltration of the rainfall and the runoff from higher elevations (Soler Bartomeus, 1983). The preferential flow across the area is towards the coast, the discharge is done by anthropogenic pumping, SGD processes and through the connection with the calcareous basement (Agència Catalana de l'Aigua, 2011c; Soler Bartomeus, 1983). This aquifer with a total extension of 259 km^2, is highly anisotropy because of its continuous lateral facies changes (Soler Bartomeus, 1983).

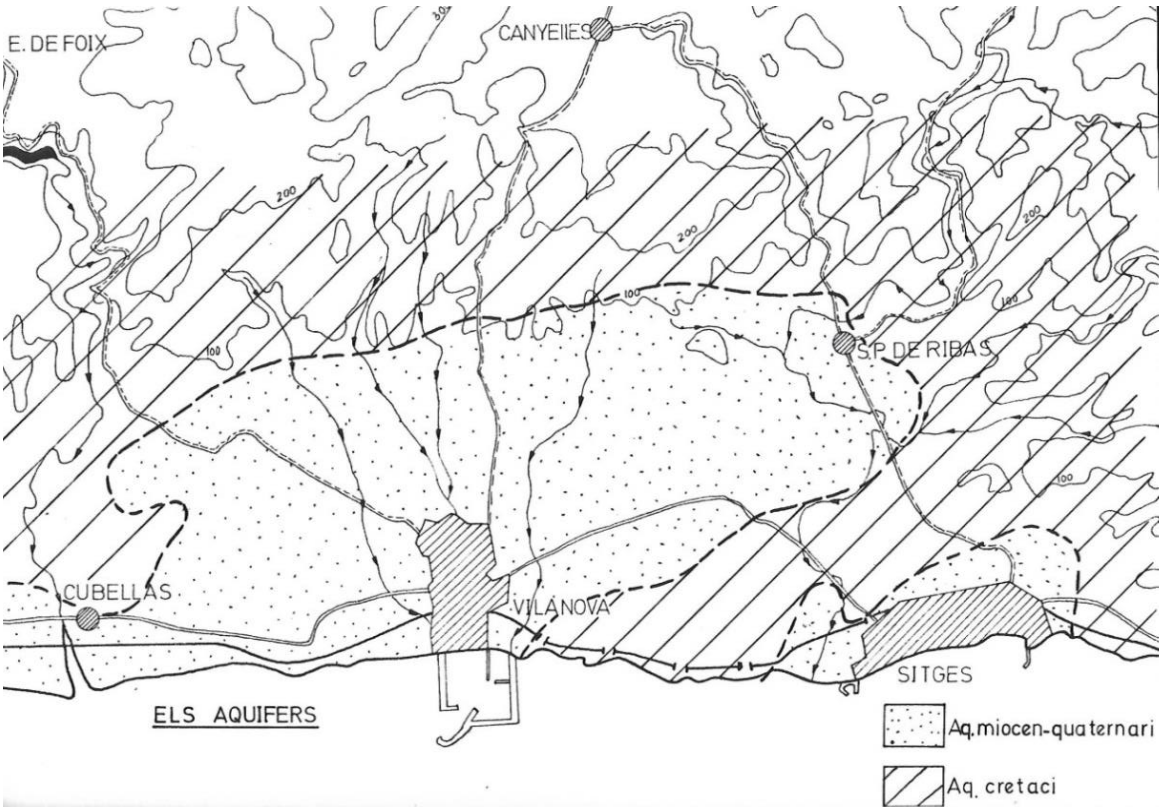


Figure 26: *Sitges cartography of the aquifer subunit (Soler Bartomeus, 1983).*

About the piezometric level, in general it has a low elevation in reference to the sea level. Medium permeability of the aquifer is moderate; it could be due to the presence of intertwined marls, even in the most detrital areas. Miocene-quaternary aquifer is strongly subject to seasonal recharge fluctuations; in some spots it behaves as phreatic but in general is a captive aquifer (Soler Bartomeus, 1983).The general hydrogeological structure is configured by a series of sand lenticular bodies, paleochannels, which a greater permeability, while the lutitic matrix encompasses it with low permeability (Agència Catalana de l'Aigua, 2011c).

Garraf Jurassic-cretaceous limestone aquifer

The Cretaceous aquifer (*Figure 27)* is composed by karstified limestone and dolomites with a more extended surface (763 km^2). It is a very relevant aquifer unit and an important water source due to its well-developed karstification. The karstification and the tectonic faults and fractures, generate a secondary high permeability and a regional anisotropy (Soler Bartomeus, 1983). The anisotropy is also due to confining marl levels and the karst evolution condition. The aquifer recharge is done by infiltration through several developed absorption areas around the massif, and through the contact zones with the Miocene-quaternary aquifer. The flow direction is in general to the sea (*Figure 27*), but the heterogeneous permeability can generate local variations due to the principal permeability fluctuations (Soler Bartomeus, 1983). The aquifer discharge is done through the SGD widely described as submarine springs where the groundwater discharges on the sea floor through outlets of large underground streams as La Falconera (Daura et al., 2014; Zektzer et al., 1973). It is known by the local citizens and is reported by different authors that the Garraf massif has multiple outlets along the coast (Daura et al., 2014; Montoriol Pous, 1948; Soler Bartomeus, 1983) as they are Aiguadolç, Punta de les Coves, La Falconera or Sant Gervasi. Bartomeus (1983) described the wet zone in two different levels with different ways to work; this is multi-layer aquifer behaviour, the deepest one "with a slow water movement and a permanent hydrostatic circulation" and the shallowest "siphon circulation with descendent movement for the circulation, and an ascendant movement for the rising springs". There are some localized karstic devices, which indicate that fossil water circulation, in some places, was diametrically opposite to current hydraulic circulation (Montoriol Pous, 1948).

Its base level would be constituted by the limit of penetration of the karstification, between the 30 m below sea level (coastal areas) and more than 500 m (Agència Catalana de l'Aigua, 2011a, 2011b). The karst evolution depends on the base level changes, the Quaternary sea level fluctuations generated a deepest karst, currently submerged (Daura et al., 2014; Soler Bartomeus, 1983).

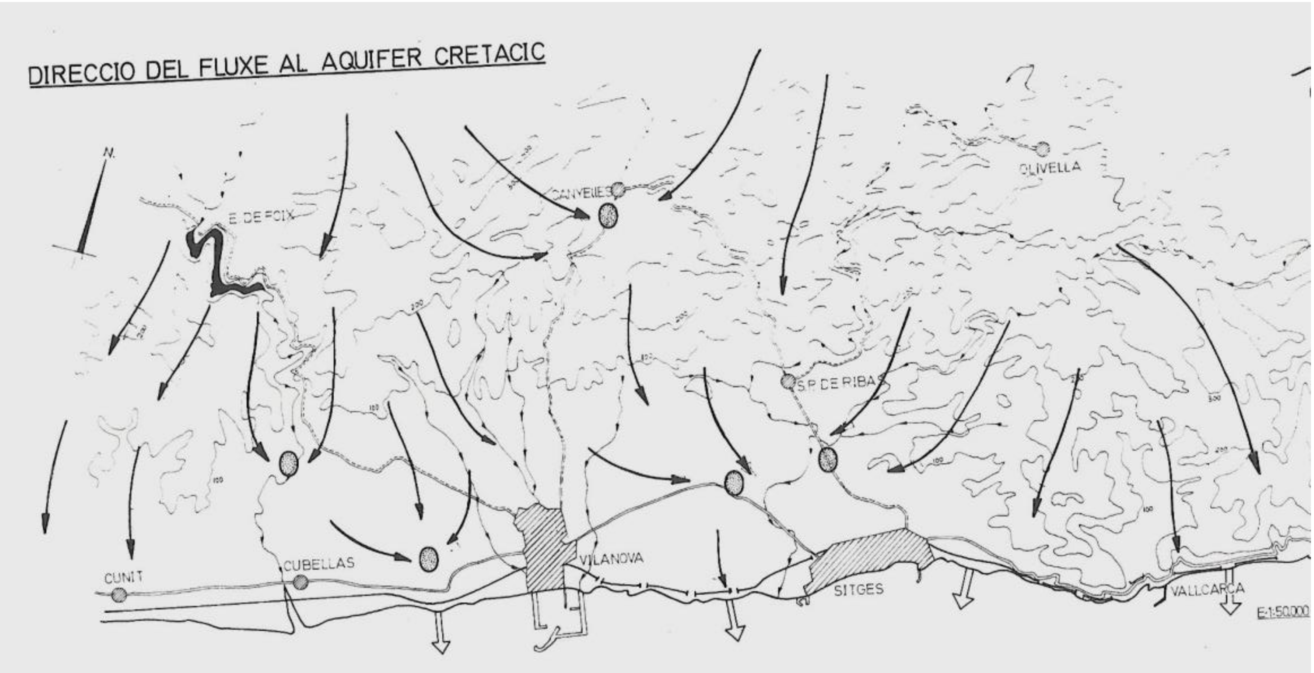


Figure 27: *Garraf Jurassic-cretaceous limestone aquifer with the principal flow directions (Soler Bartomeus, 1983).*

The association of free and confined aquifers, with predominance of the free ones, has characterized the piezometry as very depressed and variable. Groundwater is related to the river courses, to those who the relationship is variable so that they can be influential (feeding aquifers with runoff infiltration) or effluents (powered by the aquifer waters) and the intermittent and sporadic courses (Agència Catalana de l'Aigua, 2011a). The permeability decreases from the coast to inland. The coastal influence is obvious as is observable with the hydrochemical facies, which they are calcium bicarbonate inland and sodium chloride in the coastal zone (brackish water). There is no hydraulic relation between the Garraf Triassic limestone and the Jurassic-Garraf Cretaceous limestone, the flow directions are different and are separated by impermeable materials from the Keuper in the Triassic basement (*Figure 19*).

It is not uncommon to find saline contamination in groundwater as a consequence of the entry of seawater into the interior of the massif, as is the fact that groundwater pollution by leachates from the dump of Garraf associated with the Cretaceous aquifer (*Figure 28*; entorn and sitgesmodel XXI, 2008).

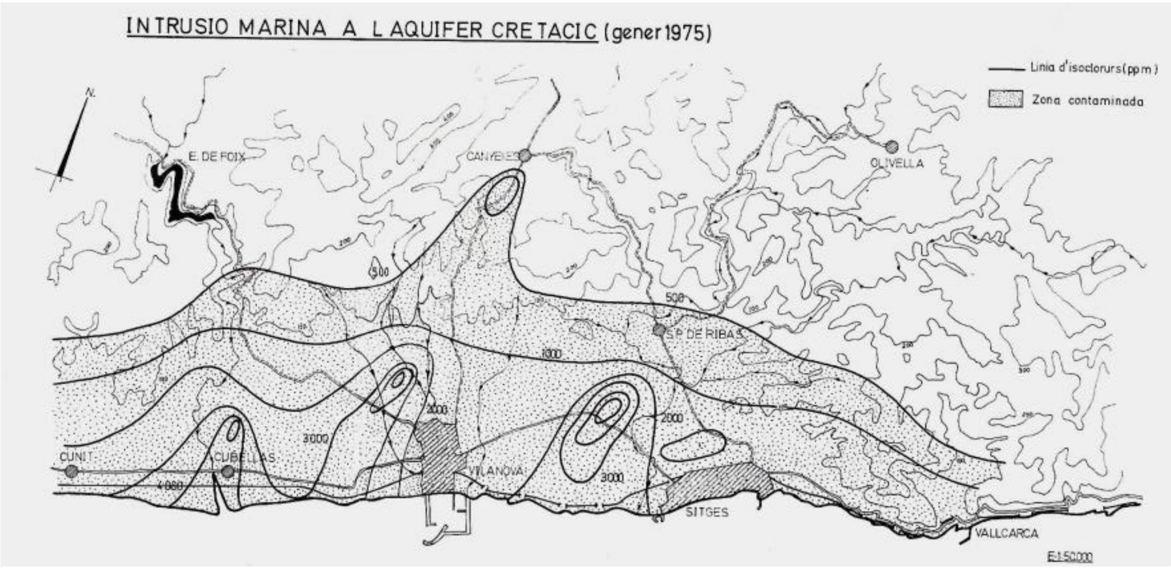


Figure 28: *Marine intrusion in the Cretaceous aquifer in 1975 (Soler Bartomeus, 1983).*

5. OBJECTIVES

5.1. GENERAL AIMS

The main aim of the present project is to describe and quantify the submarine groundwater discharge (SGD) and its driven nutrient input in an anthropized karstic system such as Aiguadolç beach in Catalonia. As a consequence we will assess the possible ecological impacts in the environment and in the social-economical context. We will also forecast of the nature and magnitude of the environmental, economic and social impacts derived from the SGD in Aiguadolç, evaluating the possible alternatives and choosing the most suitable solution to minimize and maximize the negative and positive effects on the environment, respectively. To this end, we will propose several tools for the management of SGD in Sitges.

5.2. SPECIFIC OBJECTIVES

These goals will be achieved through six specific objectives:

1- Identifying and describing qualitatively and quantitatively the magnitude and location of the SGD, providing its flow by using Ra isotopes as tracers.

2- Identifying, describing (qualitatively) and understanding how SGD interacts with the geological matrix by using geophysical techniques and bibliographic research.

3- Understanding the perception of the SGD as a hydrogeological process for the municipality and its citizens and assessing how the influence of SGD may generate some kind of social conflict or management problem by using several methods such as interviews.

4- Investigating some evidences that may link the SGD with the recurrent incidence of erosion in the coastline, with water pollution and with socioeconomical conflicts; by using SIG techniques, geophysics, isotopes, interviews and historical bibliography.

5- Proposing different kinds of management that could benefit the municipality through corrective measures in order to minimize the possible SGD driven environmental impact and to inform its citizens through signboards, pamphlets or information sessions.

6. METHODOLOGY

In this project all the work field, sampling methods and analysis technics where made by the authors in collaboration with professors and PhD students of the UAB and UB (*Figure 30*).

6.1. FIELD WORK AND SAMPLING

The field work was made in different days by doing recognition of the field and landscape, by searching for SGD evidences, by asking to the population of Sitges and by doing interviews. After this first phase, a campaign for sampling and ERTs was made under the name AD1804 the 18th of April, 2018. After the campaign some visits were made periodically to make recognition of the beach state and for research new outlet emergence events. The campaign sampling points and ERTs are shown in the *Figure 29*.

6.1.1. GEOPHYSICAL METHODS

Geophysical data was taken using Electrical Resistivity Tomography (ERT) technique with the collaboration of Juanjo Ledo, professor of geology at Universitat de Barcelona.

The two land ERTs where made in perpendicular directions, one longitudinal to the coastline and the other one across it. An electromagnetic induction survey has been made covering the entire surface of the beach and measuring from 0 to 200 cm depth by doing transects along and across the beach..

6.1.2. PHYSICOCHEMICAL PARAMETERS

The sampling for the physicochemical parameters was made in collaboration with Albert Folch, researcher in Universitat Politècnca de Catalunya, and with Institut de Ciències del Mar de Barcelona. The parameter's measurement was made with different probes determining the temperature, salinity, dissolved oxygen (DO), pH and redox potential from each sample station

A CTD was deployed at each station (except the first 2 ones of each transect) to determine profiles of temperature, salinity, density, depth and dissolved oxygen. Meanwhile, by pumping surface water, a flow cell was used to determine surface parameters of temperature, salinity, dissolved oxygen (DO), pH and redox potential. A second CTD was coupled to a paddle surf table to realize transects along the shore during the morning and the afternoon, and another measurement from Aiguadolç to the Garraf concrete factory.

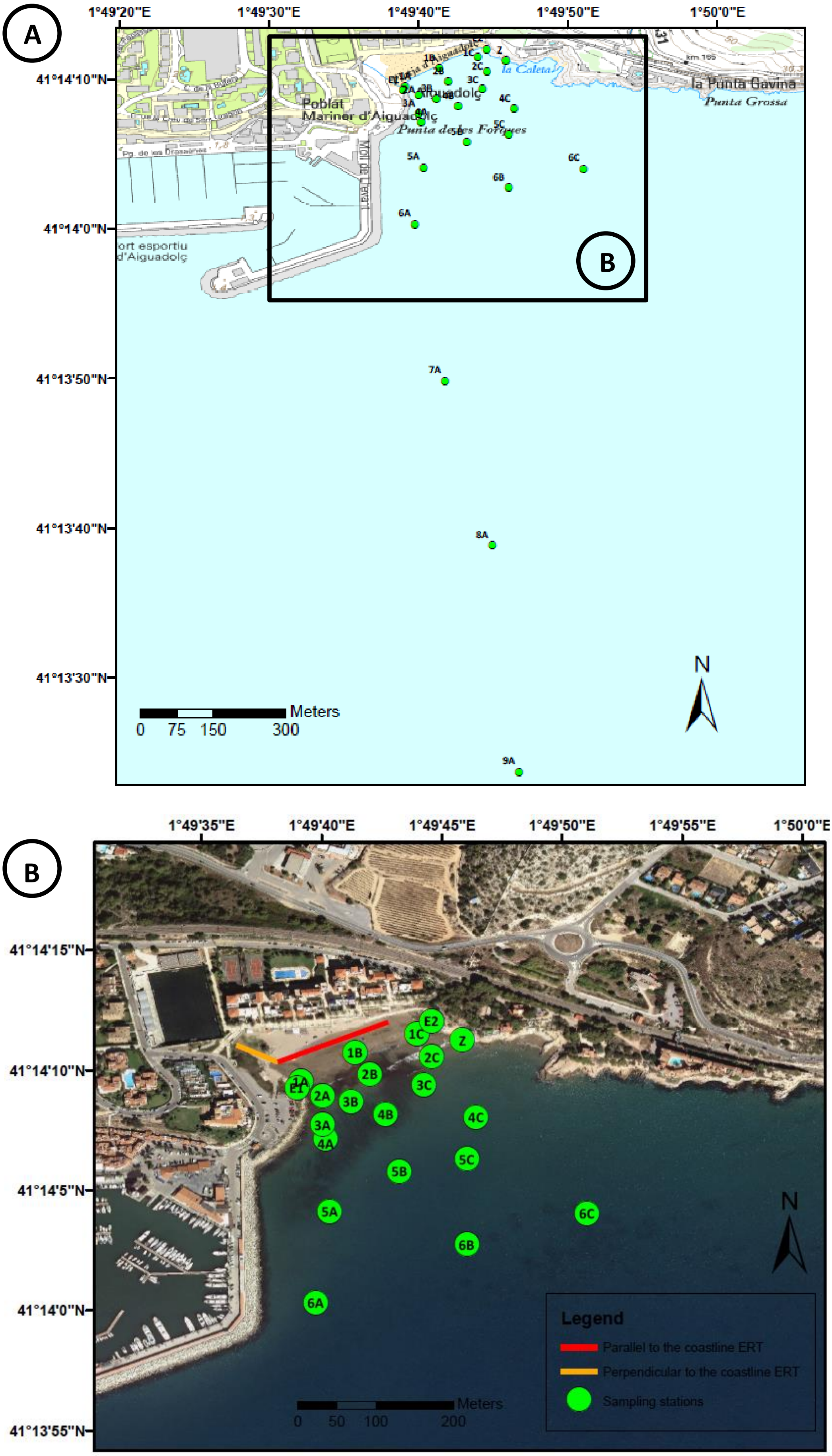


Figure 29*: Sample stations and ERTs location in Aiguadolç Beach. Where: A) demonstrates the whole of sea stations and B) is an enlargement of the closest stations and where the ERTs can be appreciated.*

6.1.3. RADON

Rn is a gas found dissolved in seawater and is very volatile. This characteristic complicates sampling because there does not have to be air in the container where the water is stored otherwise the Rn will volatilize and can't be measured.

Water has been collected to measure the Rn in the first two points of each transect, in the last point of transect closest to the port (9A) and in the two endmembers collected on the beach. Samples have been collected manually with a 2L bottle and with a pump. To prevent the air from entering the bottles, they were filled with water to the top, and then a part small portion of water was extracted from the bottle by pressing it so that the water in contact with the surface did not remain inside the container.

However the quite intense wave effect and the degassing process made the sample collection difficult and offshore samples were not collected. Therefore, concentrations of Rn are used as qualitative indicators of groundwater existence and not to calculate water flows.

Figure 30: *Image of the campaign day, the boat was equipped with the tools for measuring physicochemical parameters and storing filtered nutrients.*

Figure 31: *Plastic carboys with seawater samples filtering in Aiguadolç harbour.*

6.1.4. RADIUM

Sampling stations were oriented along 3 transects (*Figure 29)* extending from the harbor to the Eastern part of Aiguadolç shore (A, B, C). Each transect contains 6 sampling points and the Western transect and the closest to Aiguadolç harbor (A) has 3 additional stations. Offshore, 2 points were collected from each side of the beach (E1, E2) and were used as endmembers. One more seawater sample was collected near a karstic fracture at the Eastern part of the shore (Z).

Seawater samples comprising from 2L to 120 L, depending on shore distance, were acquired from the sea surface. This samples where obtained carrying water with a bucket directly from the surface to the plastic carboys (*Figure 31*). At the beach, three endmbers were made digging in two different spots (East and West) and one was taken directly from a water outlet, near a fracture. Endmember water samples were obtained using a pump in a handmade hole.

The water samples were filtered in the very close harbor as is shown in the *Figure 31*, and the tree endmembers were filtered in the laboratory. The filtration was made through cartridges containing 20 g Ra-adsorptive MnO_2-impregnated acrylic fiber (Mn-fiber), with untreated fiber acting as a pre-filter to eliminate particles and enhancing the efficiency of the Mn-fiber. The Mn-fiber removes Ra from the water, for being analysed after in the laboratory thanks to the volume's reduction of the sample.

6.1.5. NUTRIENTS

Dissolved inorganic nutrients were sampled at the very close surface (0.5 m depth) using a syringe and an acid-cleaned polypropylene cartridge filter (0.22 µm; MSI, Calyx®) and collected in polypropylene tubes for nutrients (Rodellas et al., 2014). These samples were kept frozen until analysis (Garcia-Solsona et al., 2010).

6.1.6. INTERVIEWS

Interviews have been conducted to know the point of view of different actors involved in the use or administration of Aiguadolç beach. In particular, interviews were made to personnel from the Sitges City Council, council technicians and citizens. In these interviews, special interest has been placed on historical beach data, in order to know the problems that it has had over the years, and in a more socioeconomic aspect, in order to know the maintenance price of the beach, the impact of the neighbors or the information that the habitants of Sitges have.

6.2. ANALYSE AND MESURAMENT

6.2.1. GEOPHYSICS ANALYSE

To analyse the geophysical data, two programs were used: RES2DINV and RES2DMOD. The first one is a program that generates a two-dimensional model of resistivity from the field data (Geotomo, 2010). The field data obtained is apparent resistivity and depth data. This program can get real resistivity and depth from the apparent through an "investment" to develop a geological model of what happens in the area.

Another program called RES2DMOD can create a synthetic model that comes close to reality and can create an image of real resistivity and depth. By comparing the real resistivity images of the two programs, it's possible to obtain a reliable geological model through trial and error.

At the end of the process an area is obtained where the different resistivities of the soil materials are represented, which will help to identify the SGD processes that occur in the Aiguadolç beach, and the materials that form the aquifer.

6.2.2. RADON ANALYSE

A Rad-7 Radon Detector (Durridge, 2017) is used to measure the Rn. This detector is portable, durable, sensitive and can operate in continuous mode (Rodellas et al., 2015).

For the correct functioning of the detector it is necessary to extract all the possible humidity of the detector with a function of the same detector called purge. Once the detector has been purged (moisture < 10%) it can be measured. The operation of this detector is based on volatilizing the Rn of water with a RAD-H_2O accessory (Durridge, 2017). It consists on a collection vial (250 mL) containing the sample and a closed air loop with an aerator. The air that comes out of the vial contains the Rn in the form of a gas and goes directly to the detector, passing first through a dry column containing Dryerite, a desiccant material, to prevent humidity from entering the detector.

The system uses an electric field that attracts the atoms of ^{218}Po and ^{214}Po, sons of ^{222}Rn ($T_{1/2}$ = 3.1 min, Eα = 6.00 MeV) and ^{214}Po + ($T_{1/2}$ = 164 µs, Eα = 7.67 MeV), to calculate the concentration of Rn in the air (Rodellas et al., 2015).

6.2.3. RADIUM ANALYSE

6.2.3.1. RADECC

To determinate the short-lived radium isotopes activities (^{223}Ra and ^{224}Ra) the Radium Delayed Coincidence Counter (RaDeCC) was used.

The RaDeCC is an equipment of alpha solid scintillation detection based on a closed system of helium gas flow (*Figure 32*). Moore and Arnold (1996) adapted the RaDeCC for Ra measurements. The isotopes ^{219}Rn and ^{220}Rn are derived from the decay of ^{223}Ra and ^{224}Ra embedded in Mn-fiber (placed in a PVC cartridge connected to the system). A pump sweeps along the Rn isotopes together with the inert gas, which goes through the Mn-fiber. Then, a ZnS coated 1.1 L scintillation cell, connected to a photomultiplier, detects alpha radioactive decay events in the scintillation chamber. An electronic gateway system registers the counts in three different channels, for two for each isotope and the other for the total. The background counts and the ^{222}Rn decay produced by ^{226}Ra need to be corrected, and after every sample analysis the system must be purged (Rodellas, 2014).

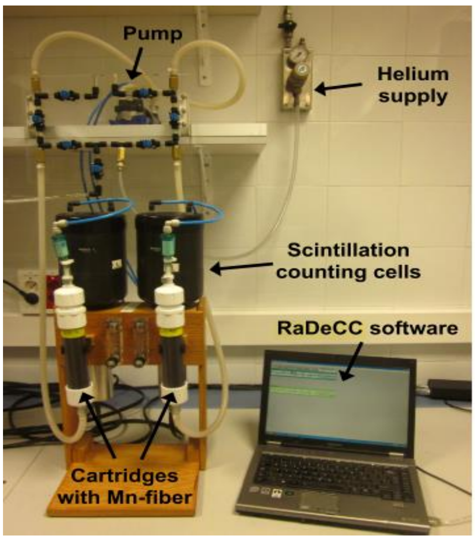


Figure 32: *RaDeCC (Rodellas, 2014).*

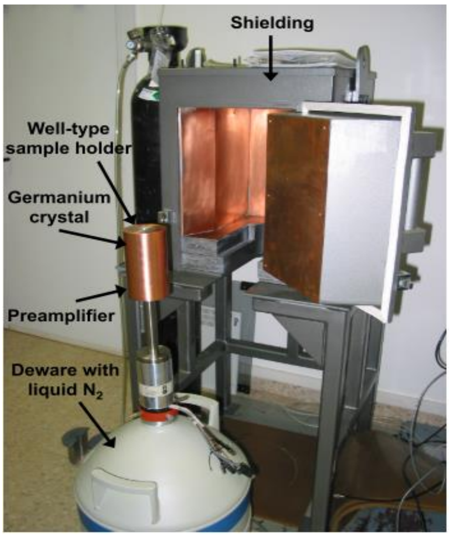


Figure 33: *Germanium detector model GMX-20190 (Rodellas, 2014).*

6.2.3.2. GAMMA SPECTROMETRY

To determinate the long-lived radium isotopes activities (^{226}Ra and ^{228}Ra) a gamma spectrometry was employed. This method consists in the detection of photon emissions by decay and the unique energy signature of each radionuclide.

The samples must be prepared, for reducing the volume the Mn-fiber is incinerated (in a porcelain crucible, at 820 ºC for 16 hours) and packing it into a sealed vial for gamma counting (Charette et al., 2001). The vials must be stored almost three weeks before start to count, to reach the equilibrium between ^{226}Ra and its daughter radionuclides, then the gamma spectrometry system is used. It consists in high-purity germanium detector (HPGe) from CANBERRA (model GMX-20190), coated with an iron, lead and copper shield; and connected to a CANBERRA ADC (model 8701) of 8192 channels of resolution (emission lines from 40 to 3000 keV) (*Figure 33)*. The detector is a high-purity germanium crystal in a cryostat (-196 ºC) by using liquid nitrogen, the detected signal is low and needs a preamplifier to not lose it.

The activity of ^{228}Ra is determined through the photopeak of its daughter ^{228Ac} ($T_{1/2}$ = 6.1 h) at 911.6 keV (q_{Y} = 27.7%), in the same way ^{226}Ra activity is measured through its daughter ^{214}Pb ($T_{1/2}$ = 26.8 min) peaks at 351.9 keV (q_{Y} = 37.2%) and 295.2 keV (q_{Y} = 19.3%). The background counts and the vial geometry efficiency should be considered.

6.2.4. NUTRIENTS ANALYSE

The nutrients were measured in Alfred Wegener Institute for Polar and Marine Research (AWI), Bremerhaven (Germany), by using the QuAAtro Analyzer multi-test method, which is an instrument of choice for the analysis of water and seawater samples. The method used is the standard method for nutrient analysis based on a colorimetric technique developed by the Nederlands Instituut for Onderzoek der Zee (NIOZ; Royal Netherlands Institute for Sea Research). The analysed nutrients are the following ones: NO_2^-, NO_3^-, NH_4^+ PO_4^{3-} and SiO_2.

6.2.5. SWOT ANALYSIS, ACTORS INVENTORY AND SOCIOGRAM

Strengths, Weaknesses, Opportunities and Threats analysis (SWOT analysis) is a tool to know the real situation in which a project is located and is useful to do a planning for a future strategy. Strengths (helpful potential consequences) and weaknesses (harmful potential consequences) depend on internal factors of the issue and the current possibilities. Opportunities (helpful potential consequences) and threats (harmful potential consequences) depend on external factors of the issue and the future possibilities. The SWOT analysis of the conflict about the outlet emergences of freshwater in Aiguadolç was made through the analysis of the interviews and the collected data during the campaign.

To characterize the conflict and developing the relations between the actors an inventory and a sociogram were made. In order to define the actors and it situation, in the inventory positions and interests are differentiated. The sociogram will complete this analysis with a graphic representation of social links that every actor has. That plots the structure of interpersonal relations in situation and contextualizes the hierarchy of powers.

7. RESULTS

7.1. GEOPHYSICAL SURVEY

Results obtained from ERTs are shown in *Figures 34 and 35*. It can be observed how the electrical resistivity of materials allowed identifying the different groundwater masses under the surface of Aiguadolç beach. The lowest resistivity detected values are around 2.1-2.2 Ω·m, while the expected value for seawater is close to 0.1 Ω·m as is specified in *table 6*. The difference is of an order of magnitude higher, confirming that this groundwater is mixed with freshwater. On the other hand the expected values were between 10-100 Ω·m, which fits very well the resistivities observed in field, with maximum values of 129 Ω·m. The resistivities showed the presence of a subterranean estuary in Aiguadolç beach.

The transverse tomography of the coastline (*Figure 34*) was made above Aiguadolç torrent, it showed two zones with very different resistivities ranked approximately between 2.1 to 5.9 Ω·m in the SE (40-70m) and 46 to 129 Ω·m in the NW (0-24m), and a diffuse boundary between them showing a gradation zone. Whilst the shoreline area presented low resistivity (saltwater), the inland area showed high resistivity (freshwater). Thus, resistivity decreased towards the sea due to the mixture of fresh groundwater with seawater (saltwater interface) with a diffuse gradient corresponding to the mixing zone where both types of water were mixed. A thin layer of freshwater can be identified in the model floating above the saline groundwater that penetrates about 30 m inland.

The longitudinal tomography (*Figure 35*) showed clearly a vertical distribution instead of the lateral structure presented in the transverse ERT, but with lateral meaningful variations. The highest resistivities between 30 to 41 Ω·m were in depth and in the E (since the 6 m depth), the lowest values located from <0.5 m depth to the roof were around 1 to 8 Ω·m. Between 0.5 and 6 m, resistivities were low in the general context, but in this transect could be assumed as intermediates (saltwater interface).

In the eastern part of the beach the highest resistivities are recorded, where the limestone bedrock was observed surficial. The lowest resistivity values were found in the western part and in the most superficial areas of the beach, where the influence of seawater was present. Must be have in consideration that the longitudinal ERT was made in the most proximal zone to the sea and the resistivities are more related with saltwater interface and saline groundwater than with fresh groundwater.

The electromagnetic image (*Figure 36*) show with more definition the 2 first meters depth and the resistivity values changed dramatically in these thin layers. In the most surficial cm the highest resistivities were located at the E and W, but in the last location, in the channel, those high resistivities had an elevated density. From 1 m to 2 m depth, the major density of higher values was located at the E in the pure karstic domain. In the first meter depth the higher resistivities were in the W and in a spread area, in the second meter depth the higher resistivities were in the E but in a most restricted area than in the channel.

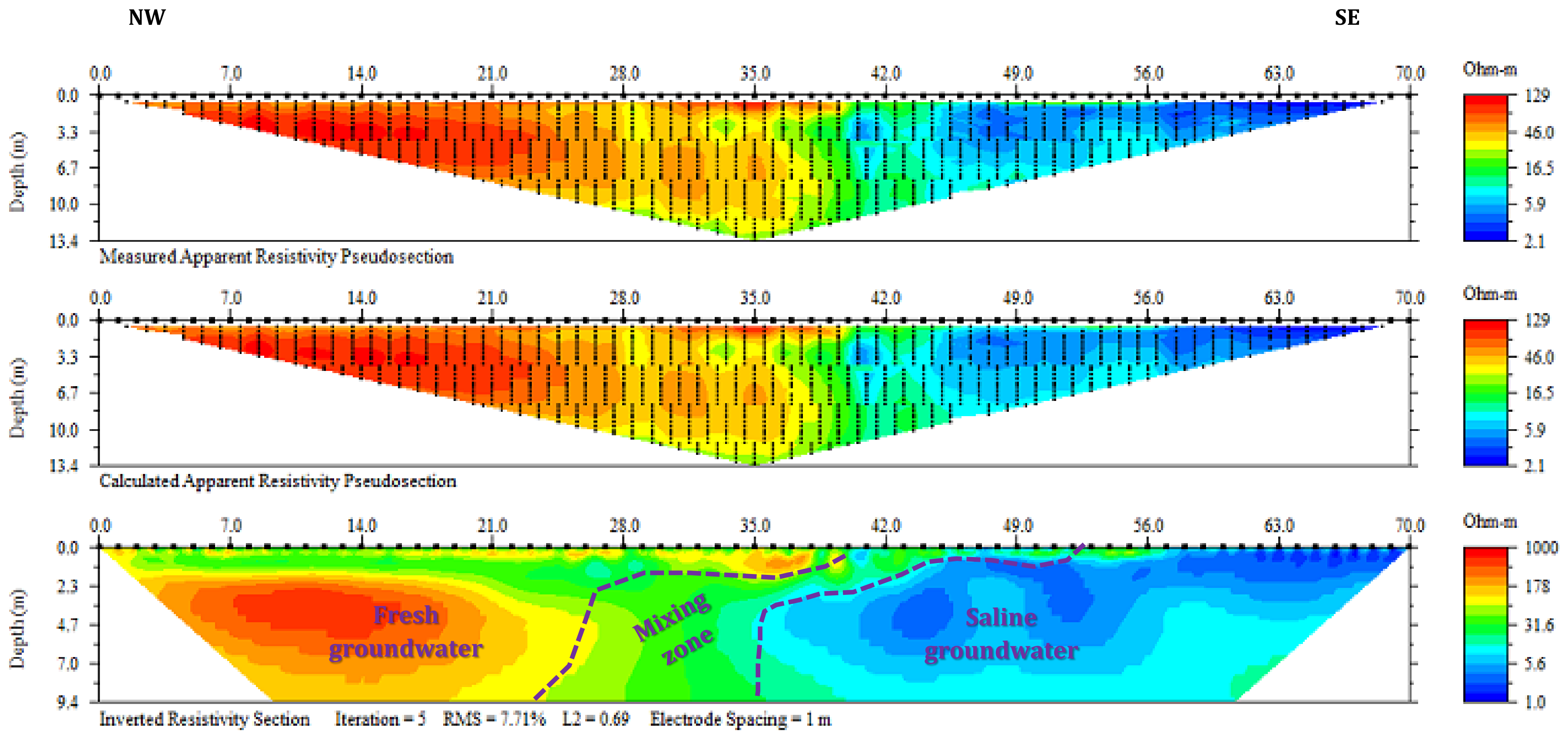


Figure 34: *Resistivity 2D image from transverse ERT section of Aiguadolç beach, in the inverted resistivity section the different parts of a subterranean estuary are shown. Personal communication: Juanjo Ledo.*

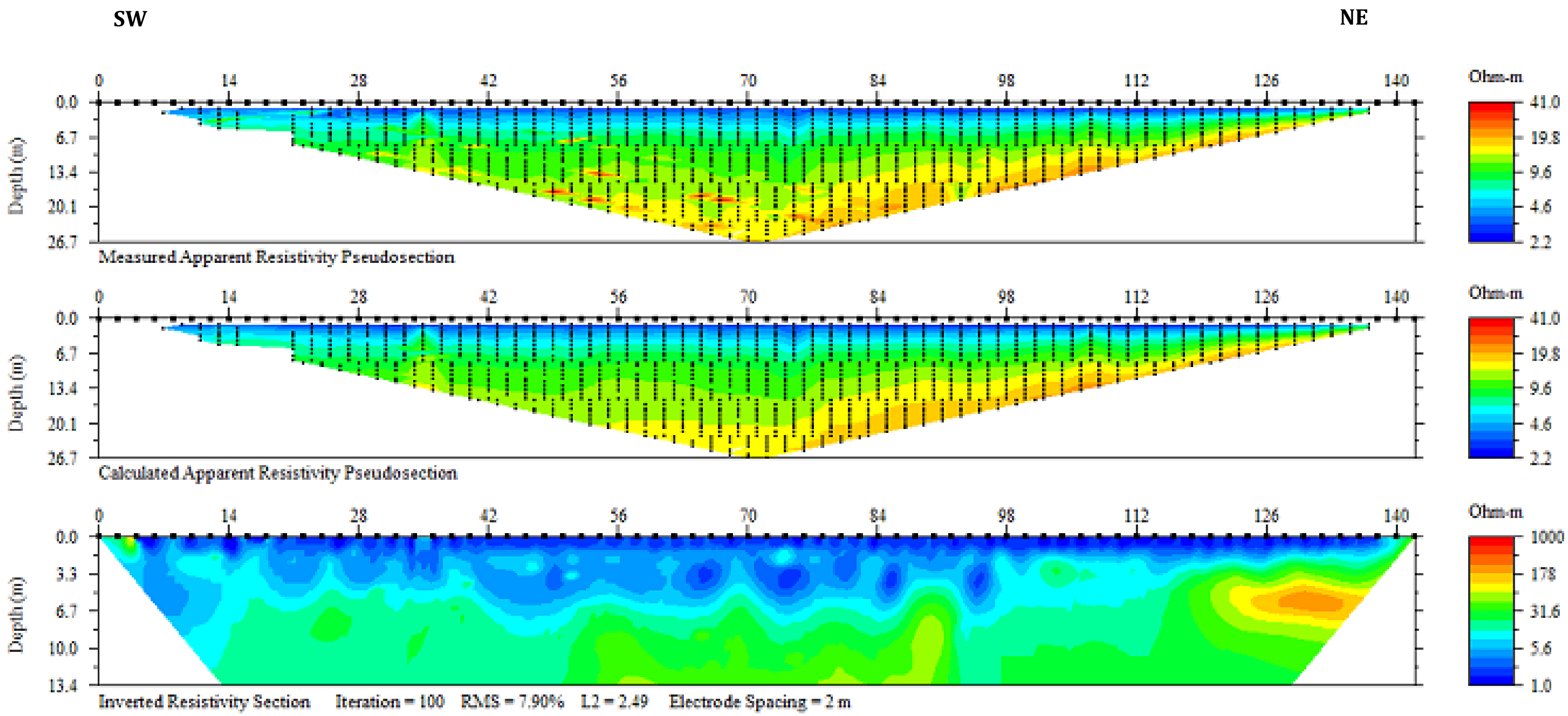


Figure 35: *Resistivity 2D image from longitudinal ERT section of Aiguadolç beach. Personal communication: Juanjo Ledo.*

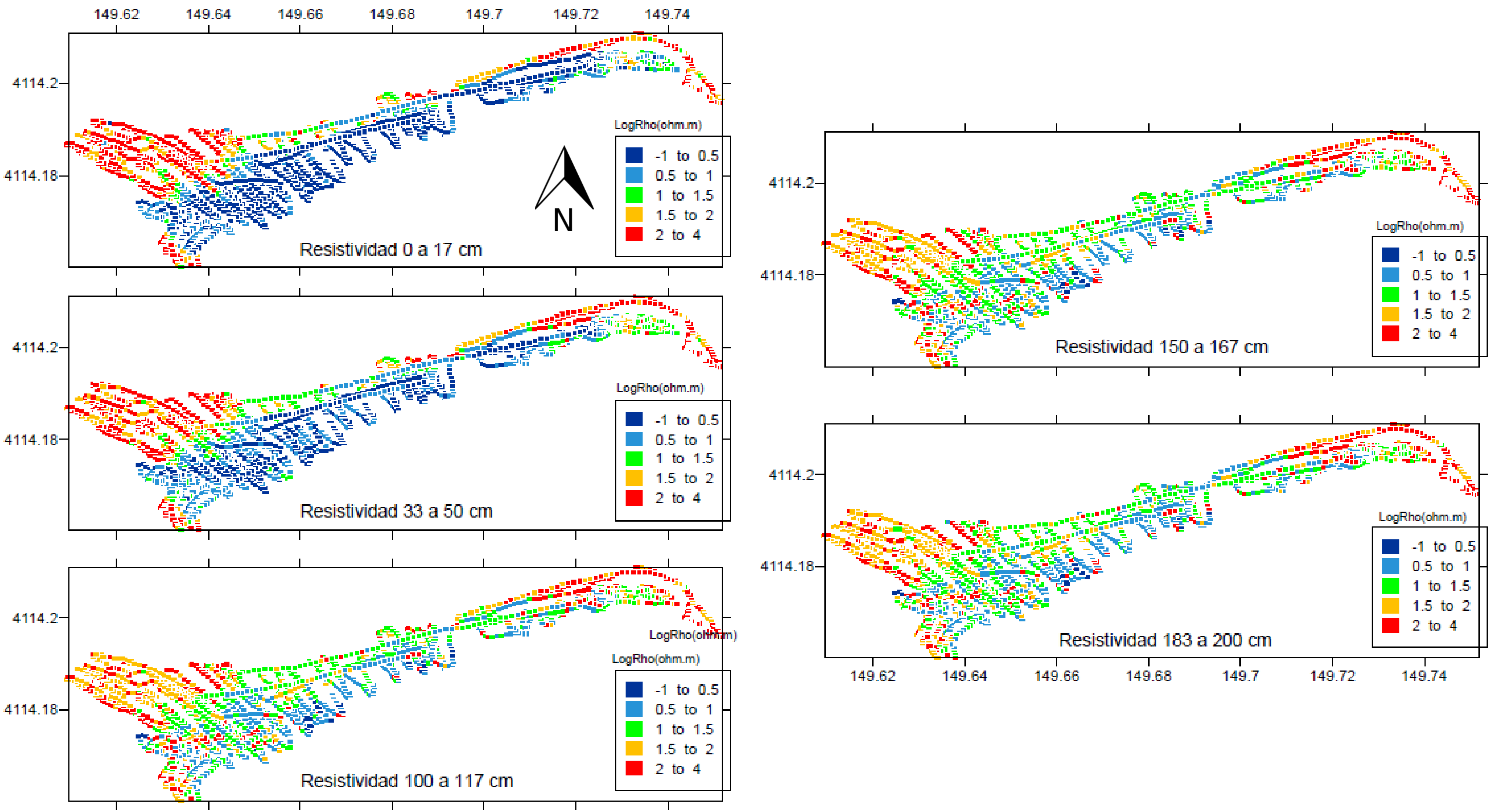


Figure 36: *Resistivity maps in different depths made by using EI in Aiguadolç beach, the values are given in logarithmic scale. Personal communication Juanjo Ledo.*

7.2. PHYSICOCHEMICAL PARAMETERS DISTRIBUTION

Results of the physicochemical parameters of the endmembers and seawater samples are shown in *Table 7*. The temperature values of the endmembers varied between 17 ºC and 18 ºC. Salinities were 14 $g \cdot L^{-1}$, 7 $g \cdot L^{-1}$ and 28 $g \cdot L^{-1}$ for E1, E2 and Z respectively, suggesting a saline intrusion into the aquifer. The content in oxygen was approximately 1 $mg \cdot L^{-1}$ in E1 and E2 and 8 $mg \cdot L^{-1}$ in Z, sampled in the sea.

All seawater samples showed similar physicochemical parameters throughout the studied area, suggesting that groundwater was well mixed with seawater and therefore no clear offshore gradient trend was observed. Temperatures were around 15 ºC, salinities varied between 35 and 38 $g \cdot L^{-1}$ and oxygen was approximately 8 $mg \cdot L^{-1}$ indicating how well oxygenated was this sample collected onshore. Therefore, salinity measured with the probe showed a significant difference in salinities, demonstrating the existence of brackish groundwater discharges.

Table 7: *Physicochemical parameters of Aiguadolç beach (N.d. means no data available).*

Sample	Code	Shore distance (m)	T (ºC)	pH	Salinity ($g \cdot L^{-1}$)	O_2 ($mg \cdot L^{-1}$)
Seawater	1A	0	14.8	8.02	35.21	N.d.
	2A	33	13.2	8.18	36.8	9.4
	3A	70	16.3	7.86	38.21	8.23
	4A	87	16.2	7.85	37.64	8.2
	5A	180	15.1	7.8	35.64	8.48
	6A	297	14.4	7.75	36.94	8.49
	7A	622	14.6	7.74	35.62	8.58
	8A	965	14.4	7.76	35.7	8.68
	9A	1434	14.6	7.73	37.78	8.86
	1B	0	16.5	8.15	36.66	11.25
	2B	33	17.3	8.3	37.66	9.2
	3B	54	15.8	7.85	38.18	8.48
	4B	87	15.7	7.89	38.35	8.37
	5B	161	14.6	7.81	36.9	8.53
	6B	271	14.5	7.85	37.88	8.64
	1C	0	16.5	8.22	37.38	11.48
	2C	34	16.5	8.3	37.6	9.3
	3C	67	15.9	7.85	37.88	8.45
	4C	122	16.2	7.85	38.3	8.5
	5C	171	14.7	7.86	36.82	8.61
	6C	284	14.4	7.9	37.78	8.64
Endmember	E1	5	17.6	7.95	14.23	1.14
	E2	0	17.9	8.12	7.37	0.88
	Z	32	17	7.97	27.79	8.27

The distribution of physicochemical parameters with depth in the sea of the studied area of Aiguadolç is shown in *Appendix 3*. Salinity concentrations showed values ranging from 37.3 to 37.6 g·L^{-1} for transect A, the closest to the port (*Figure 37*). The absence of a clear halocline indicated that groundwater discharging from the unconfined coastal aquifer and seawater were well mixed. Salinities in transects B and C presented similar ranges and distributions with depth (*Appendix 4* and *5*).

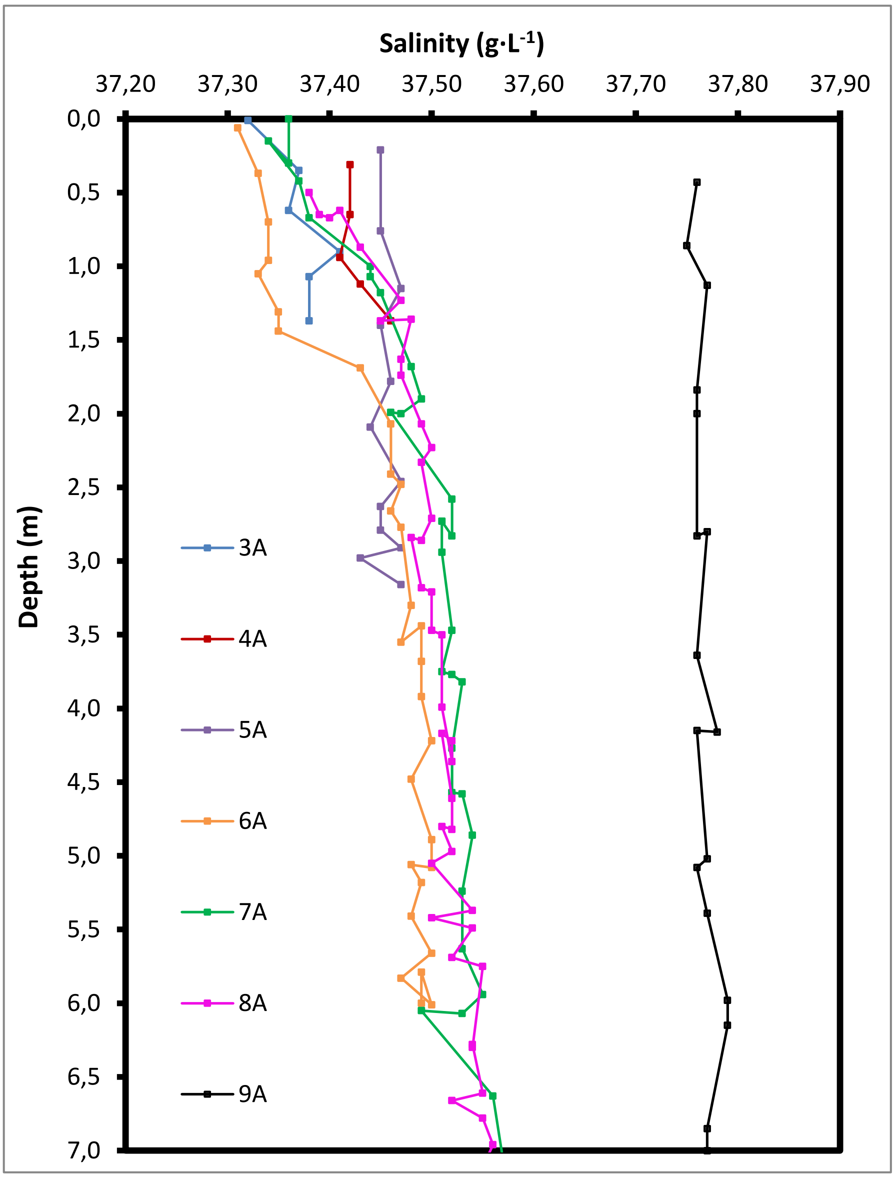


Figure 37: *Salinity concentration in depth from the closest transect to Aiguadolç port (A transect).*

7.3. RADON

Those results obtained for Rn measurements are presented in *Table 8*. Rn concentrations in the two endmembers showed different concentrations of 31036 ± 17402 dpm·100L^{-1} in E1 and 73573 ± 22413 dpm·100L^{-1} in E2. The difference between both concentrations may be due to dilution with seawater;

however, the fact that E2, with lower salinity, had the highest Rn concentration indicates the probably different origin of both kind of groundwater. Rn concentrations in seawater samples presented detectable concentrations of Rn, indicating an influence of groundwater on the seawater composition. However, those samples collected close to the shore showed lower concentrations of Rn indicating a probably degassing process due to the quite intense wave effect. This fact makes the Rn sample collection difficult and offshore samples were not collected.

Table 8: *Rn results measured with RAD7.*

Code	^{222}Rn	^{222}Rn
	Bq·m^{-3}	dpm·100L^{-1}
1A	39 ± 170	237 ± 1019
2A	218 ± 325	1311 ± 1953
9A	53 ± 234	321 ± 1406
1B	80 ± 169	483 ± 1013
2B	337 ± 302	2023 ± 1810
1C	45 ± 146	270 ± 879
2C	452 ± 473	2709 ± 2838
E1	5173 ± 2900	31036 ± 17402
E2	12262 ± 3735	73573 ± 22413

The ^{222}Rn results measured in Aiguadolç can be used to identify the SGD and to compare the concentrations with other sites. For this, only endmembers samples will be used since they are the only ones with an acceptable error (seawater samples have errors equal to or greater than the measured value). Results of ^{222}Rn concentration measured in endmembers obtained in Aiguadolç (*Table 8*) are comparable to those obtained by Rodellas et al., 2012 in Peñiscola (western Mediterranean), where discharges of groundwater to the sea were identified and studied. They are also comparable to studies with ^{222}Rn performed in other parts of the world as Ubatuba, Brazil (Burnett et al., 2008), or Indian River Lagoon, Florida (Smith et al., 2006). Thus, the presence of these concentrations of ^{222}Rn in the endmembers E1 and E2 (Table Rn) suggests the existence of subterranean groundwater discharges in Aiguadolç beach.

7.4. RADIUM

Groundwater samples were enriched in all the Ra isotopes relative to seawater samples (see *Table 9*). Ra activities for ^{224}Ra and ^{223}Ra were 83 ± 12 and 8 ± 3 dpm·100L^{-1} for E1, 351 ± 47 and 9 ± 5 dpm·100L^{-1} for E2 and 221 ± 20 and 4 ± 1 dpm·100L^{-1} for Z endmembers samples, respectively. Concentrations of ^{226}Ra and ^{228}Ra in the endmembers were 49 ± 53 and 0 dpm·100L^{-1} for E1, 124 ± 18 and 374 ± 18 dpm·100L^{-1} for E2 and 3 ± 4 and 65 ± 1 dpm·100L^{-1} for Z samples, respectively.

Considering seawater samples, short-lived Ra activities ranged from 14 to 48 dpm·100L^{-1} for ^{224}Ra and from 1 to 2 dpm·100L^{-1} for ^{223}Ra. Whilst the highest concentrations were found in those samples located near the coast, the lowest concentrations were located offshore *(Figure 39*). Specifically, short-lived Ra concentrations were higher in the first two stations of each transect, even being higher in those samples collected from stations 2 (see *Table 9 and Figure 39*), suggesting that groundwater discharges occur offshore. Long-lived Ra isotopes were almost constant in seawater samples (*Table 9*), with values ranging between 15 to 20 dpm·100L^{-1} for ^{226}Ra and 5 to 10 dpm·100L^{-1} for ^{228}Ra. Concentrations of ^{226}Ra and ^{228}Ra in the endmembers were 49 ± 53 and 0 dpm·100L^{-1} for E1, 124 ± 18 and 374 ± 18 dpm·100L^{-1} for E2 and 3 ± 4 and 65 ± 1 dpm·100L^{-1} for Z samples, respectively.

Table 9: *Concentrations of Ra isotopes in samples collected in Aiguadolç beach (MDA: Minimum Detectable Activity)*

Code	^{224}Ra	^{223}Ra	^{226}Ra	^{228}Ra	^{224}Ra/^{223}Ra	^{228}Ra/226Ra	^{224}Ra/^{228}Ra
	dpm·100L^{-1}	dpm·100L^{-1}	dpm·100L^{-1}	dpm·100L^{-1}			
1A	30.6 ± 3.3	1.1 ± 0.4	20.4 ± 2.9	8.3 ± 2.0	27.2 ± 9.3	0.4 ± 0.1	3.2 ± 0.7
2A	48.5 ± 4.3	2.0 ± 0.4	18.3 ± 1.0	14.6 ± 1.1	24.2 ± 4.9	0.8 ± 0.1	3.3 ± 0.4
3A	24.0 ± 2.3	0.9 ± 0.2	18.0 ± 2.8	12.0 ± 8.3	26.6 ± 5.9	0.7 ± 0.5	2.0 ± 1.4
4A	23.0 ± 2.3	1.0 ± 0.2	19.0 ± 1.3	6.3 ± 0.8	22.4 ± 4.0	0.3 ± 0.0	3.6 ± 0.6
5A	23.4 ± 2.2	0.9 ± 0.1	17.8 ± 0.7	5.0 ± 0.7	25.0 ± 4.1	0.3 ± 0.0	4.7 ± 0.8
6A	16.9 ± 1.7	1.0 ± 0.2	17.9 ± 1.3	8.1 ± 0.9	17.2 ± 3.5	0.5 ± 0.1	2.1 ± 0.3
7A	16.1 ± 1.5	0.9 ± 0.1	17.6 ± 1.6	7.9 ± 0.5	18.1 ± 3.1	0.4 ± 0.0	2.0 ± 0.2
8A	15.0 ± 1.3	0.8 ± 0.1	13.7 ± 0.8	8.0 ± 0.5	18.2 ± 3.3	0.6 ± 0.1	1.9 ± 0.2
9A	13.1 ± 1.3	0.8 ± 0.1	17.1 ± 1.2	7.5 ± 0.5	17.1 ± 3.1	0.4 ± 0.0	1.8 ± 0.2
1B	33.8 ± 4.7	2.2 ± 0.6	17.5 ± 2.2	13.5 ± 6.9	15.2 ± 4.6	0.8 ± 0.4	2.5 ± 1.3
2B	34.5 ± 2.9	1.3 ± 0.2	20.6 ± 0.7	10.4 ± 0.8	26.8 ± 4.9	0.5 ± 0.0	3.3 ± 0.4
3B	23.4 ± 2.2	1.2 ± 0.2	16.8 ± 0.9	6.5 ± 0.9	19.3 ± 3.9	0.4 ± 0.1	3.6 ± 0.6
4B	15.8 ± 1.7	0.7 ± 0.1	16.3 ± 0.9	8.2 ± 0.7	21.9 ± 4.0	0.5 ± 0.1	1.9 ± 0.3
5B	14.8 ± 2.0	0.6 ± 0.1	14.8 ± 0.8	11.3 ± 0.9	24.4 ± 5.1	0.8 ± 0.1	1.3 ± 0.2
6B	17.1 ± 2.3	0.9 ± 0.2	14.5 ± 0.8	7.3 ± 0.9	18.0 ± 3.9	0.5 ± 0.1	2.4 ± 0.4
1C	31.1 ± 3.4	2.1 ± 0.4	22.2 ± 1.4	10.7 ± 2.0	15.1 ± 3.3	0.5 ± 0.1	2.9 ± 0.6
2C	25.4 ± 2.7	1.2 ± 0.2	15.6 ± 1.0	10.8 ± 1.2	20.9 ± 4.4	0.7 ± 0.1	2.4 ± 0.4
3C	16.1 ± 1.9	1.0 ± 0.2	16.1 ± 0.8	5.5 ± 0.7	16.4 ± 3.2	0.3 ± 0.0	3.0 ± 0.5
4C	16.2 ± 1.9	0.9 ± 0.1	18.3 ± 0.9	8.3 ± 0.9	18.9 ± 3.6	0.5 ± 0.1	1.9 ± 0.3
5C	15.7 ± 1.7	0.8 ± 0.2	18.3 ± 1.8	7.8 ± 0.7	19.3 ± 4.7	0.4 ± 0.1	2.0 ± 0.3
6C	13.8 ± 1.5	0.7 ± 0.1	18.0 ± 2.0	9.3 ± 0.8	21.0 ± 5.1	0.5 ± 0.1	1.5 ± 0.2
E1	83.5 ± 12.0	8.0 ± 2.6	48.5 ± 52.8	<MDA ± <MDA	10.5 ± 3.7	- - -	- - -
E2	350.8 ± 47.2	9.4 ± 4.7	123.8 ± 18.5	374.5 ± 18.4	37.2 ± 19.2	3.0 ± 0.9	3.6 ± 1.0
Z	220.9 ± 20.0	4.1 ± 0.7	3.0 ± 3.6	64.7 ± 0.7	53.4 ± 10.3	21.5 ± 26.9	3.4 ± 0.3

The Figure 38 shows the plot of ^{224}Ra with salinity for all the collected samples. This figure shows how the endmembers had a lower salinity than the seawater samples and a higher concentration of ^{224}Ra. It is also observed how the E1 and E2 samples had very different salinities and ^{224}Ra concentrations, suggesting the existence of two different groundwater masses that could discharge into Aiguadolç beach. The ^{226}Ra/^{228}Ra ratio remained almost constant for all samples, unlike the ^{224}Ra/^{223}Ra ratio that varied decreasing towards the sea (*Table 9*). This is because ^{226}Ra and the ^{228}Ra being long-lived isotopes do not disintegrate and therefore the ratio between these two isotopes does not vary.

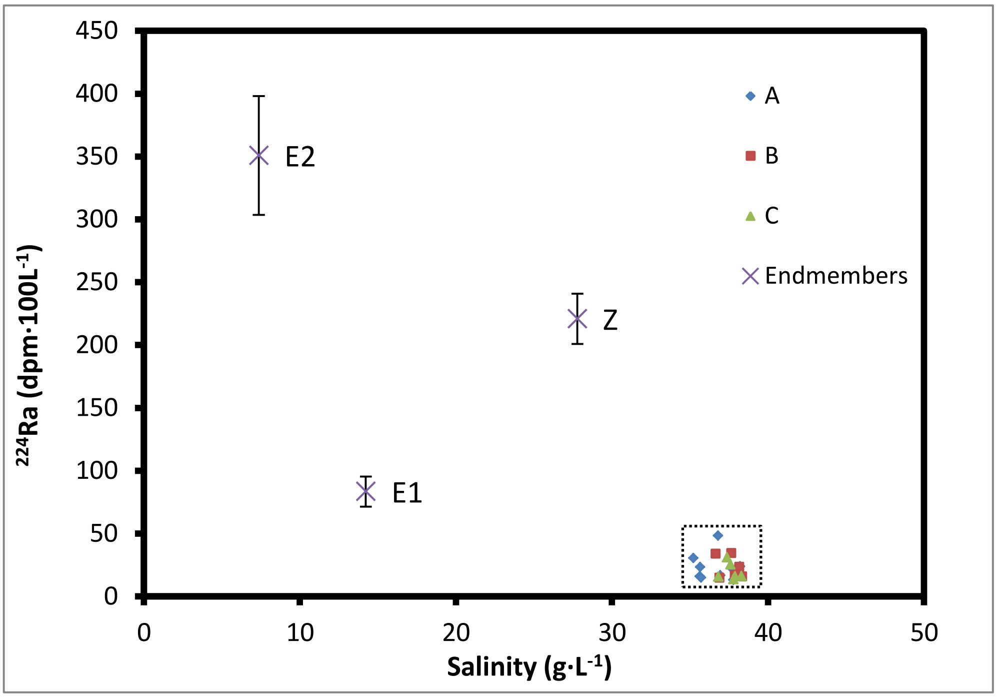


Figure 38: *^{224}Ra plotted with water salinity for all Aiguadolç samples. Seawater samples error is not represented in the plot due to it woud not be appreciated. To consult it, see Table 9.*

Mean values of ^{223}Ra and ^{224}Ra concentration in Majorca Island, Spain (Tovar-Sánchez et al., 2014) are 0.16 dpm·100L^{-1} and 1.73 dpm·100L^{-1} respectively for shelf waters, and 1.32 dpm·100L^{-1} and 14.13 dpm·100L^{-1} respectively for karst. While Aiguadolç's results ^{223}Ra and ^{224}Ra concentration in 9A (1 km offshore, the most distal sample) are about 0.8±0.1 dpm·100L^{-1} and 13±1 dpm·100L^{-1} respectively; which means that 9A considered as an offshore sample, is more approximated to a karstic sample in Majorca than an offshore one.

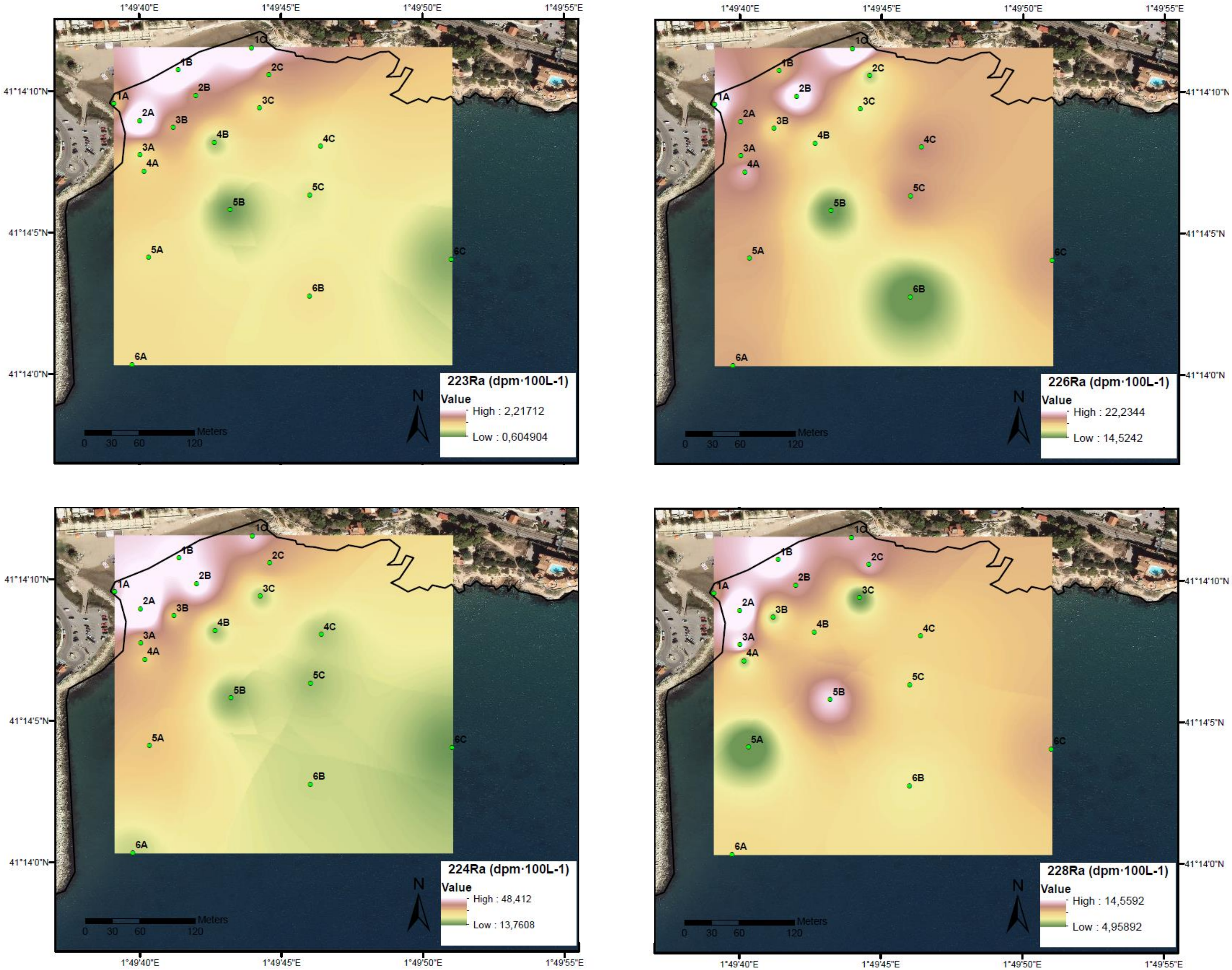


Figure 39: *Map of radium isotopes concentration (^{223}Ra, ^{224} Ra, ^{226}Ra and ^{228}Ra) distribution in Aiguadolç. Data interpolation by using IDW (ArcGIS Spatial Analyst) without considering the endmembers concentration.*

7.5. NUTRIENTS

Results of dissolved nutrients analysis are presented in *Table 10*. The concentration of dissolved nutrients decreased offshore (*Figure 41).* Nutrient concentrations measured in E1, E2 and Z endmembers were 62.138 ± 2.738 µM, 6.762 ± 0.009 µM and 7.679 ± 0.611 µM for NO_x, 5.668 ± 0.280 µM, 0.740 ± 0.362 µM and 0.458 ± 0.001 µM for PO_4^{-3}, 100.282 ± 4.138 µM, 108.426 ± 3.890 µM and 32.354 ± 0.664 µM for Si and 30.266 ± 6.363 µM, 127.094 ± 0.003 µM and 106.199 ± 1.436 µM for NH_4^+, respectively. The lowest were measured in those stations furthest from the coastline.

Table 10: *Nutrient concentration for all Aiguadolç beach samples. The uncertainity associated with the measurement of the nutrient concentration has been increased, in some cases, due to different calibrations applied to measure the nutrients within the parameters established by the measuring device (QuAAtro Analyzer), for example in E1, where it is orders of magnitude higher than other samples.*

Code	DSi	DIN				DIP
		NO_x	NO_2^-	NO_3^-	NH_4^+	PO_4^{-3}
	µM	µM	µM	µM	µM	µM
1A	4.324 ± 0.063	6.953 ± 0.504	2.693 ± 0.002	4.196 ± 0.021	3.016 ± 0.641	0.114 ± 0.002
2A	21.117 ± 0.604	5.875 ± 0.197	0.364 ± 0.142	5.511 ± 0.197	11.666 ± 0.182	0.135 ± 0.084
3A	2.887 ± 0.085	6.451 ± 0.364	0.897 ± 0.002	3.797 ± 0.009	2.709 ± 0.041	0.061 ± 0.001
4A	1.501 ± 0.004	3.514 ± 0.004	0.240 ± 0.003	3.275 ± 0.001	3.078 ± 0.007	0.057 ± 0.002
5A	2.340 ± 0.031	4.343 ± 0.422	0.283 ± 0.001	4.060 ± 0.422	4.306 ± 0.076	0.058 ± 0.003
6A	2.048 ± 0.016	3.835 ± 0.013	0.221 ± 0.001	3.615 ± 0.014	3.307 ± 0.001	0.046 ± 0.001
7A	2.356 ± 0.017	6.285 ± 0.015	0.282 ± 0.001	6.005 ± 0.015	3.128 ± 0.004	0.080 ± 0.001
8A	2.120 ± 0.006	8.346 ± 0.009	0.363 ± 0.001	7.985 ± 0.009	4.822 ± 0.052	0.143 ± 0.001
9A	3.111 ± 0.022	3.230 ± 0.019	0.273 ± 0.001	2.956 ± 0.019	0.285 ± 0.018	0.036 ± 0.001
1B	39.877 ± 0.429	6.343 ± 0.209	0.455 ± 0.113	5.887 ± 0.101	6.193 ± 0.417	0.221 ± 0.002
2B	18.797 ± 0.154	5.653 ± 0.843	0.427 ± 0.118	5.225 ± 0.782	11.463 ± 1.198	0.170 ± 0.034
3B	8.380 ± 0.001	3.814 ± 0.021	0.297 ± 0.001	3.517 ± 0.021	1.753 ± 0.002	0.069 ± 0.002
4B	1.570 ± 0.009	3.646 ± 0.004	0.242 ± 0.001	3.404 ± 0.004	4.353 ± 0.016	0.056 ± 0.002
5B	1.737 ± 0.023	4.017 ± 0.003	0.258 ± 0.001	3.759 ± 0.003	2.142 ± 0.021	0.041 ± 0.001
6B	2.243 ± 0.009	4.119 ± 0.003	0.310 ± 0.001	3.809 ± 0.003	1.737 ± 0.001	0.049 ± 0.001
1C	36.052 ± 0.248	4.783 ± 0.205	0.430 ± 0.120	4.350 ± 0.082	5.765 ± 0.336	0.210 ± 0.016
2C	2.138 ± 0.004	5.430 ± 0.003	0.236 ± 0.001	5.195 ± 0.004	7.361 ± 0.027	0.062 ± 0.001
3C	3.034 ± 1.218	8.905 ± 0.734	2.442 ± 0.003	6.609 ± 0.489	4.820 ± 0.012	0.078 ± 0.004
4C	1.547 ± 0.054	5.247 ± 0.035	0.267 ± 0.001	4.982 ± 0.036	4.135 ± 0.002	0.066 ± 0.003
5C	1.776 ± 0.009	2.972 ± 0.008	0.208 ± 0.001	2.764 ± 0.008	5.357 ± 0.028	0.044 ± 0.001
6C	1.276 ± 0.009	3.969 ± 0.008	0.210 ± 0.001	3.761 ± 0.009	1.804 ± 0.001	0.041 ± 0.001
E1	100.282 ± 4.138	62.138 ± 2.738	5.138 ± 0.206	56.984 ± 2.532	30.266 ± 6.363	5.668 ± 0.280
E2	108.426 ± 3.890	6.762 ± 0.009	0.648 ± 0.418	6.411 ± 0.011	127.094 ± 0.003	0.740 ± 0.362
Z	32.354 ± 0.664	7.679 ± 0.611	0.696 ± 0.237	6.979 ± 0.372	106.199 ± 1.436	0.458 ± 0.001

High concentrations in the endmembers suggest that groundwater discharges are a relevant source of dissolved nutrients in the Aiguadolç beach. However, the concentration of dissolved nutrients in E1 and

E2 endmembers showed a difference of an order of magnitude, except for DSi. This fact indicates that the origin of groundwater of E1 and E2 was different as also demonstrated by the Rn and Ra. On the other hand, E2 and Z samples showed very similar nutrient concentration values except for DSi, therefore these waters could be related.

As in the case of Ra isotopes concentrations, samples 2 of each transect presented higher concentrations than the rest of seawater samples for the nutrients analyzed. This reinforces the hypothesis that groundwater discharges occur offshore at some point around station 2 (*Figure 41*). NH_4^+ levels were high, especially in the E2 and Z endmember samples, with values of 127 and 106 µM respectively, suggesting that this ammonium is from an anthropic source. The *Figure 40* shows the ^{224}Ra plotted with NH_4^+. The linear correlation (R=0.97) between seawater samples and endmember samples enhances the theory that the origin of the NH_4^+ content in seawater was related to groundwater, as was de case with ^{224}Ra. Other nutrient concentrations related with Ra the same way that NH_4^+ does are Si and PO_4^{-3}.

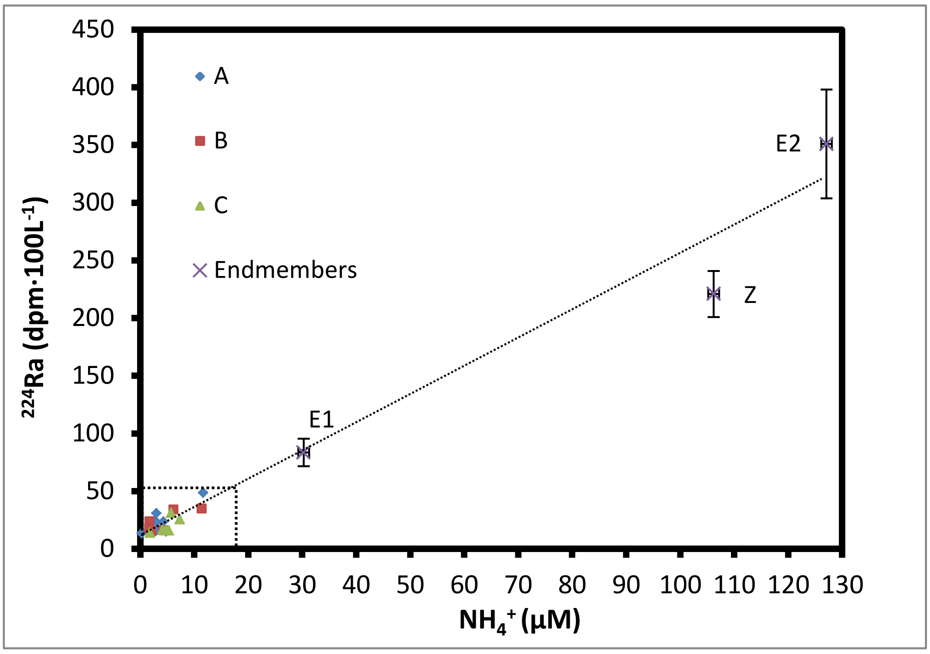


Figure 40: *^{224}Ra concentration plotted with NH_4^+ concentration. Black dotted line showing linear tendency between ^{224}Ra and NH_4^+ (R=0.97). Seawater samples error is not represented in the plot due to it would not be appreciated. To consult it, see Table 9.*

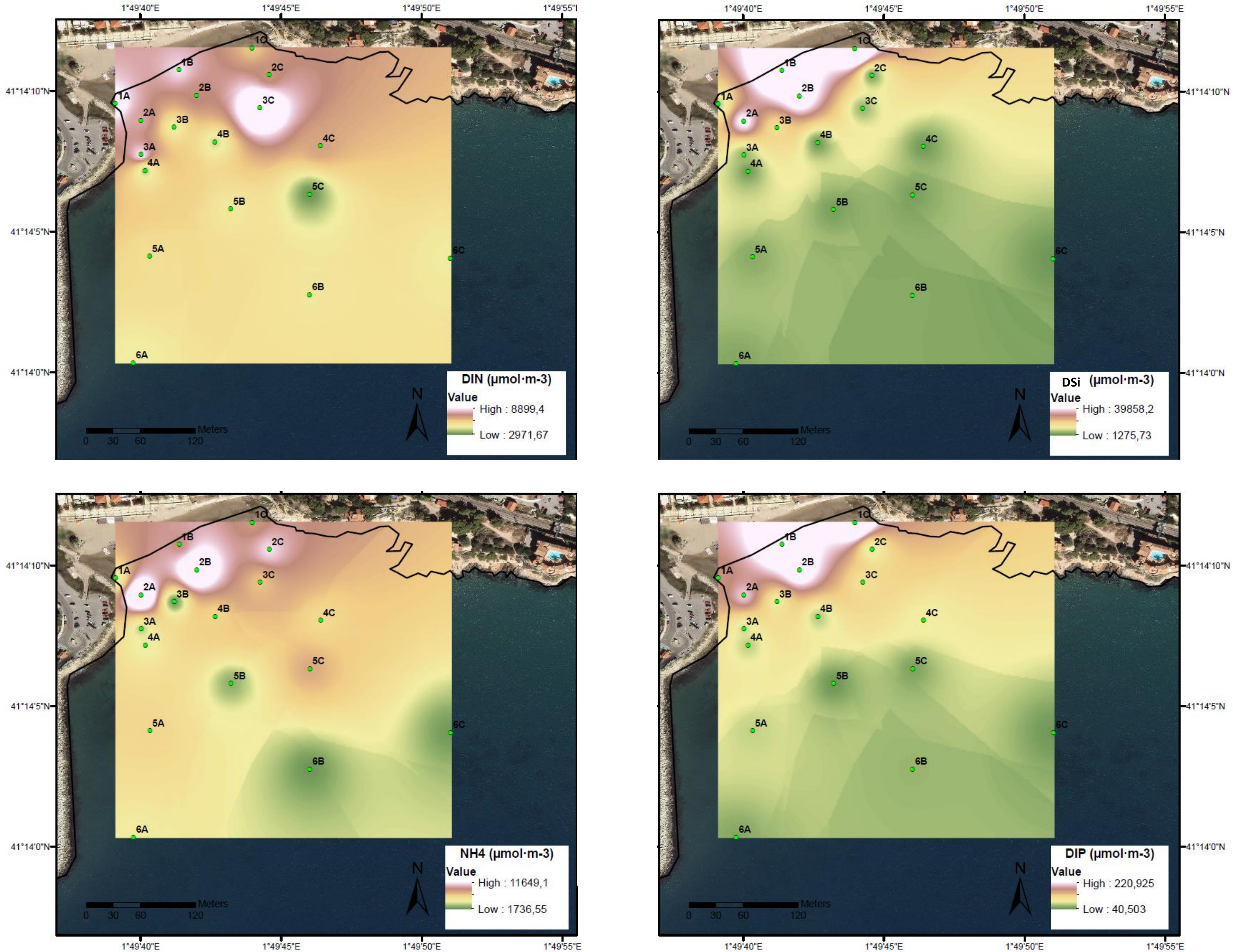


Figure 41: *Map of dissolved nutrient concentrations (DIN, DSi, DIP, NH_4^+) distribution in Aiguadolç. Data interpolation by using IDW (ArcGIS Spatial Analyst), without considering the endmembers concentration.*

7.6. SOCIAL STUDY

7.6.1. CONFLICT RECONSTRUCTION

A social conflict was identified after talking with different actors in Aiguadolç. The main issue detected was the dissatisfaction of the beach users, neighbours from Aiguadolç and tourists, about the beach quality. Some factors were described as problematic in the beach: the wet sand, which it does not allow to rest in the ground to enjoy the beach; the occurrence of some holes in the sand, which sinks if something add weigh above; and stagnant waters with green algae, which looks like unhealthy and insalubrious. These facts happen in the context of an anthropized karstic beach with the presence of SGD processes, and seem like usual behaviour of this kind of environment. These users come to Sitges city Council to present their worries to the administration.

The administration could not give an easy solution, and this fact did to consider to some neighbours to constitute a citizen platform against the problem in Aiguadolç. To face this situation the Council gave two temporary solutions: adding sand from harbour dredging and fence the most risky zone. Meanwhile, during the documentation and interviews process, other conflicts in Sitges were identified related with Garraf massif and SGD. Meanly two problematic are affecting the zone with a relevant scope: The water for consumption pollution by $NH4^+$ in Plana Novella urbanization and the bad smell in El Garraf urban core. The last phenomenon is due to the contamination of Garraf dump (Custodio et al., 2017; Pérez de Pedro, 2008) in which La Falconera subterranean river is playing an important role draining the toxic leached from the dump. To evaluate several possibilities related with management of Aiguadolç system a SWOT analysis was made and it is shown in the *Table 11*.

Table 11: *Aiguadolç conflict SWOT analysis.*

Strengths	Weaknesses
-Ecological relevance -Possibility of explode natural resources -Ecological, historical and cultural added value -Point of educational interest	-Conflict of interest between the municipality and part of the neighbourhood -Lack of knowledge about its management -Water NH_3 pollution
Opportunities	**Threats**
-Useful to comprehend Garraf massif flow paths and behaviour -Useful experience to improve the SGD management policies -Useful to manage water pollution in Garraf -It could become an educational tool for the village	-Economical costs for the studies -Particularities as the beach and the channel are difficult to extrapolate into the rest of the massif -To guarantee the conditioning of the beach for the users is needed a sand addition when there are important outlet emergence events

7.6.2. ACTORS INVENTORY

The complexity of Aiguadolç conflict requires resuming all actors to comprehend their interests and positions, in order to understand the several roles that they develop in the controversy. The *Table 12* summarizes every actor describing each one.

***Table 12:** Actors inventory of Aiguadolç conflict.*

Actor		Description	Interests	Positions
Citizens	Local residents	Some of the residents of Aiguadolç have a bad notion about the springs that often appear in the beach. These people are not organised in a platform, but some of them have informed to the council about their intention to set themselves as one.	▪ Have the possibility to enjoy the beach habitually, without problems with wet sand, holes on the beach or water stagnation. ▪ They do not want the beach to be contaminated or negatively affecting their quality of life.	▪ To solve this problem immediately because is a bad thing for the neighbourhood and could have negative impacts in their life quality. ▪ Exerting pressure to the council, to force it to take actions.
Citizens	Casual tourists	Tourist that come to Sitges for a few time but not usually.	▪ Have the possibility to enjoy the beach occasionally in the best conditions.	None.
Citizens	Usual tourists	Tourist that come to Sitges for a few or large time usually. Depending on the profile of the tourist they could be more involved in the issue of Aiguadolç, as the tourist with a second residence in Sitges.	▪ Have the possibility to enjoy the beach occasionally, without problems with wet sand, holes on the beach or water stagnation. ▪ They do not want the beach to be contaminated or negatively affecting their quality of life.	▪ To solve this problem immediately because is a bad thing for their vacations enjoy. ▪ Exerting pressure to the council, to force it to take actions.
Sitges council	Environment council	It competencies are related with the environment, as the beaches and some related natural environments and resources, overlapping it with the coast council.	▪ To maintain the tourism and the citizens. ▪ Guarantee the good life conditions of the citizens. ▪ Protect and manage the environment. ▪ To solve La Falconera's pollution trouble.	▪ Minimum intervention into the beach, because it is a natural issue. ▪ Interest in collaborations to make studies of the rising springs in Garraf.

	Coast council	It competencies are related with the coast and tourism. The beaches are a competence overlapped with the environment council.	▪ To maintain the tourism and the citizens. ▪ Guarantee the good life conditions of the citizens. ▪ Protect and manage the coast. ▪ To have more competencies in the coast management.	▪ Solving occasionally the troubles in the beach.
	Environmental municipal technicians	They are responsible for restoring the beaches as well as detecting problems in them. They are in contact with the neighbours and their knowledge; they know first-hand the problems of the beaches.	▪ Solve the technical problems in the environment and the coast. ▪ Guarantee the safety in the beach.	▪ Solving occasionally the troubles in the beach. ▪ Establishing as protected zone the area with a major influence of outlet emergences.
Local tourist related industry	Hotels and restaurants	Business situated in Aiguadolç urbanization related with the tourism.	▪ To maintain the tourism and the citizens.	▪ Showing their worry about the possibility of losing users of their services.
	Beach bar and surf school	Business situated in Aiguadolç beach related with the tourism and with a complete relation with the beach quality.	▪ To maintain the tourism and the citizens. ▪ Have the possibility to enjoy the beach habitually, without problems with wet sand, holes on the beach or water stagnation. ▪ They do not want the beach to be contaminated or negatively affecting their quality of life.	▪ Exerting pressure to the council, to force it to take actions, due to their worry of losing users of their services.
Other actors related with the issue, but not acting	Aiguadolç harbour	The administration of the harbour is not acting in the problem due to that there is no evidence of issues that affect directly the infrastructure or its working.	None.	None.

7.6.3. SOCIOGRAM

In the *Figure 42,* the sociogram of Aiguadolç controversy is shown. In this graphic is possible to appreciate the nature of interrelations between actors. In the following lines, the most relevant interactions, these which are conditioning in great measure the conflict evolution are exposed in a more accurate way. Relations between the several actors inside the council are very strong, and they have the same positioning about how to manage Aiguadolç problem. For them this is a natural occurring process and the most suitable option is to leave it to the natural dynamics pathway. But this becomes a trouble enhancing bad relations between council and other actors, due to the lack of exchange information between them. Municipal technicians have a more developed relation with neighbours due to the actions that they did to solve Aiguadolç issues. It results in an enrichment of local knowledge to technicians. The depending relations between local businesses (beach bar, surf school, hotels and restaurants) and tourist could be affected due to the quality of the beach, and for these, their interrelations are strong, and bad with Sitges city council which is not doing anything to change them controversy perception.

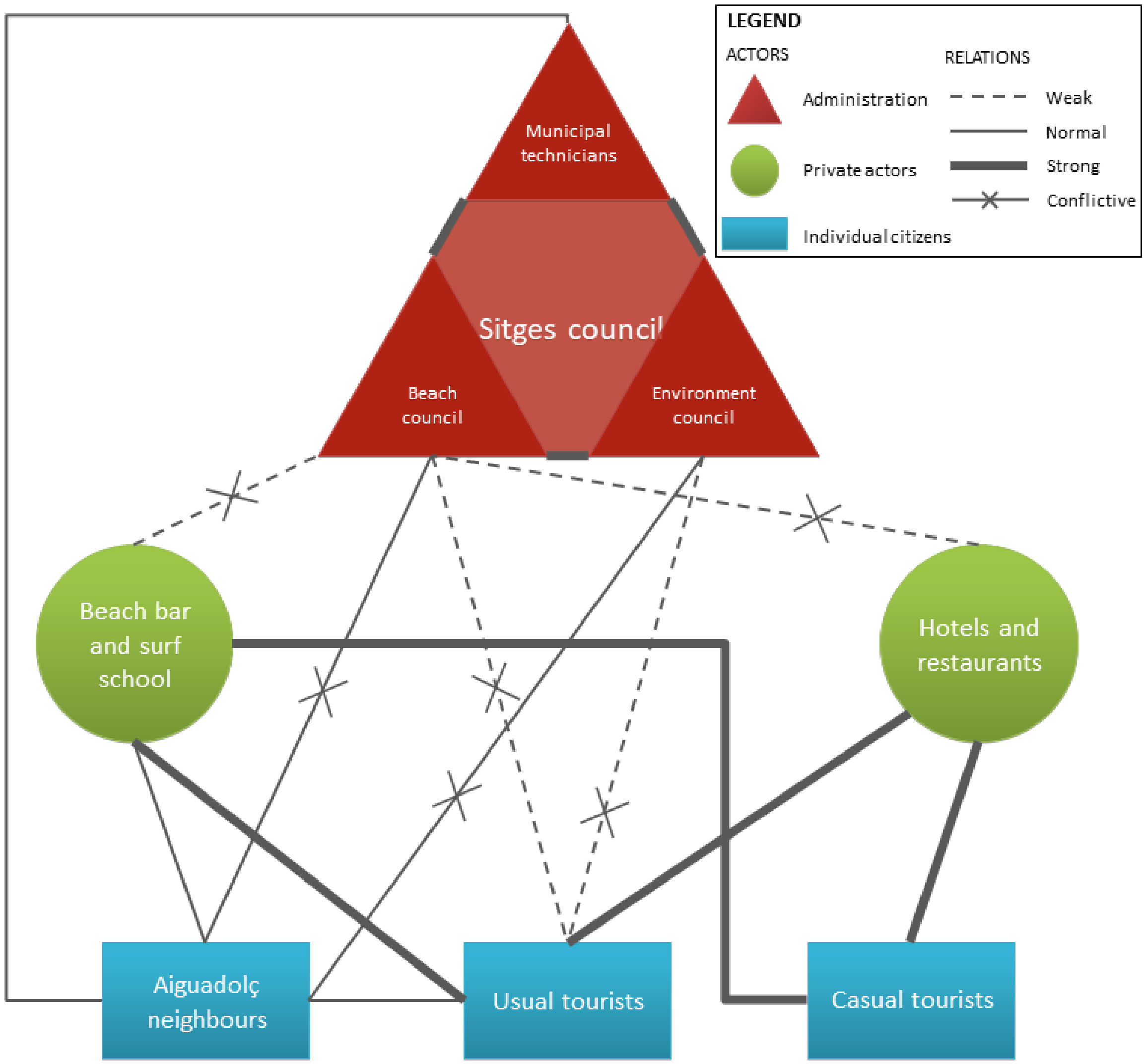


Figure 42: *Aiguadolç conflict sociogram. The interrelations between actors are described, from the top to the bottom indicates more to minus power in the hierarchy.*

8. DISCUSSION

8.1. HIDROGEOLOGY AND ANTHROPIZATION

Aiguadolç beach is situated in the interaction between Garraf-Bonastre Miocene-quaternary aquifer and Garraf Jurassic-cretaceous limestone aquifer as is shown in *Figures 23* and *26*. In the beach three different fluxes can be identified: a) a regional groundwater deep flow in the Cretaceous aquifer, which possibly is not affecting the scope zone; b) a saltwater intrusion, that seems to be restricted to deep levels in Aiguadolç; c) infiltration and flow through surficial or less deep limestone and through the Quaternary body, composed by the beach sand and the Aiguadolç stream (*Figure 43*). The unconsolidated detrital body acts as a free aquifer that infiltrates easily the rainfall due to its permeability, and discharges in the limestone karst. This karst drives the flows through chasms and fractures, due to its secondary well-developed permeability, in very anisotropy pathways. The infiltration of limestone Cretaceous in enhanced because of the quarries fractures due to the use of explosives and other technologies used to extract the limestone.

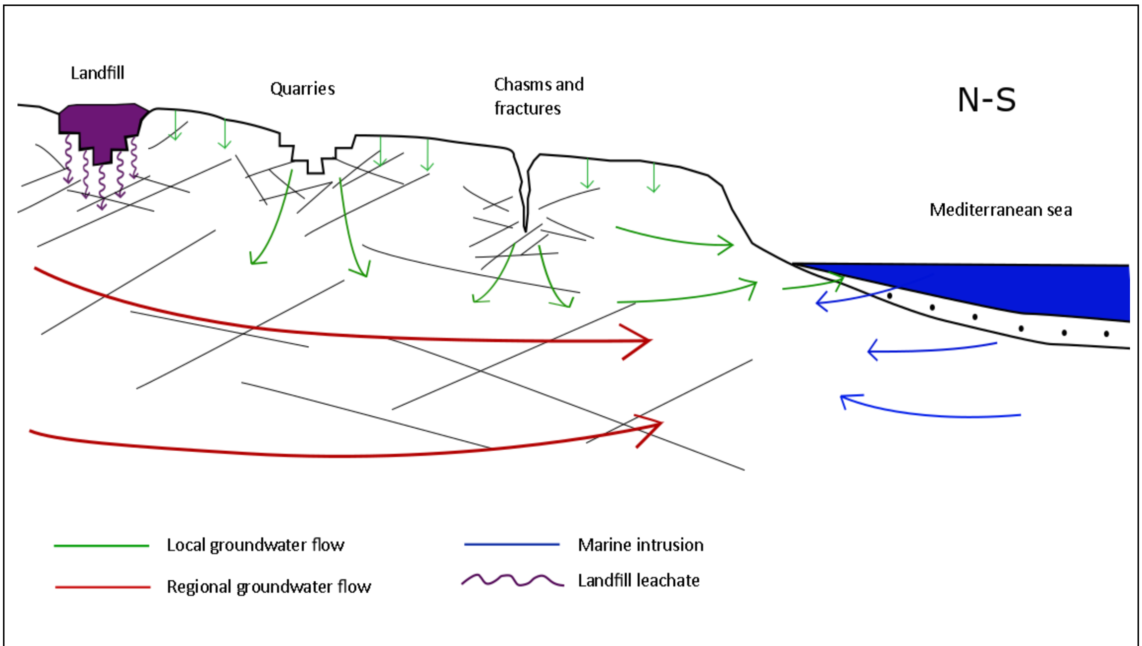


Figure 43: *Schematic profile of Garraf massif flow pathways and recharging zones.*

ERTs show the subterranean estuary along the stream, and also a great low salinity in the E of Aiguadolç. These is due to the geological matrix, in the W there are a more thick sediment layer, while in E the limestone outcrops superficially. These are agreeing with nutrient and radium high concentrations, which are showing a major flux entry through the E. As it can be observable by looking at nutrients and radium distribution, in transect A the groundwater flow happen since the second station, it must be related with sand layer distribution in the beach (thick at W and thin at E). Where the entries could be more focused in one clear spring, while in the E is a more diffuse process scoping a bigger area following the cliff.

At regional scale, in other Garraf zones, the landfill leached infiltrates contaminating the water resources. The NH_4^+ high levels in Aiguadolç may be pollution reminiscences due leached from the dump, or it could be related with the farm situated in the Aiguadolç stream course. To trace it and search for pollution source is necessary a complementary study with stable isotopes as N or O. If the landfill water level keeps stable in a high level is possible that the leached processes decrease, and only slow diffusion processes were done. A possibility for a good management planning is to monitoring SGD flows in Garraf coast to know about the landfill water table, and predict the time when the leaching process is given.

8.2. SGD QUANTIFICATION IN AIGUADOLÇ

The SGD flow in Aiguadolç can be estimated from the Ra flux supplied by SGD. This Ra flux is calculated by using a Ra mass balance with the equations *(2), (3)* and *(4)*. The box model proposed for Aiguadolç beach is shown in the *Figure 44.* Due to excess ^{224}Ra give values ≤ 0 from the stations A3, B3 and C3, volumes of coastal water are calculated with 3 boxes (*Appendix 7*), in every box the concentration considered depends on the stations inside. The calculations are made without considering a gradient of Ra concentration in the water column. On a local scale, SGD is often difficult to separate from density driven seawater recirculation (Slomp and Van Cappellen, 2004), the data given by CTD in Aiguadolç cannot be interpreted as a clear pycnocline, because of that we assume the whole water column as our SGD plume. If a Ra sampling of several depths in water column had been done, a more accurate balance can be calculated.

To characterize the endmebers that could be used to calculate the SGD is important to look at the relations between ^{224}Ra with salinity. The *Figure 40* shows how the endmembers had a lower salinity than the seawater samples and a higher concentration of ^{224}Ra, so they could serve as endmembers for our study. Samples E2 and Z were collected from the same part of the beach. This fact caused us to expect a relation between E2 and Z much clearer than that shown in the *Figure 38*, where there is no linear correlation between seawater samples, E2 and Z. In addition, Z was collected from the sea, near a visible fracture, were the water flows into the sea, so it is not a pure groundwater sample. Therefore sample Z has been ruled out as a possible endmember for this study.

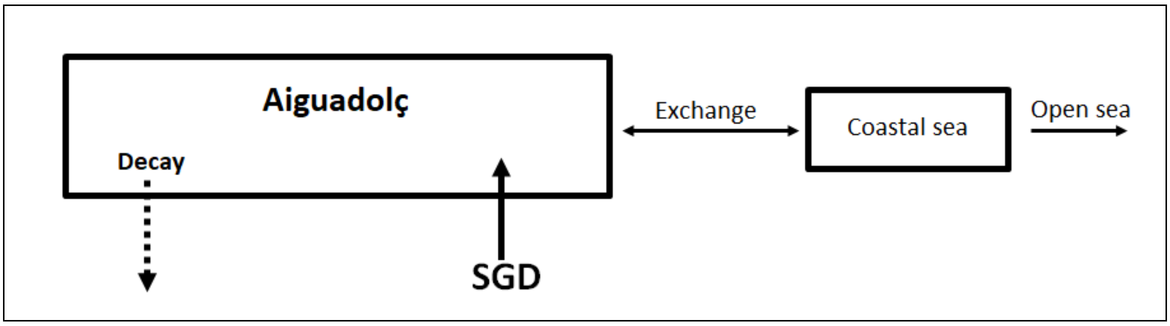


Figure 44: *Box model for calculating a mass balance in Aiguadolç beach.*

The plot ^{224}Ra/^{223}Ra ratio with salinity allows seeing how E1 sample had a ^{224}Ra/^{223}Ra ratio lower than all seawater samples (*Figure 45*). This discards E1 sample as endmember for our study since this ratio should be higher in endmembers, and it decrease towards open sea because ^{224}Ra disintegrates quicker than ^{223}Ra. Even though, endmember uncertainty is elevated relative to sample ratio, so this approximation could be wrong. Due to this, to make the calculations the only useful endmember is E2.

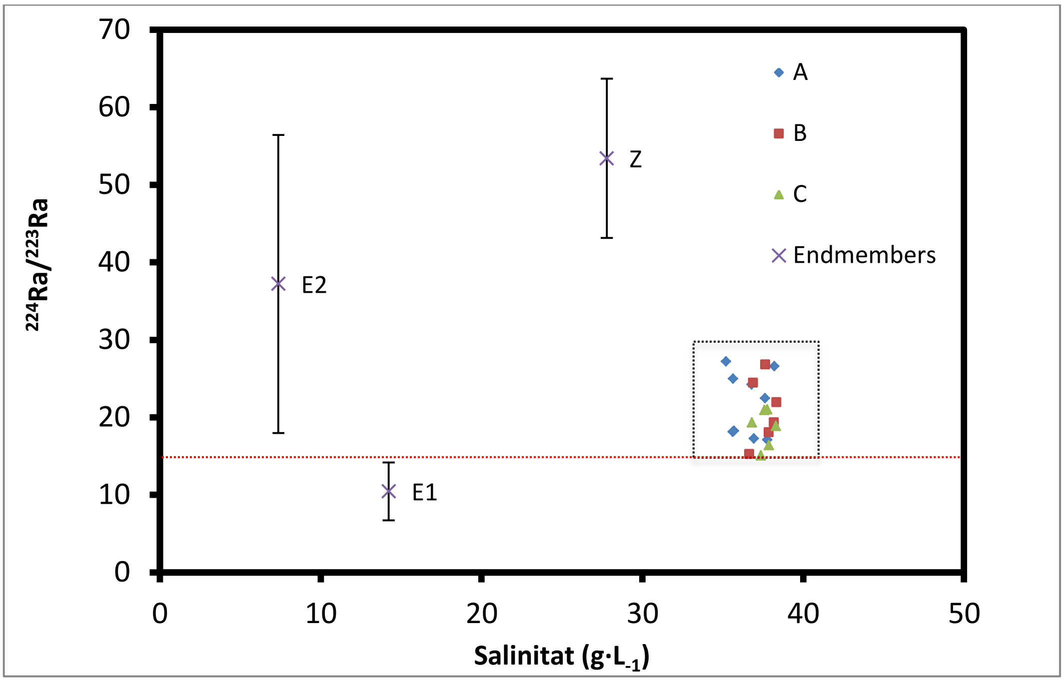


Figure 45: *$^{224}Ra/^{223}Ra$ ratio plotted against water salinity for all Aiguadolç. Red dotted line representing the lowest $^{224}Ra/^{223}Ra$ ratio of the seawater samples. Seawater samples error is not represented in the plot due to it woud not be appreciated. To consult it, see Table 9.*

The SGD flow in Aiguadolç is estimated in $4.0\pm0.8\cdot10^{3}$ $m^{3}\cdot d^{-1}$, and if coastline is considered the flow is about $9.7\pm1.4\cdot10^{6}$ $m^{3}\cdot km^{-1}\cdot yr^{-1}$. The residence time is estimated in 42.9h (1.8 days). This is a low residence time and it is typical of open karstic coastal regions (Garcia-Solsona et al., 2010), like in Santanyi, Romàntica and Sa Nau, in Spain which show a residence time of 1.7, 1.5 and 1.2 days respectively (Tovar-Sánchez et al., 2014). Aiguadolç freshwater flow is of $3.2\pm0.7\cdot10^{3}$ $m^{3}\cdot d^{-1}$, which is two orders of magnitude less than La Falconera, the most important spring in Garraf, which estimated flow is about $7.7\pm1.4\cdot10^{5}$ $m^{3}\cdot d^{-1}$ (Custodio et al., 2017). The ACA estimates a localized and diffuse total discharge along the entire coastline of $3.0\pm0.3\cdot10^{4}$ $m^{3}\cdot d^{-1}$, this means an order of magnitude more than Aiguadolç and an order of magnitude less than La Falconera estimation. Considering that, these two springs are some of the most important springs in Garraf massif, these values are very suitable and they fit well with the karstic anisotropic behaviour and with its temporal variability. If the calculated SGD in Aiguadolç is the average value in the beach, it represents 10.6% of the total SGD in Garraf.

The seasonality in precipitation will also influence SGD for the detritic body of sand that works as phreatic and allows to very quick infiltration, and for the calcareous basement (Cretaceous limestone aquifer) with its siphon like behaviour. This fact could result as a very variation of flow magnitude. The saltwater/freshwater interface will change too depending on the recharging and the flow paths. For this a large spatial and temporal variability of SGD is deducted in this zone.

8.3. SGD IN THE MEDITERRANEAN CONTEXT

Normalizing the SGD flow by the total shore length of the Mediterranean Sea, approximately 64,000 km (Stewart, 2009), a flow ranging from $6 \cdot 10^6$ to $100 \cdot 10^6$ $m^3 \cdot km^{-1} \cdot y^{-1}$ is obtained (Rodellas, 2014). The SGD flow obtained in this study (*Table 13*) fits between this ranges, reinforcing the consistency of our estimations. In addition, it is similar to SGD flows obtained from other Mediterranean Sea locations like Marina Lagoon, Egypt (El-Gamal et al., 2012) and La Palme Lagoon, France (Stieglitz et al., 2013). Also, this values are similar to other karstic springs or coves like Alcafar, Spain (Garcia-Solsona et al., 2010a); Badum, Spain (Garcia-Solsona et al., 2010b); Dor Beach, Israel (Weinstein et al., 2011); El Maestrat, Spain (Mejías et al., 2012); Sa Nau, Spain (Tovar-Sánchez et al., 2014) and Stoupa, Greece (Pavlidou et al., 2014). A study conducted in Calanques massif, France, which is karstic system very similar to Garraf, shows a flow of SGD of $16 \cdot 10^6$ $m^3 \cdot km^{-1} \cdot yr^{-1}$ (Tamborski et al., (in preparation)). This flow doubles the one obtained in Aiguadolç, although there are points in the Garraf where the discharges seem to be greater scale as La Falconera.

Table 13: *SGD flow comparison in different karstic sites of the Mediterranean Sea.*

Study site	**SGD** ($\cdot 10^6$ $m^3 \cdot km^{-1} \cdot yr^{-1}$)	**Reference**
Alcafar, Spain	0.4	Garcia-Solsona et al., 2010a
Badum, Spain	19	Garcia-Solsona et al., 2010b
Calanques Massif, France	16	Tamborski et al., (in preparation)
Dor Beach, Israel	1.8	Weinstein et al., 2011
El Maestrat, Spain	8.3	Mejías et al., 2012
La Palme Lagoon, France	7.9	Stieglitz et al., 2013
Marina Lagoon, Egypt	8.0	El-Gamal et al., 2012
Sa Nau, Spain	21	Tovar-Sánchez et al., 2014
Stoupa, Greece	11	Pavlidou et al., 2014
Aiguadolç, Spain	9.7	The present study

8.4. NUTRIENT FLUXES IN AIGUADOLÇ

Nutrient concentrations ($\mu mol \cdot L^{-1}$) measured in Aiguadolç are presented in *Table 14*, these values show comparable results with other studies conducted in the Mediterranean Sea. Taking into account the amount of $NH4^+$ in Aiguadolç samples, the concentrations of DIN, DIP and DSi (133, 0.74 and 108 $\mu mol \cdot L^{-1}$, respectively) are comparable to the measures in Badum, Spain (Garcia-Solsona et al., 2010b); Dor Beach, Israel (Weinstein et al., 2011); Santanyí, Spain (Tovar-Sánchez et al., 2014); Sa Nau, Spain (Tovar-Sánchez et al., 2014) and Palma Bay, Spain (Rodellas et al., 2014), and far away (for DIN) from results measured in Alcafar, Spain (Garcia-Solsona et al., 2010a). On the other hand, if we only consider NOx as input of nutrients, the results of DIN concentration are much lower, comparable with the results obtained in Marina Lagoon, Egypt (El-Gamal et al., 2012). This indicates that the contributions of NO_x^- in Aiguadolç are much lower than in the rest of the sites and that instead, the contribution of NH_4^+ is higher.

Table 14: *DIN, DIP and DSi concentrations in different sites of the Mediterranean Sea.*

Study site	DIN	DIP	DSi	DIN:DIP	Reference
	(µmol·L^{-1})				
Alcafar cove, Spain	1000	0.25	66	4200	Garcia-Solsona et al., 2010a
Badum, Spain	61	0.41	56	150	Garcia-Solsona et al., 2010b
Dor Beach, Israel	80	0.5	100	160	Weinstein et al., 2011
Marina Lagoon, Egypt	9	0.5	26	17	El-Gamal et al., 2012
Palma Bay, Spain	150	1.3	77	120	Rodellas et al., 2014
Romántica, Spain	180		190		Tovar-Sánchez et al., 2014
Sa Nau, Spain	120		230		Tovar-Sánchez et al., 2014
Santanyí, Spain	74		77		Tovar-Sánchez et al., 2014
Aiguadolç, Spain (E2)	133	0.74	108	180	The present study

Nutrient fluxes can be calculated by multiplying the concentration of these in the groundwater endmembers by the SGD flow obtained. This method of flow calculation can be applied in our study because the groundwater samples have been obtained right at the point of discharge (Garcia-Solsona et al., 2010). The SGD-associated nutrient fluxes are presented in *Table 15*.

The importance of nutrient fluxes related to SGD can be compared to nutrient inputs from rivers (Ludwig et al., 2010) and atmospheric deposition (Koçac et al., 2010; Markaki et al., 2010) to the Mediterranean Sea. In addition, the input related to SGD can be much more important in zones where rivers do not flow into the sea.

Table 15: *Aiguadolç nutrient fluxes.*

DIN flow	DIP flow	DSi flow	$NH4^{+}$ flow
µmol·m^{-2}·d^{-1}	µmol·m^{-2}·d^{-1}	µmol·m^{-2}·d^{-1}	µmol·m^{-2}·d^{-1}
78060 ± 16493	432 ± 91	63230 ± 13360	74116 ± 15660

DIN fluxes results obtained in Aiguadolç exceed the values obtained from Slomp and Van Cappellen, 2004, meanwhile DIP fits within this values, calculated in other regions, where the inputs are from natural origin (9-900 µmol·m^{-2}·d^{-1} for DIP and 160-2400 µmol·m^{-2}·d^{-1} for DIN; Slomp and Van Cappellen, 2004). This suggests that the origin of these nutrients is anthropic. Also, Aiguadolç nutrient fluxes were higher than other calculated in different Mediterranean sites like Badum, Spain (1500-8300 µmol·m^{-2}·d^{-1} of DIN and 19-40 µmol·m^{-2}·d^{-1} of DIP; Garcia-Solsona et al., 2010b), Santanyí, Spain (28 mmol· m^{-1}·d^{-1} of

DIN; Tovar-Sánchez et al., 2014), Romàntica, Spain (21 mmol· $m^{-1}\cdot d^{-1}$ of DIN; Tovar-Sánchez et al., 2014) and Palma Bay, Spain (1900 mmol· $m^{-1}\cdot d^{-1}$ of DIN; Rodellas et al., 2014).

Nutrient input from contaminated groundwater with a high N:P ratio can cause coastal waters to change from N-limited system to P limited system (Lapointe, 1997), stimulating algal blooms (Lee et al., 2010)Results from Slomp and Van Cappellen, 2004 indicate that substantial contamination of coastal groundwater with N is needed to change the N-limitation system to P-limitation system and to enhance primary production in coastal zone.

Studies carried out in shallow waters of La Selva and Baix Empordà (Catalonia) show concentrations of nitrates and phosphates in offshore areas of 1 $\mu mol\cdot L^{-1}$ and 0.1 $\mu mol\cdot L^{-1}$, respectively (Agència Catalana de l'Aigua, 2006). Nitrate values measured in Aiguadolç are higher, while phosphate concentration shows similar concentrations. High nitrates concentrations in Aiguadolç coastal water, as well as the elevated concentrations in the endmembers suggest that Aiguadolç receives elevated nitrogen inputs due to the SGD.

The Mediterranean is considered a P-limited sea (Krom et al., 1991). According to the Redfield ratio (Si: N: P = 16: 16: 1) for the study area, Aiguadolç coastal zone is actually P-limited because the seawater mean ratio Si: N: P = 16: 52: 0.4 (*Table 16*) similar to other areas on the NW Mediterranean (Diaz et al., 2001; Garcia-Solsona et al., 2010) where the limiting factor is also P. Phosphorous is a limited nutrient in the Mediterranean sea mainly because is rapidly removed from groundwater (Slomp and Van Cappellen, 2004). Also, in karstic areas, P may become a limiting nutrient because it is sequestered in calcareous sediments (Elser et al., 2007), due to its mineral precipitation Ca, Al and Fe in apatite training (Charette and Sholkovitz, 2002). N:P ratio is above the average N:P ratio in the western basin of the Mediterranean sea (24:1; Pujo-Pay et al., 2011).

Karstic formations such as the Garraf massif are susceptible to anthropogenic contamination (Tapia et al., 2008) and can lead to a rapid pathway of nutrients and pollutants to the sea. This makes coastal ecosystems ecologically vulnerable (Young et al., 2008). Groundwater N concentration from anthropogenic sources is usually in form of NO_3^-, while NH_4^+ is nitrified in the unsaturated oxic zone (Jordan et al., 1997). If the groundwater has a substantial NH_4^+ concentration, as in this case, it can be due to land-fills leachates (Christensen et al., 2001) but it can also be due to the denitrification produced in anoxic systems from NO_3^- to NH_4^+, among other causes (Slomp and Van Cappellen, 2004). Another possible cause to take into account to explain the presence of high NH_4^+ concentrations in the Aiguadolç samples is the presence of riding clubs located near the stream of Aiguadolç, which could be introducing ammonium in the groundwater fluxes.

Real Decreto 140/2003, of February 7th, establishes health criteria for the quality of water for human consumption. The parametric value for NH_4^+ is 0.5 $mg\cdot L^{-1}$, as soon as the parametric value is exceeded, corrective measures must be taken (>1 $mg\cdot L^{-1}$ means that water is considered not potable and not available to human consumption). The presence of ammonium can be an indicator of fecal, agricultural or industrial contamination. The presence of NH_4^+ is also detected in other zones in the Garraf massif (Plana Novella urbanization and El Garraf), and for these places the origin of pollution is attributed to the dump's leaching. Aiguadolç endmembers show 1.78 $mg\cdot L^{-1}$ for E2 and 1.49 $mg\cdot L^{-1}$ for Z, and a maximum value of 0.16 in seawater samples, meaning that the endmebers are contaminated, but that seawater dilutes the pollutants concentration enough to be safe. Total ammonia is the amount of NH_4^+ and NH_3. The balance between these two phases is controlled by the reaction: $NH_4^+ + OH^- \leftrightarrow NH_3 + H_2O$ (Emerson et al., 1975) and depends on pH and temperature. Unionized ammonia is very toxic to aquatic animals, particularly to fish, while ionized ammonia is nontoxic or appreciably less toxic (Camargo and

Alonso, 2006). Numerous fish kills have been observed as a consequence of discharges of water with anthropic contaminants, with high levels of total ammonia (Constable et al., 2003). The nitrites and nitrates do not raise the legal limits but they can become a problem if ammonium is nitrified to NO_2^- or NO_3^-. E1 shows the maximum concentration is about 0.80 mg·L^{-1} for NO_3^- and 0.07 mg·L^{-1} for NO_2^-, versus the parametric values established in 50 mg·L^{-1} and 0.5 mg·L^{-1} respectively.

Table 16: *DSi, DIN and DIP ratios for Aiguadolç beach samples.*

Code	DSi:DIN:DIP		
1A	16.00	36.89	0.42
2A	16.00	13.29	0.10
3A	16.00	50.77	0.34
4A	16.00	70.29	0.60
5A	16.00	59.13	0.39
6A	16.00	55.81	0.36
7A	16.00	63.94	0.54
8A	16.00	99.38	1.08
9A	16.00	18.07	0.19
1B	16.00	5.03	0.09
2B	16.00	14.57	0.14
3B	16.00	10.63	0.13
4B	16.00	81.54	0.57
5B	16.00	56.73	0.37
6B	16.00	41.77	0.35
1C	16.00	4.68	0.09
2C	16.00	95.74	0.46
3C	16.00	72.38	0.41
4C	16.00	97.03	0.68
5C	16.00	75.05	0.40
6C	16.00	72.42	0.51
E1	16.00	14.74	0.90
E2	16.00	19.75	0.11
Z	16.00	56.32	0.23
Average total	16.00	49.41	0.39
Average sea	16.00	52.15	0.39
Avergae E1-E2-Z	16.00	30.27	0.41
Average 1-2-3	16.00	33.78	0.24
Average 4-5-6	16.00	67.75	0.47
Average 7-8-9	16.00	60.46	0.60

8.5. THE INFLUENCE OF SGD IN THE BEACH MANAGEMENT

8.5.1. EROSION

According to the interviews conducted in this study (*Appendix 6*), Aiguadolç was originally a rocky-boulder beach. The modification of the beach sediment composition changed the coastal geomorphology, possibly from a reflective to a refractive profile. To study the influence of erosion accurately is necessary to analyze it with GIS and field studies; hence another study would be necessary to quantify the erosion caused only by the SGD.

But with field recognition is possible to give some objective observations. The torrential rains that occur in the Mediterranean climate erode the coast, transporting sand from the beaches to the sea. But runoff erosion is not the only way that erodes coastal areas. In fact is possible that SGD actively participates in the beach's losses in a regular way, as a continuous phenomenon. The freshwater inflow flux pressure can remobilize the sediments to more stable locations, becoming another variable to have an account in the coastline management. Also, pore pressure increased by water saturation in the sand could help the runoff improving its transport capacity (*Figure 46 A*). In Aiguadolç this factor can be relevant since the sand of this beach is usually wet, and therefore with water in its porous space, much of the year.

Figure 46: *SGD erosion hints after a rainfall event. A) Beach erosion in Aiguadolç after the rainfall and B) La Falconera discharge showing a terrigenous plume after a rainy day (12th of February, 2018).*

In addition, the presence of plumes with a lot of suspended material located in the discharge points evidence the SGD potential to transport sediments through the coastal areas to hundreds of meters offshore, as is the case of La Falconera (*Figure 46 B*), one of the most important discharges in the Garraf coastal area. In Aiguadolç the erosion by SGD was evident, different ways of erosion were identified. As is shown in the *Figures 46* and *47* the erosion transport could make small braided streams as a surficial erosion, or truly erosion channels, depending on the flow intensity. In the *Figure 48* is possible to be noticed that the flow emerge from inside the sand and erodes the sediments and transports it, including the enriched in organic matter soil horizons and its solutes.

Figure 47: *Aiguadolç beach erosion and SGD fluxes becoming surficial in some areas (photo by Jordi Garcia-Orellana).*

The action of the erosion by SGD in Aiguadolç is relevant but it must be studied in a more accurate way and taking in consideration the continuous erosion by SGD, not only in rainfall events; the runoff erosion and deposition, and it relative fraction in comparison with SGD erosion; the characteristic deposition and remobilization dynamics in Aiguadolç; the effect of waves and currents and other possible variables that may affect the beach.

Figure 48: *Deep erosion produced by SGD on surficial sediments in Aiguadolç, it is possible to identify low deep reduced sediments with dark colors showing the high content in organic matter.*

8.5.2. SOCIOECONOMIC IMPACTS

The tourism is very important in Sitges (*Table 2*) *2* and represents an important part of the income for the population (*Table 3*). Any influence on the quality of beaches bathing water could generate a loss of tourism and therefore an investment of the municipality to recover the ecological status of the coast and recover the possible tourism lost. However, after the analysis of the collected data from the different interviews, the main conclusion is that there is not a big socioeconomical impact derived from the SGD influence in Aiguadolç. Some of the neighbors and the tourists become mad with the beach state, and some of them are leaving the neighborhood, but there are no evidences of real problems in the quality of Aiguadolç waters and the council does not know about a relevant losing of population or tourism in Aiguadolç.

During this study no evidence of N contamination has been detected that could generate episodes of eutrophication or that could represent a human health risk. Erosion is also not a problem for the beach management due to its sedimentary distribution dynamics, so there are no economic losses. The only thing that generates a real problem is the misinterpretation of the emerging water by the population If an environmental education campaign were carried out, raising awareness of the submarine and coastal groundwater discharge process in coastal areas could be a solution to this potential conflict. Thus, if the population were informed about the mechanisms of groundwater discharge that occurs on the beach, it would probably change their perception and their positioning with respect to this process.

It is important to exploit the added value of the beach in terms of natural resources. To solve the other circumstantial issues, it is enough to fence the problematic beach area. Regarding the persistence of wet sand on the beach, there is no real solution to this problem as sand is the natural connection between fresh groundwater and seawater. There are to alternatives to face this last issue; on is to leave the beach work as the nature wants, and the other is to put sand from the harbor dredging, which could serve as a punctual solution.

8.6. MANAGEMENT PROPOSALS

Here a proposal of some actions to improve the management for the Sitges council is exposed. The different actions are synthesized trying to create options for mutual gain by using objective criteria. Two strategic lines are determined to solve Aiguadolç conflict: Population awareness and environmental education, and a research program. And four actions are proposed in order to give an example of tools for enhance the management:

01. Aiguadolç outlet emergence signage and protection
02. Natural resources itinerary to do environmental education
03. Awareness campaign through environmental education for neighbours and business
04. Monitoring of Aiguadolç and study of the whole Garraf

Below there are different sheets with the detailed description of the actions.

Strategic line	Population awareness and environmental education	
Action	**01. Aiguadolç outlet emergence signage and protection**	
Objective	To protect the area and to give information for the users on the beach, avoiding accidents and educating.	
Description	The action is to surround with a fence the emergence and in to install a wooden board with information about the SGD processes that are happening in the beach. The fence will be made with wooden poles tied between them with a rope. The poster information will be made in collaboration with the UAB. The information must be easy to understand by all the population, but it must have a scientific background. The poster will be written in Spanish, Catalan and English. It will have some illustrations and maps for enhance the comprehension of the phenomenon.	
Thematic	Socioeconomic and educational	
Typology	Projects and works	
Priorization: Urgent	Implantation period: Short (<6 months)	Execution period: About one 2 weeks
Actors: Sitges Council, and UAB	Economical expense: 1.500€	Actors: Sitges Council, and UAB
Synergies:	With the actions nº 2 and 3.	
Monitoring indicators:	No tracking indicator	

Strategic line	Population awareness and environmental education
Action	**02. Natural resources itinerary to do environmental education**
Objective	To warn and educate the population about the enriched Garraf ecosystem and protect it.
Description	The action is to realize an itinerary that could be employed for the schools, entities and people at individual level. This itinerary will have signals showing the way to follow and some information boards to explain a concrete natural interesting spot or landscape. The boards will be made in collaboration with UAB, and will be traduced to Spanish, Catalan and English. The council will have a triptych or a guide to give for free in several municipal buildings. The itinerary will pass through Aiguadolç beach and through the Garraf massif.
Thematic	Socioeconomic and educational
Typology	Projects and works

Priorization: Medium	Implantation period: Short (<1 year)	Execution period: About one month
Actors: Sitges council, Sitges schools and institutes, UAB and Generalitat de Catalunya	Economical expense: 4.000€	Funding source: Sitges Council and Generalitat de Catalunya
Synergies:	With the action nº 1 and 3.	
Monitoring indicators:	No tracking indicator	

Strategic line	Population awareness and environmental education
Action	**03. Awareness campaign through environmental education for neighbours and business**
Objective	To sensitize population about Aiguadolç emergence phenomenon and normalize it; trying to explode it's important to added value.
Description	The action is to realize an awareness campaign in the neighbourhood and surroundings. This campaign will be made by using environmental educators that could give the essential notions about Aiguadolç natural occurring processes. This campaign will be executed during 1 year in order to reach the entire Aiguadolç population and business. The council will made a public tender to choose the corporation entrusted of the campaign.
Thematic	Socioeconomic and educational
Typology	Projects and works

Priorization: Urgent	Implantation period: Short (approximately 1 year)	Execution period: About one year
Actors Sitges council and the winner corporation of the public tender	Economical expense 24.000€	Funding source Sitges council

Synergies	With the action nº 1 and 2.
Monitoring indicators	Surveys will be conducted immediately after the campaign and 2 years later to know how the campaign has influenced the population perception of the Aiguadolç emergence.

Strategic line	Research program
Action	**04. Monitoring of Aiguadolç and study of the whole Garraf**
Objective	To comprehend how the Garraf system works, to describe its dynamics and to track the pollution effects in the ecosystem by the Garraf landfill. This will be useful to find new management tools for the SGD systems.
Description	The action is to realize a monitoring of Aiguadolç and a new campaign along the entire massif. The campaign will be made by using radioisotopes, stable isotopes, water ERTs, bioindicators and chemical analytical pollutants analysis. This study will be led by UAB in collaboration with other research groups/corporations.
Thematic	Environmental
Typology	Projects and works

Priorization Medium	Implantation period Medium (approx. 2-3 years)	Execution period About 4 years
Actors Sitges council, Agència Catalana de l'Aigua, UAB and other research groups/companies in collaboration with UAB	Economical expense 1.650.000€	Funding source Sitges council and Agència Catalana de l'Aigua
Synergies	With the action nº 1 and the present project.	
Monitoring indicators	No tracking indicator	

9. CONCLUSIONS

In order to investigate the role of submarine groundwater discharge through karstic aquifer of Aiguadolç (Catalonia, Spain) and its influence on seawater quality, Ra isotopes were used, together with dissolved nutrients (DIN, DIP and DSi) were analyzed in April, 2018. Thus, considering a Ra mass balance, SGD flow was $4.0 \pm 0.8 \cdot 10^3$ $m^3 \cdot d^{-1}$. This water flow agrees with previous estimations with other methods in Garraf massif and it is comparable to others studied karstic sites in Mediterranean Sea. The SGD in Aiguadolç represents the 10.6% of the whole SGD flow in Garraf massif.

SGD flows were used to estimate the associated inputs of DSi, DIN and DIP to the coastal waters of the Aiguadolç area that may after seawater quality. The estimated nutrient fluxes were 63 ± 13 $mmol \cdot m^{-2} \cdot d^{-1}$, 78 ± 16 $mmol \cdot m^{-2} \cdot d^{-1}$, and 432 ± 91 $\mu mol \cdot m^{-2} \cdot d^{-1}$, respectively. The study highlighted a significant flux of NH_4^+ of 74 ± 15 $mmol \cdot m^{-2} \cdot d^{-1}$, suggesting an anthropic nutrient source, possibly produced by the Garraf landfill. These inputs of dissolved nutrients result in an average ratio in the sea samples obtained from Aiguadolç of Si: N: P = 16: 52: 0.4, which could lead to a P-limitation in the marine ecosystem. In addition, the high NH_4^+ content of the water could cause some alterations in the ecosystem, especially when it is transformed into NH_3 or NO_3^-. Future research on groundwater discharge in Garraf area should include a study of the consequences of the high nitrogen concentrations (NH_4^+), for the marine ecosystem, as well as a study of its origin. This pollution is surpassing the legal limits for human consumption in the endmember (E2) and in seawater (Z).

The interpretation of the SGD in this study has been made considering only one endmember (E2). Even so, it is evident that in Aiguadolç there are other areas where SGD is influencing. The characterization of the endmembers suggests that E1 represents a local flow, with low residence time within the detrital aquifer, whereas the E2 sample groundwater appears to come from a regional flow.

Mean values of ^{223}Ra and ^{224}Ra concentration in Mallorca Island, show that our offshore sample is more close to a karstic sample than an offshore one. To collect a more distal sample could be useful to calculate more accurately the Ra excess in coastal waters to the mass balance. This fact together with the satellite image (*Figure 1*) and the resistivity results are showing that the SGD influence in Aiguadolç is great, and our campaign did not exit the edges of the plume.

Geophysical methods contributed in the study to identify submarine groundwater discharge; but also it would be interesting to use this methodology to find areas with more susceptibility to be eroded by the SGD action, in order to improve beach management tools.

In reference to the social conflict study, we conclude that there is a problematic that could be solved with easy and cheap management measures by Sitges municipallity, through the use of environmental education and sensitization. But is necessary a big study to the whole Garraf massif in order to solve other issues identified in the municipality related with the anthropization of the massif and the pollution of the karst.

10. SUGGESTIONS FOR IMPROVEMENT

The opportunity to develop a scientific project has allowed us to realize that there are a number of pending issues that could not be addressed due to lack of resources, time and knowledge. This section presents a proposal for different measures that could improve this project but also future projects with similar characteristics. The main points that we propose are due to the natural limitations of a TFG (*Treball Final de Grau*), such as the limited time to develop the study and the limited available budget.

In order to improve the work carried out, some considerations are given in relation to some aspects that were not possible to much better achieve. The most important topic found was the characterization of the groundwater endmembers. After analyzing the endmembers, we found that one of the endmembers was not credible because the concentrations of Ra were lower than expected. A follow-up of this spring would have allowed us to find out its origin and its real impact on the beach. Due to the rocky-boulder basement, we had great difficulty digging and making piezometers, and it became a major obstacle to collect and characterize more groundwater endmembers. By using seepage meters could also help to improve the understanding of groundwater endmembers and constrain SGD and chemical fluxes. Moreover, one of the initial objectives was to carry out a sampling campaign after a strong rain event. However, a successful campaign was not achieved due to the complexity of the karst system and its siphon operation. Thus, each time a sampling was attempted after a rainfall event there was not enough evidences of a relevant SGD flow that exceeded the main sampling campaign. Throughout the study several considerations were made, such as the mixing of the entire water column and therefore the homogenous distribution of Ra isotopes and nutrient in the seawater column. Thus, an improvement of this study that probably could constrain both the SGD flow and the nutrients fluxes would be the best characterization of the water column with the analysis of various profiles of, at least, salinity, Ra and nutrients.

To achieve a more complete endmember characterization another chemical analysis can be combined with radionuclides: as stable isotopes trace metals and organic compounds. Oxygen ($\delta^{18}O$), deuterium (^{2}H or D) and tritium (^{3}H or T) can also help to comprehend the water origin and its residence time. The $\delta^{18}O$ could also be useful to understand the origin and paths of water throughout the massif, and could complement radionuclides to calculate the percentage of mixed freshwater in the brackish water. Stable isotopes as carbon ($\delta^{13}C$) and nitrogen ($\delta^{15}N$) are another useful tool to trace the contamination nutrient origin.

Some other proposals for complement and improve the Aiguadolç study are given below. One important tool to characterize where and how SGD flows to the sea is the ERT. Thus, in order to much better understand the SGD flowing mechanism is by performing more ERTs along and across the beach, but also in the sea. The only transversal ERT carried out was coinciding with Aiguadolç ephemeral stream, which is only a small portion of the total beach surface, and works in a different way than the rest of the beach. The increase of the number of ERTs could provide a more accurate image of the SGD flow. The performing of ERT in seawater is a very interesting tool for being tested since would provide a useful information about the possible existence of offshore submarine springs. This tool will be also very helpful to analyse anomalous offshore concentrations of radionuclides, nutrients or pollutants.

A single one-day campaign is probably a poor picture of the evolution of SGD in a karstic massif for the whole year. Thus, without a periodical monitoring of the beach is not possible estimate the SGD behaviour and flow in Aiguadolç, and relate it with rainfalls and recharge zones. In order to record SGD flow fluctuations in the study area is totally necessary to comprehend the evolution of the system and its periodical behaviour. One important and interesting improvement, although it is expensive and difficult to materialize in Aiguadolç, is to launch a seawater monitoring station, with ERT, cameras and on-line CTD and Rn detector. This is a fundamental issue for a study in karstic environment where temporal changes can be very drastic. In addition, the monitoring of the SGD springs (endmembers) can provide important information on groundwater and seawater quality to improve the beach management.

Another important improvement of this project could be to investigate the ecological impacts of the SGD on benthic and nectonic communities. According to this aim, dives could be carried out to locate bioindicators of water quality, and to observe and describe possible impacts of SGD on the communities of *Posidonia oceanica* and *Cymodocea nodosa*. Finally, it could be interesting to analyze the bacteria and look for a possible relationship between bacterial communities and SGD.

11. SCHEDULE

Table 17: *Aiguadolç study schedule*

Procedures	2018											2019	
	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb
Campaign organization													
Research and bibliographical reading													
Sample collection													
Sample treatment													
1st sample analysis													
2nd sample analysis													
3rd sample analysis													
Bibliographical reading													
Sample treatment													
4th sample analysis													
Introduction and objectives redaction													
Background redaction													
Methodology redaction													
Budget													
Interviews													
Results interpretation													
Bibliographical reading													
Results redaction													
Flow calculations													
Discussion redaction													
Review													
Presentation													

12. BUDGET

***Table 18**: Aiguadolç study budget*

Concept		Description	Total
Cost associated to the project realization		1200 h x 20€/h(*)	24.000 €
Cost associated to transport		Train tickets and gasoline	1.100 €
Cost associated to laboratory and field work	Rental of geophysical equipment	250€/d x 3 days + transport	850 €
	Ra analysis (RaDeCC)	72 samples x 50€/sample	3.600 €
	Ra analysis (gamma detector)	24 samples x 100€/sample	2.400 €
	Rn analisys (RAD7)	9 samples x 25€/sample	225 €
	Nutrients analysis	24 samples x 35€/sample	840 €
	Boat rental	1 day x 600€/d	600 €
Consumable material		Laboratory and field material	50 €
Memory costs		Printing and presentation costs	100 €
		Subtotal	33.765 €
		Electricity, gas and water (20% subtotal)	6.753 €
		IVA (21%)	7.091 €
		Total	**47.609 €**

* Price according to Col·legi d'Ambientòlegs for non-professional projects.

13. ACKNOWLEDGMENTS

A la primera persona a la que volem agrair la seva participació en el projecte que teniu entre les mans és al Dr. Jordi Garcia-Orellana, ja que sense ell aquest estudi mai s'hagués realitzat. No només va ser ell qui ens va proposar fer el TFG a Aiguadolç, sinó que també ens ha ajudat, ens ha aconsellat, ens ha inspirat i ens ha esbroncat. Volem donar-li les gràcies pel temps que ens ha dedicat i per haver-nos ensenyat tantes coses, que no es limiten únicament al pla científicoacadèmic, sinó també a nivell humà, se'ns dubte és un dels millors docents amb els que ens hem trobat al llarg del grau. Moltes gràcies Jordi!

També volem fer una especial menció a en Marc Diego i l'Aaron Alorda. Què hagués sigut de nosaltres sense les hores de revisions d'Excel, les seves explicacions sobre el laboratori, les rutes (varies) en la furgo i la resta de favors que en han fet entre cafès que s'allargaven matins sencers. I a en Joan Manel Bruach, que ens va fer companyia al laboratori durant l'estiu i sempre arribava a temps a arreglar les nostres destrosses.

El Dr. Mario Zarroca també a col·laborat en aquest treball de forma decisiva, cosa que no es deu únicament als seus consell respecte al projecte, sinó també al fet d'haver-nos descobert els mètodes geofísics durant el grau. Gràcies a ell vam descobrir una vessant de la geologia pràctica que ens era completament desconeguda.

Agrair també a totes aquelles persones ens van donar un cop demà en la campanya el Dr. Juanjo Ledo, el Dr. Albert Folch i la Dra. Clara Ruiz, ja que sense elles hagués sigut impossible fer tots els mostrejos i analítiques que vam realitzar. Així com a aquelles persones que ens han donat suport fora de l'àmbit del departament, com la Marta Bretos, que ens ha fet alguna que altra revisió de l'anglès i ha estat allà aguantant els drames i donant la seva energia positiva. També a la Claudia Garcia, que ens ha donat suport en tot moment i ens ha ensenyat que no fa falta estar pensant sempre en el TFG, i la Foix Soler, que quan ha calgut ens ha acompanyat fins a Sitges per fer entrevistes.

Finalment volem mencionar a un col·lectiu de persones que han influït en gran mesura en la realització tècnica d'aquest treball. Ens referim aquí a totes aquelles persones que pengen continguts audiovisuals per YouTube a mode de tutorials gratuïts i accessibles per tothom. Sense aquestes persones, que ens han ofert gran quantitat de classes particulars de diferents softwers com Arcmap, Excel, Res2Dinv i Res2Dmod, la dedicació per a processar dades hagués sigut molt menys òptima i ràpida.

14. REFERENCES

Agència Catalana de l'Aigua. (2006). *Directiva Marc de l'Aigua a Catalunya*.

Agència Catalana de l'Aigua. (2011a). Pla Especial de Protecció i restauració de la Riera de Ribes.

Agència Catalana de l'Aigua. (2011b). Planificació de l'espai fluvial a la conca del Foix. Hidrogeologia., 1–24. Retrieved from http://aca-web.gencat.cat/aca/documents/ca/publicacions/espais_fluvials/publicacions/estudis_pef/h_besos/pef_besos.htm

Agència Catalana de l'Aigua. (2011c). Planificació de l'espai fluvial a la conca del Gaià. Hidrogeologia., 1–24. Retrieved from http://aca-web.gencat.cat/aca/documents/ca/publicacions/espais_fluvials/estudis/015P0001/06068_01A05_AX_Hidrogeologia_v4.pdf

Al, E. (1948). La hidrología kárstica del P1h de les Basses y sus rela- ciones con la de otras zonas del macizo de Garraf (Barcelona), (55).

Alley, W. M. (2002). Flow and Storage in Groundwater Systems. *Science*, *296*(5575), 1985–1990. https://doi.org/10.1126/science.1067123

Belaval, M., Lane, J. W., Lesmes, D. P., & Kineke, G. C. (2003). Continuous-resistivity profiling for coastal groundwater investigations: three case studies. *Symposium on the Application of Geophysics to Engineering and Environmental Problems (SAGEEP), April 6-10, 2003, San Antonio, Texas*. https://doi.org/10.4133/1.2923186

Brenner, J. (2007). Valuation of ecosystem services in the Catalan coastal zone. *Laboratori d'Enginyeria Marítima, Universitat Politècnica de Catalunya*, 1–178. https://doi.org/10.1111/j.1440-1843.2006.00937_1.x

Burnett, W. C., Bokuniewicz, H., Huettel, M., Moore, W. S., & Taniguchi, M. (2003). Groundwater and pore water inputs to the coastal zone Introduction and scope, 3–33.

Burnett, W. C., Peterson, R., Moore, W. S., & de Oliveira, J. (2008). Radon and radium isotopes as tracers of submarine groundwater discharge - Results from the Ubatuba, Brazil SGD assessment intercomparison. *Estuarine, Coastal and Shelf Science*, *76*(3), 501–511. https://doi.org/10.1016/j.ecss.2007.07.027

Camargo, J. A., & Alonso, Á. (2006). Ecological and toxicological effects of inorganic nitrogen pollution in aquatic ecosystems: A global assessment. *Environment International*, *32*(6), 831–849. https://doi.org/10.1016/j.envint.2006.05.002

Charette, M. A., Buesseler, K. O., & Andrews, J. E. (2001). Utility of Radium Isotopes for Evaluating the Input and Transport of Groundwater-Derived Nitrogen to a Cape Cod Estuary Published by : American Society of Limnology and Oceanography Stable URL : http://www.jstor.org/stable/2670886. *Limnology*, *46*(2), 465–470.

Charette, M. A., Moore, W. S., & Burnett, W. C. (2008). Uranium- and Thorium-Series Nuclides as Tracers of Submarine Groundwater Discharge. *Radioactivity in the Environment*, *13*(07), 155–191. https://doi.org/10.1016/S1569-4860(07)00005-8

Charette, M. A., & Sholkovitz, E. R. (2002). Oxidative precipitation of groundwater-derived ferrous iron in the subterranean estuary of a coastal bay. *Geophysical Research Letters*, *29*(10), 85-1-85–4. https://doi.org/10.1029/2001GL014512

Charette, M. A., Splivallo, R., Herbold, C., Bollinger, M. S., & Moore, W. S. (2003). Salt marsh submarine groundwater discharge as traced by radium isotopes. *Marine Chemistry*, *84*(1–2), 113–121. https://doi.org/10.1016/j.marchem.2003.07.001

Christensen, T. H., Kjeldsen, P., Jensen, D. L., Christensen, J. B., Bjerg, P. L., Baun, A., … Heron, G. (2001). Biogeochemistry of landill leachate plumes: review. *Applied Geochemistry*, *16*(7–8), 659–718. https://doi.org/10.1016/S0883-2927(00)00082-2

Constable M, Charlton M, Jensen F, McDonald K, Craig G, Taylor KW. Anecological risk assessment of ammonia in the aquatic environment. HumEcol Risk Assess 2003;9:527–48.

Cuaternario, M. D. E. L., & España, D. E. (1989). Instituto Tecnológico GeoMinero de España. https://doi.org/10.1108/AEAT-02-2013-0046

Custodio, E., Fernández, D., & Sánchez, J. (2017). *Salinización de las aguas subterráneas en los acuíferos costeros mediterráneos e insulares españoles*.

Daura, J., Sanz, M., Fornós, J. J., Asensio, A., & Julià, A. R. (2014). Karst evolution of the Garraf Massif (Barcelona, Spain): Doline formation, chronology and archaeopalaeontological archives. *Journal of Cave and Karst Studies*, *76*(2), 69–87. https://doi.org/10.4311/2011ES0254

De Lapuente, J., González-Linares, J., Pique, E., & Borràs, M. (2014). Ecotoxicological impact of MSW landfills: Assessment of teratogenic effects by means of an adapted FETAX assay. *Ecotoxicology*, *23*(1), 102–106. https://doi.org/10.1007/s10646-013-1155-9

Diaz, P., Raimbault, F., Boudjellal, B., Garcia, N., & Moutin, T. (2001). Early spring phosphorus limitation of primary productivity in a NW Mediterranean coastal zone (Gulf of Lions). *Marine Ecology Progress Series*, *211*(McGill 1965), 51–62. https://doi.org/10.3354/meps211051

Durridge. (2017). RAD7 Electronic Radon Detector.

Eikenberg, J. (2002). Radium isotope systematics in nature: applications in geochronology and hydrogeochemistry, 1–200. https://doi.org/10.1103/PhysRevB.79.165438

El-Dine, N. W., El-Shershaby, A., Ahmed, F., & Abdel-Haleem, A. S. (2001). Measurement of radioactivity and radon exhalation rate in different kinds of marbles and granites. *Applied Radiation and Isotopes*, *55*(6), 853–860. https://doi.org/10.1016/S0969-8043(01)00107-5

El-Gamal, A. A., Peterson, R. N., & Burnett, W. C. (2012). Detecting freshwater inputs via groundwater discharge to marina lagoon, mediterranean coast, Egypt. *Estuaries and Coasts*, *35*(6), 1486–1499. https://doi.org/10.1007/s12237-012-9539-2

Elser, J. J., Bracken, M. E. S., Cleland, E. E., Gruner, D. S., Harpole, W. S., Hillebrand, H., … Smith, J. E. (2007). Global analysis of nitrogen and phosphorus limitation of primary producers in freshwater, marine and terrestrial ecosystems. *Ecology Letters*, *10*(12), 1135–1142. https://doi.org/10.1111/j.1461-0248.2007.01113.x

Emerson, K., Russo, R. C., Lund, R. E., & Thurston, R. V. (1975). Aqueous Ammonia Equilibrium Calculations: Effect of pH and Temperature. *Journal of the Fisheries Research Board of Canada*, *32*(12), 2379–2383. https://doi.org/10.1139/f75-274

entorn & sitgesmodel XXI. (2008). Pla Especial Urbanístic del sector B-5, Port d'Aiguadolç.

Garcia-Orellana, J., Cochran, J. K., Bokuniewicz, H., Daniel, J. W. R., Rodellas, V., & Heilbrun, C. (2014). Evaluation of224Ra as a tracer for submarine groundwater discharge in Long Island Sound (NY). *Geochimica et Cosmochimica Acta*, *141*, 314–330. https://doi.org/10.1016/j.gca.2014.05.009

Garcia-Solsona, E. (2009). Submarine groundwater discharge in coastal Mediterranean areas by using radium isotope: Venice Lagoon, Minorca and Castelló.

Garcia-Solsona, E., Garcia-Orellana, J., Masqué, P., Garcés, E., Radakovitch, O., Mayer, A., … Basterretxea, G. (2010). An assessment of karstic submarine groundwater and associated nutrient discharge to a Mediterranean coastal area (Balearic Islands, Spain) using radium isotopes. *Biogeochemistry*, *97*(2), 211–229. https://doi.org/10.1007/s10533-009-9368-y

Garcia-Solsona, E., Garcia-Orellana, J., Masqué, P., Rodellas, V., Mejías, M., Ballesteros, B., & Domínguez, J. A. (2010). Groundwater and nutrient discharge through karstic coastal springs (Castelló, Spain). *Biogeosciences*, *7*(9), 2625–2638. https://doi.org/10.5194/bg-7-2625-2010

Geotomo. (2010). RES2DINV ver. 3.59 - Rapid 2-D Resistivity & IP inversion using the least-squares method Wenner (α,β,γ), dipole-dipole, inline pole-pole, pole- dipole, equatorial dipole-dipole, offset pole-dipole, Wenner-Schlumberger, gradient and non-conventional arrays, 1–148.

Guimerà, J. J. (1988). Estudi estructural de l'enllaç entre la Serralada Ibèrica i la Serralada Costanera Catalana, 600. https://doi.org/10.1109/ICSE.2007.41

ICGC. (2017). Mapa geològic de Catalunya 1:25.000 Castelldefels-Vallcarca. Fulls 448-1-1 (71-33), 448-1-2 (71-34)

Johnson, A. G., Glenn, C. R., Burnett, W. C., Peterson, R. N., & Lucey, P. G. (2008). Aerial infrared imaging reveals large nutrient-rich groundwater inputs to the ocean. *Geophysical Research Letters*, *35*(15), 1–6. https://doi.org/10.1029/2008GL034574

Jordan, T. E., Correll, D. L., & Weller, D. E. (1997). and fossil fuel combustion Cambridge. *Water Resources*, *33*(11), 2579–2590. https://doi.org/10.1007/s12686-009-9162-0

Knee, K. L., & Paytan, A. (2012). Submarine Groundwater Discharge: A Source of Nutrients, Metals, and Pollutants to the Coastal Ocean. *Treatise on Estuarine and Coastal Science*, *4*, 205–233. https://doi.org/10.1016/B978-0-12-374711-2.00410-1

Koç, M., Kubilay, N., Tuğrul, S., & Mihalopoulos, N. (2010). Atmospheric nutrient inputs to the northern levantine basin from a long-term observation: Sources and comparison with riverine inputs. *Biogeosciences*, *7*(12), 4037–4050. https://doi.org/10.5194/bg-7-4037-2010

Krest, J. (2000). Marsh nutrient export supplied by groundwater discharge : Boreholes, *14*(1), 167–176.

Krest, J. M., Moore, W. S., & Rama. (1999). 226Ra and228Ra in the mixing zones of the Mississippi and Atchafalaya rivers: Indicators of groundwater input. *Marine Chemistry*, *64*(3), 129–152. https://doi.org/10.1016/S0304-4203(98)00070-X

Krom, M. D., Kress, N., Brenner, S., & Gordon, L. I. (1991). Phosphorus limitation of primary productivity in the eastern Mediterranean Sea. *Limnology and Oceanography*, *36*(3), 424–432. https://doi.org/10.4319/lo.1991.36.3.0424

Lapointe, B. E. (1997). Nutrient thresholds for bottom-up control of macroalgal blooms on coral reefs in Jamaica and southeast Florida. *Limnology and Oceanography*, *42*(5part2), 1119–1131. https://doi.org/10.4319/lo.1997.42.5_part_2.1119

Lee, Y. W., Kim, G., Lim, W. A., & Hwang, D. W. (2010). A relationship between submarine groundwater-borne nutrients traced by Ra isotopes and the intensity of dinoflagellate red-tides occurring in the southern sea of Korea. *Limnology and Oceanography*, *55*(1), 1–10. https://doi.org/10.4319/lo.2010.55.1.0001

Ludwig, W., Dumont, E., Meybeck, M., & Heussner, S. (2009). River discharges of water and nutrients to the Mediterranean and Black Sea: Major drivers for ecosystem changes during past and future decades? *Progress in Oceanography*, *80*(3–4), 199–217. https://doi.org/10.1016/j.pocean.2009.02.001

Markaki, Z., Loÿe-Pilot, M. D., Violaki, K., Benyahya, L., & Mihalopoulos, N. (2010). Variability of atmospheric deposition of dissolved nitrogen and phosphorus in the Mediterranean and possible link to the anomalous seawater N/P ratio. *Marine Chemistry*, *120*(1–4), 187–194. https://doi.org/10.1016/j.marchem.2008.10.005

Mejías, M., Ballesteros, B. J., Antón-Pacheco, C., Domínguez, J. A., Garcia-Orellana, J., Garcia-Solsona, E., & Masqué, P. (2012). Methodological study of submarine groundwater discharge from a karstic aquifer in the Western Mediterranean Sea. *Journal of Hydrology*, *464–465*, 27–40. https://doi.org/10.1016/j.jhydrol.2012.06.020

Michael, H. A., Mulligan, A. E., & Harvey, C. F. (2005). Seasonal oscillations in water exchange between aquifers and the coastal ocean. *Nature*, *436*(7054), 1145–1148. https://doi.org/10.1038/nature03935

Montoriol, J., & Jaime, P. Y. (n.d.). Las líneas de costa.

Montoriol Pous, J. (1948). La hidrología kárstica del Plà de les Basses y sus relaciones con la de otras zonas del macizo de Garraf (Barcelona), (55).

Moore, W. S. (1996). Large groundwater inputs to coastal waters revealed by 226Ra enrichments. Nature. *Nature*, *380*, Garcia-Solsona, E. (2009). Submarine groundwater d.

Moore, W. S. (1999). The subterranean estuary: A reaction zone of ground water and sea water. *Marine Chemistry*, *65*(1–2), 111–125. https://doi.org/10.1016/S0304-4203(99)00014-6

Moore, W. S. (2003). Sources and fluxes of submarine groundwater discharge delineated by radium isotopes. *Biogeochemistry*, *66*(1–2), 75–93. https://doi.org/10.1023/B:BIOG.0000006065.77764.a0

Moore, W. S. (2010). The Effect of Submarine Groundwater Discharge on the Ocean. *Annual Review of Marine Science*, *2*(1), 59–88. https://doi.org/10.1146/annurev-marine-120308-081019

Moore, W. S., & Arnold, R. (1996). using a delayed coincidence counter Air flow, *101*, 1321–1329.

Muntaner, I. M. (1986). *Els noms de lloc del terme de Sitges i de les terres veïnes.* (Grup d'estudis sitgetans., Ed.).

Nowroozi, A. A., Horrocks, S. B., & Henderson, P. (1999). Saltwater intrusion into the freshwater aquifer in the eastern shore of Virginia: A reconnaissance electrical resistivity survey. *Journal of Applied Geophysics*, *42*(1), 1–22. https://doi.org/10.1016/S0926-9851(99)00004-X

Palomino de Dios, A., Cabrera Salvat, M., Martinez Garrido, E., & Sanchez-Cabeza, J. A. (2012). Environmental quality of Sitges (Catalonia, NE Spain) beaches during the bathing season. *Ocean and Coastal Management*, *55*, 128–134. https://doi.org/10.1016/j.ocecoaman.2011.10.004

Panareda, J. M. (1986). *Descobrim Garraf. Diputació de Barcelona. Institut de Ciències de l'Educació de la Universitat de Barcelona. Col•lecció Pau Vila no 6. 163 pp. Publicacions i Edicions de la Universitat de Barcelona.*

Pavlidou, A., Papadopoulos, V. P., Hatzianestis, I., Simboura, N., Patiris, D., & Tsabaris, C. (2014). Chemical inputs from a karstic submarine groundwater discharge (SGD) into an oligotrophic Mediterranean coastal area. *Science of the Total Environment*, *488–489*(1), 1–13. https://doi.org/10.1016/j.scitotenv.2014.04.056

Pérez de Pedro, P. (2008). *Olor de podrit. El despropòsit del Garraf.* Terrassa.

Pujo-Pay, M., Conan, P., Oriol, L., Cornet-Barthaux, V., Falco, C., Ghiglione, J. F., … Prieur, L. (2011). Integrated survey of elemental stoichiometry (C, N, P) from the western to eastern Mediterranean Sea. *Biogeosciences*, *8*(4), 883–899. https://doi.org/10.5194/bg-8-883-2011

Rama, & Moore, W. S. (1996). Using the radium quartet for evaluating groundwater input and water exchange in salt marshes. *Geochimica et Cosmochimica Acta*, *60*(23), 4645–4652. https://doi.org/10.1016/S0016-7037(96)00289-X

Rodellas, V. (2014). Evaluating submarine groundwater discharge to the Mediterranean sea by using radium isotopes. *Mycological Research*, *106*(11), 1323–1330.

Rodellas, V., Garcia-Orellana, J., Garcia-Solsona, E., Masqué, P., Domínguez, J. A., Ballesteros, B. J., … Zarroca, M. (2012). Quantifying groundwater discharge from different sources into a Mediterranean wetland by using222Rn and Ra isotopes. *Journal of Hydrology*, *466–467*, 11–22. https://doi.org/10.1016/j.jhydrol.2012.07.005

Rodellas, V., Garcia-Orellana, J., Masqué, P., Feldman, M., & Weinstein, Y. (2015). Submarine groundwater discharge as a major source of nutrients to the Mediterranean Sea. *Proceedings of the National Academy of Sciences*, *112*(13), 3926–3930. https://doi.org/10.1073/pnas.1419049112

Rodellas, V., Garcia-Orellana, J., Masqué, P., & Font-Muñoz, J. S. (2015). The influence of sediment sources on radium-derived estimates of Submarine Groundwater Discharge. *Marine Chemistry*, *171*, 107–117. https://doi.org/10.1016/j.marchem.2015.02.010

Rodellas, V., Garcia-Orellana, J., Tovar-Sánchez, A., Basterretxea, G., López-Garcia, J. M., Sánchez-Quiles, D., … Masqué, P. (2014). Submarine groundwater discharge as a source of nutrients and trace metals in a Mediterranean bay (Palma Beach, Balearic Islands). *Marine Chemistry*, *160*, 56–66. https://doi.org/10.1016/j.marchem.2014.01.007

Rodellas, V., Garcia-Orellana, J., Trezzi, G., Masqué, P., Stieglitz, T. C., Bokuniewicz, H., … Berdalet, E. (2017). Using the radium quartet to quantify submarine groundwater discharge and porewater exchange. *Geochimica et Cosmochimica Acta*, *196*, 58–73. https://doi.org/10.1016/j.gca.2016.09.016

Ruiz, J.M., Guillén, E., Ramos Segura A., O. M. (2015). Atlas de las praderas marinas de España. *IEO/IEL/UICN, Murcia-Alicante-Málaga*, 681 pp.

Sánchez-Chardi, A., & Nadal, J. (2007). Bioaccumulation of metals and effects of landfill pollution in small mammals. Part I. The greater white-toothed shrew, Crocidura russula. *Chemosphere*, *68*(4), 703–711. https://doi.org/10.1016/j.chemosphere.2007.01.042

Sánchez-Chardi, A., Peñarroja-Matutano, C., Borrás, M., & Nadal, J. (2009). Bioaccumulation of metals and effects of a landfill in small mammals. Part III: Structural alterations. *Environmental Research*, *109*(8), 960–967. https://doi.org/10.1016/j.envres.2009.08.004

Sánchez-Chardi, A., Peñarroja-Matutano, C., Oliveira Ribeiro, C. A., & Nadal, J. (2007). Bioaccumulation of metals and effects of a landfill in small mammals. Part II. The wood mouse, Apodemus sylvaticus. *Chemosphere*, *70*, 101–109. https://doi.org/10.1016/j.chemosphere.2007.06.047

Sheets, K. R., & Hendrickx, J. M. H. (1995). Noninvasive soil water content measurement using electromagnetic induction. *Water Resources Research*, *31*(10), 2401–2409.

Slomp, C. P., & Van Cappellen, P. (2004). Nutrient inputs to the coastal ocean through submarine groundwater discharge: Controls and potential impact. *Journal of Hydrology*, *295*(1–4), 64–86. https://doi.org/10.1016/j.jhydrol.2004.02.018

Smith, C. G., Cable, J. E., Martin, J. B., Cherrier, J., & Roi, M. (2006). Mixing in the Subterranean Estuary:

a Comparison of Radon-222 Pore Water Models. *Coastal Hydrology and Processes*, 355–368.

Soler Bartomeus, X. (1983). Estudi de l'evolució de la intrusió marina a l'aqüífer cretaci de la comarca de Garraf I problemàtica de l'abastament a les poblacions costeres.

Soler, E., Cortina, A., Cortina, A., Soler, E., Fuguet, M., Salafranca, M., & Quiroz, K. (2012). *Carta de paisatge del Priorat*. Retrieved from http://territori.gencat.cat/ca/01_departament/04_actuacions_i_obres/01_actuacions_de_territori_i_mobilitat/paisatge/cartes_de_paisatge/priorat

Stewart I., Morhange C (2009). The physical geography of the Mediterranean, ed Woodward J (Oxford University Press Inc., New York), pp 385–413.

Stieglitz, T.C., van Beek, P., Souhaut, M., Cook, P.G., 2013. Karstic groundwater discharge and seawater recirculation through sediments in shallow coastal Mediterranean lagoons, determined from water, salt and radon budgets. Mar. Chem. 156, 73–84. doi:10.1016/j.marchem.2013.05.005(Ciccone et al., 2018)

Sun, Y., & Torgersen, T. (1998). The effects of water content and Mn-fiber surface conditions on 224Ra measurement by 220Rn emanation. *Marine Chemistry*, *62*(3–4), 299–306. https://doi.org/10.1016/S0304-4203(98)00019-X

Tapia González, F. U., Herrera-Silveira, J. A., & Aguirre-Macedo, M. L. (2008). Water quality variability and eutrophic trends in karstic tropical coastal lagoons of the Yucatán Peninsula. *Estuarine, Coastal and Shelf Science*, *76*(2), 418–430. https://doi.org/10.1016/j.ecss.2007.07.025

Tovar-Sánchez, A., Basterretxea, G., Rodellas, V., Sánchez-Quiles, D., García-Orellana, J., Masqué, P., … Garcia-Solsona, E. (2014). Contribution of groundwater discharge to the coastal dissolved nutrients and trace metal concentrations in Majorca Island: Karstic vs detrital systems. *Environmental Science and Technology*, *48*(20), 11819–11827. https://doi.org/10.1021/es502958t

Trezzi, G. (2016). Assessing the significance of submarine groundwater discharge as a source of trace metals to the Mediterranean Sea.

Weinstein, Y., Yechieli, Y., Shalem, Y., Burnett, W. C., Swarzenski, P. W., & Herut, B. (2011). What is the role of fresh groundwater and recirculated seawater in conveying nutrients to the coastal ocean? *Environmental Science and Technology*, *45*(12), 5195–5200. https://doi.org/10.1021/es104394r

Young, M. B., Gonneea, M. E., Fong, D. A., Moore, W. S., Herrera-Silveira, J., & Paytan, A. (2008). Characterizing sources of groundwater to a tropical coastal lagoon in a karstic area using radium isotopes and water chemistry. *Marine Chemistry*, *109*(3–4), 377–394. https://doi.org/10.1016/j.marchem.2007.07.010

Zarroca, M., Bach, J., Linares, R., & Pellicer, X. M. (2011). Electrical methods (VES and ERT) for identifying, mapping and monitoring different saline domains in a coastal plain region (Alt Empordà, Northern Spain). *Journal of Hydrology*, *409*(1–2), 407–422. https://doi.org/10.1016/j.jhydrol.2011.08.052

Zarroca, M., Linares, R., Roqué, C., Rosell, J., & Gutiérrez, F. (2014). Integrated geophysical and morphostratigraphic approach to investigate a coseismic (?) translational slide responsible for the destruction of the Montclús village (Spanish Pyrenees). *Landslides*, *11*(4), 655–671. https://doi.org/10.1007/s10346-013-0427-z

Zektzer, I. S., Ivanov, V. A., & Meskheteli, A. V. (1973). The problem of direct groundwater discharge to the seas. *Journal of Hydrology*, *20*(1), 1–36. https://doi.org/10.1016/0022-1694(73)90042-5

15.APPENDIX

Appendix 1: *Lithologies legend according to Geological map of Catalonia Castelldefels-Vallcarca 1:25.000, ICGC.*

Code	Description
At	Deposits of anthropic origin. Filling of areas where extractive activity has occurred. Corresponding to sands, gravels and silts. Geological epoch: Anthropocene
QHps	Well-selected sands with medium-thick granulometries. Shape small Garraf beaches. Geological epoch: Holocene
QHt_1	Gravels and blocks with sandy matrix with clay levels of carbonaceous composition. Correspond to levels of swamps and beach sands. Geological epoch: Holocene
QPHdt	Red clays with some block and carbonate nodules. They correspond to deposits of dissolution of carbonaceous rocks. Geological epoch: Plistocene-holocene
QPg_3	Succession of gravel, silt and clays. Glacis deposits. Geological epoch: Upper Plistocene
$QPfv_3$	Succession of gravel, sand and silt. They are interpreted as deposits of valley bottoms. Geological epoch: Upper Plistocene.
QPg_4	Succession of gravel, silt and clays. Glacis deposits. Geological epoch: Upper Plistocene.
NMSg	Massive silicic sandstones with conglomerate intercalations. Deltaic front deposits. Geological age: Serravallian
Cld	Massive dolomite and dolomitic breccias. Corresponding to a dolomitization front. Geological epoch: Lower Cretaceous.
CIApcamc	Carbonates and marls in massive intervals with intercalations of shales. They are interpreted as marine platform sediments. Geological age: Aptian.
CIBca CIBcab	Micritical and bioclastic carbonates. They contain bivalves, gasteropods, algae and orbitolines. Sediments deposited on shallow marine platform. Geological age: Barremian.

CIVHca	Micritical and bioclastic carbonates with intercalations of ocher shales. They contain bivalves, gasteropods, algae and orbitolines. Sediments deposited on shallow marine platform. Geological age: Valanginian-Hauterivian.
JSKd	Dolomicrites and dolosparites of transitional platform environment. Geological age: Kimmeridgian.
Tk	Lutites and sandstones with evaporites corresponding to a distal plane. Geological age: Carnian-Norian
Tm_3	Laminated carbonates and carbonate breccias. Transitional low-energy platform environment. Geological age: Ladinian
Tm_2	Red Shales and red sandstones with interspersed evaporites. Sediments of endorheic fluvial plain. Geological age: Anisian-Ladinian
Tm_1	Carbonates and carbonated breccias and marls of massive aspect. Transitional platform environment with little energy. Geological age: Anisian

Appendix 2: *Symbol legend (cuts (Geological map of Catalonia 1:25.000, ICGC).*

	Concordant contact
	Discordant contact
	Normal fault
	Normal fault fossilized by quaternary
	Open-air extraction
	Geologic cut trace

Appendix 3: *CTD data from transect A in Aiguadolç.*

Sample	Ser	Meas	Sal.	Temp	F (µg/l)	T (FTU)	Density (Kg/m^3)	Depth (m)	Date	Time
A9	1,00	55,00	37,81	12,48	1,78	0,16	28,75	16,86	10/04/2018	8:36:28 AM
A9	1,00	56,00	37,80	12,48	1,76	0,17	28,75	16,52	10/04/2018	8:36:30 AM
A9	1,00	57,00	37,81	12,48	1,62	0,20	28,75	16,23	10/04/2018	8:36:32 AM
A9	1,00	58,00	37,81	12,48	1,63	0,18	28,75	15,97	10/04/2018	8:36:34 AM
A9	1,00	59,00	37,79	12,48	1,63	0,17	28,73	15,32	10/04/2018	8:36:36 AM
A9	1,00	60,00	37,78	12,48	1,53	0,20	28,72	14,93	10/04/2018	8:36:38 AM
A9	1,00	61,00	37,80	12,48	1,65	0,37	28,74	14,60	10/04/2018	8:36:40 AM
A9	1,00	62,00	37,79	12,48	1,46	0,19	28,73	13,85	10/04/2018	8:36:42 AM
A9	1,00	63,00	37,79	12,48	1,49	0,18	28,73	13,66	10/04/2018	8:36:44 AM
A9	1,00	64,00	37,78	12,48	1,48	0,18	28,72	13,46	10/04/2018	8:36:46 AM
A9	1,00	65,00	37,79	12,48	1,32	0,18	28,72	12,50	10/04/2018	8:36:48 AM
A9	1,00	66,00	37,79	12,48	1,37	0,17	28,72	12,56	10/04/2018	8:36:50 AM
A9	1,00	67,00	37,81	12,47	1,28	0,18	28,73	11,63	10/04/2018	8:36:52 AM
A9	1,00	68,00	37,80	12,47	1,30	0,19	28,73	12,05	10/04/2018	8:36:54 AM
A9	1,00	69,00	37,78	12,47	1,26	0,19	28,71	10,87	10/04/2018	8:36:56 AM
A9	1,00	70,00	37,80	12,47	1,22	0,17	28,72	10,86	10/04/2018	8:36:58 AM
A9	1,00	71,00	37,80	12,47	1,17	0,21	28,72	10,34	10/04/2018	8:37:00 AM
A9	1,00	72,00	37,80	12,48	1,16	0,18	28,72	9,83	10/04/2018	8:37:02 AM
A9	1,00	73,00	37,80	12,48	1,14	0,17	28,72	9,60	10/04/2018	8:37:04 AM
A9	1,00	74,00	37,81	12,47	1,17	0,21	28,72	9,13	10/04/2018	8:37:06 AM
A9	1,00	75,00	37,80	12,48	1,09	0,20	28,71	8,69	10/04/2018	8:37:08 AM
A9	1,00	76,00	37,79	12,49	1,00	0,23	28,70	8,29	10/04/2018	8:37:10 AM
A9	1,00	77,00	37,77	12,51	1,04	0,25	28,68	7,87	10/04/2018	8:37:12 AM
A9	1,00	78,00	37,79	12,51	0,98	0,25	28,69	7,61	10/04/2018	8:37:14 AM
A9	1,00	79,00	37,77	12,51	0,96	0,26	28,67	7,00	10/04/2018	8:37:16 AM
A9	1,00	80,00	37,77	12,51	0,94	0,37	28,67	6,85	10/04/2018	8:37:18 AM
A9	1,00	81,00	37,79	12,52	0,90	0,32	28,68	6,15	10/04/2018	8:37:20 AM
A9	1,00	82,00	37,79	12,52	0,87	0,25	28,68	5,98	10/04/2018	8:37:22 AM
A9	1,00	83,00	37,77	12,54	0,84	0,28	28,66	5,39	10/04/2018	8:37:24 AM
A9	1,00	84,00	37,76	12,53	0,85	0,29	28,65	5,08	10/04/2018	8:37:26 AM
A9	1,00	85,00	37,77	12,54	0,28	0,32	28,66	5,02	10/04/2018	8:37:28 AM
A9	1,00	86,00	37,76	12,53	0,27	0,37	28,65	4,15	10/04/2018	8:37:30 AM
A9	1,00	87,00	37,78	12,54	0,27	0,32	28,66	4,16	10/04/2018	8:37:32 AM
A9	1,00	88,00	37,76	12,54	0,26	0,37	28,64	3,64	10/04/2018	8:37:34 AM
A9	1,00	89,00	37,77	12,54	0,26	0,31	28,65	2,80	10/04/2018	8:37:36 AM
A9	1,00	90,00	37,76	12,54	0,25	0,30	28,64	2,83	10/04/2018	8:37:38 AM
A9	1,00	91,00	37,76	12,55	1,17	0,29	28,64	2,00	10/04/2018	8:37:40 AM
A9	1,00	92,00	37,76	12,55	2,35	0,31	28,63	1,84	10/04/2018	8:37:42 AM
A9	1,00	93,00	37,77	12,56	1,82	0,37	28,64	1,13	10/04/2018	8:37:44 AM
A9	1,00	94,00	37,75	12,56	2,49	0,32	28,62	0,86	10/04/2018	8:37:46 AM
A9	1,00	95,00	37,76	12,56	2,49	0,34	28,63	0,43	10/04/2018	8:37:48 AM

A8	8,00	224,00	37,69	13,13	28,58	0,91	28,51	13,34	18/04/2018	8:47:19 AM
A8	8,00	225,00	37,70	13,13	33,67	1,17	28,52	13,32	18/04/2018	8:47:21 AM
A8	8,00	226,00	37,67	13,14	30,77	1,12	28,50	13,30	18/04/2018	8:47:23 AM
A8	8,00	227,00	37,69	13,13	26,35	1,03	28,51	13,02	18/04/2018	8:47:25 AM
A8	8,00	228,00	37,68	13,13	27,96	1,13	28,50	13,11	18/04/2018	8:47:27 AM
A8	8,00	229,00	37,69	13,13	27,73	1,08	28,51	13,12	18/04/2018	8:47:29 AM
A8	8,00	230,00	37,68	13,12	25,91	1,21	28,50	12,90	18/04/2018	8:47:31 AM
A8	8,00	231,00	37,68	13,13	26,26	1,07	28,50	12,82	18/04/2018	8:47:33 AM
A8	8,00	232,00	37,68	13,13	26,13	1,34	28,50	12,93	18/04/2018	8:47:35 AM
A8	8,00	233,00	37,69	13,13	25,31	1,11	28,51	12,88	18/04/2018	8:47:37 AM
A8	8,00	234,00	37,69	13,13	27,52	1,07	28,51	12,76	18/04/2018	8:47:39 AM
A8	8,00	235,00	37,68	13,13	27,80	1,11	28,50	12,49	18/04/2018	8:47:41 AM
A8	8,00	236,00	37,69	13,13	27,52	1,16	28,51	12,83	18/04/2018	8:47:43 AM
A8	8,00	237,00	37,67	13,13	29,67	1,10	28,49	12,40	18/04/2018	8:47:45 AM
A8	8,00	238,00	37,68	13,13	27,92	1,17	28,50	12,46	18/04/2018	8:47:47 AM
A8	8,00	239,00	37,69	13,13	33,60	1,19	28,51	11,96	18/04/2018	8:47:49 AM
A8	8,00	240,00	37,69	13,13	28,44	1,12	28,51	11,74	18/04/2018	8:47:51 AM
A8	8,00	241,00	37,69	13,13	27,34	1,36	28,51	11,71	18/04/2018	8:47:53 AM
A8	8,00	242,00	37,69	13,13	26,91	1,19	28,51	11,54	18/04/2018	8:47:55 AM
A8	8,00	243,00	37,69	13,13	26,98	1,04	28,50	11,19	18/04/2018	8:47:57 AM
A8	8,00	244,00	37,69	13,15	28,44	1,36	28,50	11,03	18/04/2018	8:47:59 AM
A8	8,00	245,00	37,68	13,15	30,07	1,09	28,49	10,74	18/04/2018	8:48:01 AM
A8	8,00	246,00	37,68	13,15	33,70	1,20	28,49	10,88	18/04/2018	8:48:03 AM
A8	8,00	247,00	37,66	13,17	32,92	1,17	28,47	10,39	18/04/2018	8:48:05 AM
A8	8,00	248,00	37,64	13,20	35,35	1,10	28,44	10,03	18/04/2018	8:48:07 AM
A8	8,00	249,00	37,62	13,23	37,12	1,06	28,42	9,85	18/04/2018	8:48:09 AM
A8	8,00	250,00	37,61	13,24	46,50	0,92	28,41	9,76	18/04/2018	8:48:11 AM
A8	8,00	251,00	37,60	13,25	44,52	0,86	28,40	9,49	18/04/2018	8:48:13 AM
A8	8,00	252,00	37,58	13,25	43,11	0,93	28,38	9,34	18/04/2018	8:48:15 AM
A8	8,00	253,00	37,59	13,26	48,63	0,80	28,39	9,10	18/04/2018	8:48:17 AM
A8	8,00	254,00	37,58	13,26	45,59	0,73	28,38	8,80	18/04/2018	8:48:19 AM
A8	8,00	255,00	37,59	13,27	43,83	0,80	28,39	8,71	18/04/2018	8:48:21 AM
A8	8,00	256,00	37,56	13,26	42,78	0,99	28,36	8,40	18/04/2018	8:48:23 AM
A8	8,00	257,00	37,55	13,27	43,94	0,91	28,35	8,14	18/04/2018	8:48:25 AM
A8	8,00	258,00	37,57	13,27	45,84	0,72	28,37	7,92	18/04/2018	8:48:27 AM
A8	8,00	259,00	37,57	13,27	42,34	0,82	28,37	7,80	18/04/2018	8:48:29 AM
A8	8,00	260,00	37,57	13,27	40,15	0,94	28,36	7,52	18/04/2018	8:48:31 AM
A8	8,00	261,00	37,55	13,27	40,22	0,93	28,35	7,11	18/04/2018	8:48:33 AM
A8	8,00	262,00	37,56	13,27	39,80	1,01	28,35	6,96	18/04/2018	8:48:35 AM
A8	8,00	263,00	37,55	13,28	40,78	0,93	28,34	6,78	18/04/2018	8:48:37 AM
A8	8,00	264,00	37,52	13,28	40,67	0,85	28,32	6,66	18/04/2018	8:48:39 AM
A8	8,00	265,00	37,55	13,28	38,64	0,95	28,34	6,61	18/04/2018	8:48:41 AM
A8	8,00	266,00	37,54	13,28	42,82	0,80	28,33	6,28	18/04/2018	8:48:43 AM
A8	8,00	267,00	37,54	13,29	41,79	0,98	28,33	6,30	18/04/2018	8:48:45 AM

A8	8,00	268,00	37,55	13,30	40,54	0,90	28,33	5,75	18/04/2018	8:48:47 AM
A8	8,00	269,00	37,52	13,31	45,34	0,93	28,31	5,69	18/04/2018	8:48:49 AM
A8	8,00	270,00	37,54	13,31	41,91	1,03	28,32	5,49	18/04/2018	8:48:51 AM
A8	8,00	271,00	37,50	13,31	40,54	1,01	28,29	5,42	18/04/2018	8:48:53 AM
A8	8,00	272,00	37,54	13,32	40,34	1,09	28,32	5,37	18/04/2018	8:48:55 AM
A8	8,00	273,00	37,50	13,32	37,73	1,48	28,29	5,05	18/04/2018	8:48:57 AM
A8	8,00	274,00	37,52	13,32	37,60	1,16	28,30	4,97	18/04/2018	8:48:59 AM
A8	8,00	275,00	37,51	13,33	40,87	0,93	28,29	4,80	18/04/2018	8:49:01 AM
A8	8,00	276,00	37,52	13,33	39,46	0,89	28,30	4,82	18/04/2018	8:49:03 AM
A8	8,00	277,00	37,52	13,33	35,72	0,94	28,30	4,61	18/04/2018	8:49:05 AM
A8	8,00	278,00	37,51	13,34	36,16	0,84	28,29	4,17	18/04/2018	8:49:07 AM
A8	8,00	279,00	37,52	13,34	35,43	0,88	28,30	4,22	18/04/2018	8:49:09 AM
A8	8,00	280,00	37,52	13,34	36,57	0,81	28,30	4,36	18/04/2018	8:49:11 AM
A8	8,00	281,00	37,51	13,35	33,28	0,89	28,29	3,99	18/04/2018	8:49:13 AM
A8	8,00	282,00	37,51	13,35	32,63	0,78	28,28	3,50	18/04/2018	8:49:15 AM
A8	8,00	283,00	37,50	13,36	32,19	0,76	28,27	3,47	18/04/2018	8:49:17 AM
A8	8,00	284,00	37,50	13,37	30,86	0,76	28,27	3,21	18/04/2018	8:49:19 AM
A8	8,00	285,00	37,49	13,37	30,72	0,80	28,26	3,18	18/04/2018	8:49:21 AM
A8	8,00	286,00	37,48	13,38	29,64	0,76	28,25	2,84	18/04/2018	8:49:23 AM
A8	8,00	287,00	37,49	13,38	31,54	0,68	28,26	2,86	18/04/2018	8:49:25 AM
A8	8,00	288,00	37,50	13,39	29,36	0,74	28,26	2,71	18/04/2018	8:49:27 AM
A8	8,00	289,00	37,49	13,41	28,51	0,69	28,25	2,33	18/04/2018	8:49:29 AM
A8	8,00	290,00	37,50	13,43	28,73	0,74	28,25	2,23	18/04/2018	8:49:31 AM
A8	8,00	291,00	37,49	13,45	27,79	0,70	28,24	2,07	18/04/2018	8:49:33 AM
A8	8,00	292,00	37,47	13,47	27,72	0,67	28,22	1,74	18/04/2018	8:49:35 AM
A8	8,00	293,00	37,47	13,49	39,70	0,69	28,22	1,63	18/04/2018	8:49:37 AM
A8	8,00	294,00	37,48	13,51	60,77	0,77	28,22	1,36	18/04/2018	8:49:39 AM
A8	8,00	295,00	37,45	13,52	74,29	0,71	28,19	1,37	18/04/2018	8:49:41 AM
A8	8,00	296,00	37,47	13,57	45,84	0,87	28,20	1,23	18/04/2018	8:49:43 AM
A8	8,00	297,00	37,43	13,64	58,31	0,85	28,15	0,87	18/04/2018	8:49:45 AM
A8	8,00	298,00	37,41	13,72	72,57	1,11	28,11	0,62	18/04/2018	8:49:47 AM
A8	8,00	299,00	37,40	13,76	72,64	1,08	28,10	0,67	18/04/2018	8:49:49 AM
A8	8,00	300,00	37,39	13,78	74,89	1,13	28,09	0,65	18/04/2018	8:49:51 AM
A8	8,00	301,00	37,38	13,79	74,89	0,96	28,08	0,50	18/04/2018	8:49:53 AM
A7	9,00	382,00	37,65	13,22	41,65	1,16	28,45	10,19	18/04/2018	9:15:59 AM
A7	9,00	383,00	37,64	13,23	38,84	1,12	28,44	10,17	18/04/2018	9:16:01 AM
A7	9,00	384,00	37,63	13,23	40,94	1,34	28,43	10,11	18/04/2018	9:16:03 AM
A7	9,00	385,00	37,64	13,23	35,49	1,09	28,44	10,15	18/04/2018	9:16:05 AM
A7	9,00	386,00	37,63	13,23	38,06	0,98	28,43	9,93	18/04/2018	9:16:07 AM
A7	9,00	387,00	37,63	13,23	41,60	1,07	28,43	9,84	18/04/2018	9:16:09 AM
A7	9,00	388,00	37,64	13,22	37,68	1,24	28,44	9,63	18/04/2018	9:16:11 AM
A7	9,00	389,00	37,62	13,22	36,49	1,14	28,42	9,30	18/04/2018	9:16:13 AM
A7	9,00	390,00	37,62	13,22	39,78	1,13	28,42	9,24	18/04/2018	9:16:15 AM
A7	9,00	391,00	37,62	13,22	38,77	1,05	28,42	9,25	18/04/2018	9:16:17 AM

A7	9,00	392,00	37,62	13,22	38,56	1,21	28,42	8,79	18/04/2018	9:16:19 AM
A7	9,00	393,00	37,63	13,23	36,50	1,07	28,42	8,40	18/04/2018	9:16:21 AM
A7	9,00	394,00	37,59	13,23	41,92	1,20	28,39	8,26	18/04/2018	9:16:23 AM
A7	9,00	395,00	37,58	13,25	43,21	1,12	28,38	8,06	18/04/2018	9:16:25 AM
A7	9,00	396,00	37,58	13,25	44,37	1,11	28,38	7,65	18/04/2018	9:16:27 AM
A7	9,00	397,00	37,58	13,26	45,53	1,06	28,38	7,61	18/04/2018	9:16:29 AM
A7	9,00	398,00	37,55	13,27	44,50	1,03	28,35	7,36	18/04/2018	9:16:31 AM
A7	9,00	399,00	37,57	13,27	44,62	0,99	28,36	7,06	18/04/2018	9:16:33 AM
A7	9,00	400,00	37,56	13,28	47,79	1,30	28,35	6,63	18/04/2018	9:16:35 AM
A7	9,00	401,00	37,49	13,29	44,67	1,14	28,29	6,05	18/04/2018	9:16:37 AM
A7	9,00	402,00	37,53	13,29	47,41	1,22	28,32	6,07	18/04/2018	9:16:39 AM
A7	9,00	403,00	37,55	13,30	44,55	1,29	28,34	5,94	18/04/2018	9:16:41 AM
A7	9,00	404,00	37,53	13,30	43,70	1,21	28,32	5,63	18/04/2018	9:16:43 AM
A7	9,00	405,00	37,53	13,31	41,84	1,32	28,32	5,24	18/04/2018	9:16:45 AM
A7	9,00	406,00	37,54	13,31	41,87	1,60	28,32	4,86	18/04/2018	9:16:47 AM
A7	9,00	407,00	37,53	13,32	40,97	1,10	28,31	4,58	18/04/2018	9:16:49 AM
A7	9,00	408,00	37,52	13,32	39,64	1,25	28,30	4,57	18/04/2018	9:16:51 AM
A7	9,00	409,00	37,52	13,33	39,44	1,19	28,30	4,27	18/04/2018	9:16:53 AM
A7	9,00	410,00	37,53	13,33	38,59	1,10	28,30	3,82	18/04/2018	9:16:55 AM
A7	9,00	411,00	37,52	13,34	39,10	1,08	28,29	3,77	18/04/2018	9:16:57 AM
A7	9,00	412,00	37,51	13,34	37,28	1,20	28,29	3,75	18/04/2018	9:16:59 AM
A7	9,00	413,00	37,52	13,35	35,51	1,13	28,29	3,47	18/04/2018	9:17:01 AM
A7	9,00	414,00	37,51	13,36	33,93	1,05	28,28	2,94	18/04/2018	9:17:03 AM
A7	9,00	415,00	37,51	13,37	33,36	0,99	28,28	2,73	18/04/2018	9:17:05 AM
A7	9,00	416,00	37,52	13,38	32,46	1,04	28,28	2,83	18/04/2018	9:17:07 AM
A7	9,00	417,00	37,52	13,42	28,39	1,02	28,27	2,58	18/04/2018	9:17:09 AM
A7	9,00	418,00	37,46	13,45	27,58	0,98	28,22	1,99	18/04/2018	9:17:11 AM
A7	9,00	419,00	37,47	13,46	25,23	0,98	28,22	2,00	18/04/2018	9:17:13 AM
A7	9,00	420,00	37,49	13,48	25,41	0,95	28,23	1,90	18/04/2018	9:17:15 AM
A7	9,00	421,00	37,48	13,49	50,89	1,01	28,22	1,68	18/04/2018	9:17:17 AM
A7	9,00	422,00	37,45	13,54	52,95	0,97	28,19	1,18	18/04/2018	9:17:19 AM
A7	9,00	423,00	37,44	13,57	57,01	1,12	28,17	1,07	18/04/2018	9:17:21 AM
A7	9,00	424,00	37,44	13,63	74,89	1,17	28,16	1,00	18/04/2018	9:17:23 AM
A7	9,00	425,00	37,38	13,76	74,89	1,22	28,08	0,67	18/04/2018	9:17:25 AM
A7	9,00	426,00	37,37	13,80	72,29	12,46	28,07	0,42	18/04/2018	9:17:27 AM
A7	9,00	427,00	37,34	13,83	74,89	12,42	28,04	0,15	18/04/2018	9:17:29 AM
A7	9,00	428,00	37,36	13,82	72,86	1,15	28,05	0,30	18/04/2018	9:17:31 AM
A7	9,00	429,00	37,36	13,84	74,89	12,48	28,05	0,00	18/04/2018	9:17:33 AM
A6	10,00	576,00	37,50	13,46	50,98	1,22	28,26	6,25	18/04/2018	9:34:30 AM
A6	10,00	577,00	37,48	13,46	46,84	1,28	28,25	6,14	18/04/2018	9:34:32 AM
A6	10,00	578,00	37,51	13,46	44,59	1,40	28,27	6,15	18/04/2018	9:34:34 AM
A6	10,00	579,00	37,47	13,46	45,01	1,29	28,24	6,04	18/04/2018	9:34:36 AM
A6	10,00	580,00	37,48	13,46	44,63	1,37	28,25	6,10	18/04/2018	9:34:38 AM
A6	10,00	581,00	37,48	13,46	47,06	1,28	28,25	6,14	18/04/2018	9:34:40 AM

A6	10,00	582,00	37,50	13,46	49,59	1,41	28,26	6,01	18/04/2018	9:34:42 AM
A6	10,00	583,00	37,49	13,46	51,97	2,06	28,26	6,08	18/04/2018	9:34:44 AM
A6	10,00	584,00	37,49	13,46	43,00	1,37	28,26	5,96	18/04/2018	9:34:46 AM
A6	10,00	585,00	37,49	13,46	45,25	1,34	28,26	6,00	18/04/2018	9:34:48 AM
A6	10,00	586,00	37,49	13,46	47,72	1,39	28,26	5,79	18/04/2018	9:34:50 AM
A6	10,00	587,00	37,50	13,46	47,21	1,45	28,26	6,01	18/04/2018	9:34:52 AM
A6	10,00	588,00	37,47	13,46	43,82	1,21	28,24	5,83	18/04/2018	9:34:54 AM
A6	10,00	589,00	37,50	13,46	43,55	1,43	28,26	5,66	18/04/2018	9:34:56 AM
A6	10,00	590,00	37,48	13,46	38,75	1,26	28,25	5,41	18/04/2018	9:34:58 AM
A6	10,00	591,00	37,49	13,46	38,13	1,31	28,25	5,18	18/04/2018	9:35:00 AM
A6	10,00	592,00	37,48	13,46	41,37	1,25	28,24	5,06	18/04/2018	9:35:02 AM
A6	10,00	593,00	37,50	13,47	41,32	1,45	28,26	5,08	18/04/2018	9:35:04 AM
A6	10,00	594,00	37,50	13,46	41,02	1,20	28,26	4,89	18/04/2018	9:35:06 AM
A6	10,00	595,00	37,48	13,47	39,63	1,23	28,24	4,48	18/04/2018	9:35:08 AM
A6	10,00	596,00	37,50	13,47	33,40	1,58	28,25	4,22	18/04/2018	9:35:10 AM
A6	10,00	597,00	37,49	13,47	34,31	1,64	28,24	3,92	18/04/2018	9:35:12 AM
A6	10,00	598,00	37,49	13,48	33,57	1,39	28,24	3,68	18/04/2018	9:35:14 AM
A6	10,00	599,00	37,49	13,48	29,93	1,39	28,24	3,44	18/04/2018	9:35:16 AM
A6	10,00	600,00	37,47	13,48	29,64	1,45	28,23	3,55	18/04/2018	9:35:18 AM
A6	10,00	601,00	37,48	13,48	30,44	1,53	28,23	3,30	18/04/2018	9:35:20 AM
A6	10,00	602,00	37,47	13,50	27,16	1,51	28,22	2,77	18/04/2018	9:35:22 AM
A6	10,00	603,00	37,46	13,51	26,19	1,58	28,21	2,66	18/04/2018	9:35:24 AM
A6	10,00	604,00	37,47	13,51	26,41	1,61	28,21	2,48	18/04/2018	9:35:26 AM
A6	10,00	605,00	37,46	13,52	25,25	1,72	28,20	2,41	18/04/2018	9:35:28 AM
A6	10,00	606,00	37,46	13,54	22,63	1,73	28,20	2,07	18/04/2018	9:35:30 AM
A6	10,00	607,00	37,43	13,59	21,05	1,78	28,16	1,69	18/04/2018	9:35:32 AM
A6	10,00	608,00	37,35	13,69	19,66	1,83	28,08	1,44	18/04/2018	9:35:34 AM
A6	10,00	609,00	37,35	13,84	22,53	1,97	28,05	1,31	18/04/2018	9:35:36 AM
A6	10,00	610,00	37,33	13,95	16,42	1,65	28,01	1,05	18/04/2018	9:35:38 AM
A6	10,00	611,00	37,34	13,97	74,09	1,31	28,01	0,96	18/04/2018	9:35:40 AM
A6	10,00	612,00	37,34	13,97	29,63	1,30	28,01	0,70	18/04/2018	9:35:42 AM
A6	10,00	613,00	37,33	13,97	36,27	1,37	28,00	0,37	18/04/2018	9:35:44 AM
A6	10,00	614,00	37,31	13,98	74,89	1,26	27,98	0,06	18/04/2018	9:35:46 AM
A5	16,00	970,00	37,47	13,89	18,51	3,61	28,14	3,16	18/04/2018	10:30:37 AM
A5	16,00	971,00	37,43	13,88	21,09	3,17	28,11	2,98	18/04/2018	10:30:39 AM
A5	16,00	972,00	37,47	13,87	19,69	4,12	28,14	2,91	18/04/2018	10:30:41 AM
A5	16,00	973,00	37,45	13,86	20,33	4,81	28,13	2,79	18/04/2018	10:30:43 AM
A5	16,00	974,00	37,45	13,88	19,96	4,76	28,12	2,63	18/04/2018	10:30:45 AM
A5	16,00	975,00	37,47	13,93	15,60	2,46	28,12	2,46	18/04/2018	10:30:47 AM
A5	16,00	976,00	37,44	13,95	13,90	2,16	28,10	2,09	18/04/2018	10:30:49 AM
A5	16,00	977,00	37,46	13,97	13,54	1,94	28,11	1,78	18/04/2018	10:30:51 AM
A5	16,00	978,00	37,45	13,97	45,98	2,39	28,10	1,40	18/04/2018	10:30:53 AM
A5	16,00	979,00	37,47	13,97	53,62	2,14	28,11	1,15	18/04/2018	10:30:55 AM
A5	16,00	980,00	37,45	13,96	74,90	2,50	28,09	0,76	18/04/2018	10:30:57 AM

A5	16,00	981,00	37,45	13,96	74,89	1,92	28,09	0,21	18/04/2018	10:30:59 AM
A4	19,00	1144,00	37,46	14,95	0,38	2,40	27,89	1,37	18/04/2018	1:56:02 PM
A4	19,00	1145,00	37,43	14,95	0,38	1,99	27,86	1,12	18/04/2018	1:56:04 PM
A4	19,00	1146,00	37,41	14,96	0,35	2,07	27,85	0,94	18/04/2018	1:56:06 PM
A4	19,00	1147,00	37,42	14,95	0,35	3,03	27,85	0,65	18/04/2018	1:56:08 PM
A4	19,00	1148,00	37,42	14,97	0,41	3,14	27,85	0,31	18/04/2018	1:56:10 PM
A3	20,00	1179,00	37,36	15,48	1,53	5,30	27,69	1,29	18/04/2018	2:06:08 PM
A3	20,00	1180,00	37,39	15,44	1,54	3,66	27,72	1,28	18/04/2018	2:06:10 PM
A3	20,00	1181,00	37,38	15,40	1,68	4,52	27,73	1,37	18/04/2018	2:06:12 PM
A3	20,00	1182,00	37,38	15,40	1,64	3,67	27,73	1,07	18/04/2018	2:06:14 PM
A3	20,00	1183,00	37,41	15,38	1,37	3,76	27,75	0,90	18/04/2018	2:06:16 PM
A3	20,00	1184,00	37,36	15,35	2,56	2,80	27,72	0,62	18/04/2018	2:06:18 PM
A3	20,00	1185,00	37,37	15,38	1,29	2,78	27,72	0,35	18/04/2018	2:06:20 PM
A3	20,00	1186,00	37,32	15,47	1,21	3,44	27,66	0,01	18/04/2018	2:06:22 PM

Appendix 4: *CTD data from transect B in Aiguadolç.*

Sample	Ser	Meas	Sal.	Temp	F (µg/l)	T (FTU)	Density (Kg/m^3)	Depth (m)	Date	Time
B6	12	717	37,49	13,558	24,48	5,11	28,228	4,44	18/04/2018	9:46:25 AM
B6	12	718	37,48	13,556	27,05	3,89	28,22	4,4	18/04/2018	9:46:27 AM
B6	12	719	37,49	13,556	28,22	3,61	28,228	4,35	18/04/2018	9:46:29 AM
B6	12	720	37,65	13,561	24,2	3,28	28,351	4,36	18/04/2018	9:46:31 AM
B6	12	721	37,49	13,557	21,38	3,36	28,227	4,1	18/04/2018	9:46:33 AM
B6	12	722	37,49	13,557	20,22	3,19	28,226	3,97	18/04/2018	9:46:35 AM
B6	12	723	37,44	13,547	18,34	3,27	28,189	3,96	18/04/2018	9:46:37 AM
B6	12	724	37,49	13,541	21,11	3,04	28,228	3,61	18/04/2018	9:46:39 AM
B6	12	725	37,39	13,57	15,72	1,31	28,142	3,24	18/04/2018	9:46:41 AM
B6	12	726	37,39	13,655	13,61	1,24	28,124	3,12	18/04/2018	9:46:43 AM
B6	12	727	37,45	13,712	16,27	1,28	28,157	2,81	18/04/2018	9:46:45 AM
B6	12	728	37,46	13,737	14,5	1,19	28,158	2,6	18/04/2018	9:46:47 AM
B6	12	729	37,46	13,781	26,99	1,3	28,147	2,1	18/04/2018	9:46:49 AM
B6	12	730	37,46	13,815	54,78	1,37	28,139	1,94	18/04/2018	9:46:51 AM
B6	12	731	37,45	13,841	42,2	1,35	28,123	1,37	18/04/2018	9:46:53 AM
B6	12	732	37,44	13,868	74,9	1,09	28,108	1	18/04/2018	9:46:55 AM
B6	12	733	37,35	13,943	74,89	1,52	28,021	0,82	18/04/2018	9:46:57 AM
B6	12	734	37,39	13,984	74,82	1,24	28,043	0,6	18/04/2018	9:46:59 AM
B6	12	735	37,37	13,994	74,9	1,16	28,024	0,33	18/04/2018	9:47:01 AM
B5	15	913	37,41	14,112	24,96	12,44	28,036	1,83	18/04/2018	10:18:46 AM
B5	15	914	37,42	14,115	74,72	12,44	28,043	1,72	18/04/2018	10:18:48 AM
B5	15	915	37,4	14,111	66,8	9,38	28,028	1,72	18/04/2018	10:18:50 AM
B5	15	916	37,4	14,109	21,31	6,29	28,028	1,7	18/04/2018	10:18:52 AM
B5	15	917	37,41	14,105	25,54	5,54	28,036	1,5	18/04/2018	10:18:54 AM

B5	15	918	37,4	14,106	42,01	4,16	28,027	1,36	18/04/2018	10:18:56 AM
B5	15	919	37,4	14,108	15,85	3,17	28,025	0,97	18/04/2018	10:18:58 AM
B5	15	920	37,4	14,116	15,53	3,8	28,023	0,83	18/04/2018	10:19:00 AM
B5	15	921	37,4	14,121	38,47	3,36	28,02	0,4	18/04/2018	10:19:02 AM
B5	15	922	37,39	14,129	66,35	3,72	28,01	0,26	18/04/2018	10:19:04 AM
B4	18	1097	37,43	14,969	0,48	2,06	27,861	1,31	18/04/2018	1:43:38 PM
B4	18	1098	37,4	14,972	2,18	7,8	27,837	1,26	18/04/2018	1:43:40 PM
B4	18	1099	37,4	14,979	0,39	3,93	27,835	1,26	18/04/2018	1:43:42 PM
B4	18	1100	37,41	14,982	0,59	2,76	27,841	1,12	18/04/2018	1:43:44 PM
B4	18	1101	37,39	14,981	0,35	1,9	27,826	1,04	18/04/2018	1:43:46 PM
B4	18	1102	37,42	14,984	0,35	2,13	27,848	0,9	18/04/2018	1:43:48 PM
B4	18	1103	37,4	14,994	0,35	2,55	27,83	0,87	18/04/2018	1:43:50 PM
B4	18	1104	37,39	15,005	0,35	4,09	27,819	0,67	18/04/2018	1:43:52 PM
B4	18	1105	37,41	15,006	0,34	2,4	27,834	0,56	18/04/2018	1:43:54 PM
B4	18	1106	37,39	15,01	0,35	2,09	27,817	0,55	18/04/2018	1:43:56 PM
B4	18	1107	37,41	15,008	0,35	2,45	27,833	0,56	18/04/2018	1:43:58 PM
B4	18	1108	37,39	14,998	0,34	2,09	27,819	0,45	18/04/2018	1:44:00 PM
B4	18	1109	37,41	15,002	0,39	2,83	27,833	0,34	18/04/2018	1:44:02 PM
B4	18	1110	37,43	14,998	0,88	7,57	27,848	0	18/04/2018	1:44:04 PM
B3	21	1223	37,38	15,527	0,41	62,21	27,695	1,09	18/04/2018	2:18:31 PM
B3	21	1224	37,38	15,518	0,63	21,06	27,696	0,98	18/04/2018	2:18:33 PM
B3	21	1225	37,38	15,521	0,48	13,14	27,694	0,72	18/04/2018	2:18:35 PM
B3	21	1226	37,36	15,559	0,39	13,49	27,67	0,57	18/04/2018	2:18:37 PM
B3	21	1227	37,37	15,569	0,47	12,39	27,674	0,32	18/04/2018	2:18:39 PM
B3	21	1228	37,1	15,846	0,42	13,57	27,401	0,01	18/04/2018	2:18:41 PM

***Appendix 5**: CTD data from transect C in Aiguadolç.*

Sample	Ser	Meas	Sal.	Temp	F (µg/l)	T (FTU)	Density (kg/m^3)	Depth (m)	Date	Time
C6	13	786	37,48	13,605	29,22	7,57	28,206	3,5	18/04/2018	9:55:39 AM
C6	13	787	37,48	13,607	30,36	8,14	28,205	3,48	18/04/2018	9:55:41 AM
C6	13	788	37,47	13,609	28,35	6,18	28,196	3,2	18/04/2018	9:55:43 AM
C6	13	789	37,44	13,603	24,99	5,99	28,172	2,84	18/04/2018	9:55:45 AM
C6	13	790	37,47	13,588	22,82	3,11	28,199	2,81	18/04/2018	9:55:47 AM
C6	13	791	37,45	13,581	21,37	3,49	28,184	2,62	18/04/2018	9:55:49 AM
C6	13	792	37,45	13,58	19,48	2,58	28,183	2,32	18/04/2018	9:55:51 AM
C6	13	793	37,47	13,58	17,91	2,06	28,197	2,03	18/04/2018	9:55:53 AM
C6	13	794	37,45	13,589	25,93	1,83	28,179	1,89	18/04/2018	9:55:55 AM
C6	13	795	37,44	13,639	14,99	1,47	28,16	1,75	18/04/2018	9:55:57 AM
C6	13	796	37,44	13,707	13,46	1,25	28,144	1,42	18/04/2018	9:55:59 AM
C6	13	797	37,43	13,761	52,3	1,34	28,124	1,34	18/04/2018	9:56:01 AM
C6	13	798	37,41	13,799	20,96	1,29	28,099	1	18/04/2018	9:56:03 AM
C6	13	799	37,46	13,836	66,1	1,23	28,129	0,77	18/04/2018	9:56:05 AM

C6	13	800	37,44	13,893	74,89	1,21	28,1	0,39	18/04/2018	9:56:07 AM
C6	13	801	37,44	13,93	74,89	1,27	28,09	0,07	18/04/2018	9:56:09 AM
C6	13	802	37,43	13,942	74,9	1,35	28,08	0,15	18/04/2018	9:56:11 AM
C5	14	857	37,48	13,598	30,05	4,14	28,207	3,44	18/04/2018	10:07:20 AM
C5	14	858	37,48	13,597	30,9	4,56	28,207	3,3	18/04/2018	10:07:22 AM
C5	14	859	37,48	13,597	31,43	3,52	28,206	3,2	18/04/2018	10:07:24 AM
C5	14	860	37,48	13,599	28,57	4,28	28,204	2,7	18/04/2018	10:07:26 AM
C5	14	861	37,48	13,6	25,5	4,42	28,203	2,57	18/04/2018	10:07:28 AM
C5	14	862	37,46	13,596	23,59	3,03	28,186	2,08	18/04/2018	10:07:30 AM
C5	14	863	37,47	13,591	37,3	2,41	28,193	1,7	18/04/2018	10:07:32 AM
C5	14	864	37,46	13,593	56,26	1,58	28,183	1,36	18/04/2018	10:07:34 AM
C5	14	865	37,43	13,623	37,21	1,32	28,153	1,1	18/04/2018	10:07:36 AM
C5	14	866	37,45	13,858	18,21	1,48	28,117	0,74	18/04/2018	10:07:38 AM
C5	14	867	37,42	13,985	74,9	1,45	28,065	0,38	18/04/2018	10:07:40 AM
C5	14	868	37,44	14,02	32,33	1,24	28,071	0,07	18/04/2018	10:07:42 AM
C5	14	869	37,42	14,026	74,9	12,48	28,054	0,01	18/04/2018	10:07:44 AM
C4	17	1032	37,44	14,064	43,78	12,45	28,073	2,67	18/04/2018	10:40:00 AM
C4	17	1033	37,44	14,065	70,67	12,44	28,073	2,61	18/04/2018	10:40:02 AM
C4	17	1034	37,44	14,062	70,32	56,24	28,073	2,57	18/04/2018	10:40:04 AM
C4	17	1035	37,43	14,073	74,85	49,29	28,063	2,48	18/04/2018	10:40:06 AM
C4	17	1036	37,42	14,089	19,75	37,78	28,051	2,27	18/04/2018	10:40:08 AM
C4	17	1037	37,4	14,1	17,12	23,24	28,032	2,21	18/04/2018	10:40:10 AM
C4	17	1038	37,41	14,153	17,35	14,12	28,028	2,11	18/04/2018	10:40:12 AM
C4	17	1039	37,43	14,173	15,75	15	28,038	1,88	18/04/2018	10:40:14 AM
C4	17	1040	37,41	14,202	48,25	13,02	28,015	1,58	18/04/2018	10:40:16 AM
C4	17	1041	37,37	14,22	30,23	13,24	27,98	1,5	18/04/2018	10:40:18 AM
C4	17	1042	37,37	14,291	43,84	9,61	27,963	1,21	18/04/2018	10:40:20 AM
C4	17	1043	37,33	14,33	31,85	9,95	27,924	1,23	18/04/2018	10:40:22 AM
C4	17	1044	37,32	14,355	66,57	8,95	27,911	1,3	18/04/2018	10:40:24 AM
C4	17	1045	37,35	14,399	74,89	10,03	27,924	1,14	18/04/2018	10:40:26 AM
C4	17	1046	37,35	14,396	74,9	9,35	27,924	1,05	18/04/2018	10:40:28 AM
C4	17	1047	37,38	14,288	74,89	9,14	27,971	1,06	18/04/2018	10:40:30 AM
C4	17	1048	37,3	14,525	74,59	10,74	27,857	0,88	18/04/2018	10:40:32 AM
C4	17	1049	37,18	14,565	73,8	10,66	27,755	0,89	18/04/2018	10:40:34 AM
C4	17	1050	37,26	14,687	64,9	10,21	27,788	0,48	18/04/2018	10:40:36 AM
C4	17	1051	37,23	14,724	73,41	9,47	27,757	0,48	18/04/2018	10:40:38 AM
C4	17	1052	37,23	14,736	74,9	10,15	27,754	0,5	18/04/2018	10:40:40 AM
C4	17	1053	37,23	14,736	74,9	10,17	27,753	0,3	18/04/2018	10:40:42 AM

Appendix 6: *Interviews*

5/Octubre/2018

Entrevista a Jordi Mas Castellà, regidor de l'Ajuntament de Sitges

Registre sobre l'aigua subterrània i la costa

1- Sabeu de l'existència de surgències d'aigua dolça a la platja d'Aiguadolç?

Sí, se sap des de fa molt de temps. El nom mateix ho diu. Existeixen des de sempre (histories urbanes, etc). En alguns moments sembla que hi ha certs repunts però no tenen patró concret. Si coincideix en moments de bany d'estiu si que hi ha queixes dels usuaris.

2- Des de quan es coneix?

Des de sempre.

3- Com era la platja en el passat?

Mireu fotos. Parleu amb pescadors o gent gran. No se si abans era de pedra i ara es de sorra. Però pot ser que abans hagués sigut una platja de pedra.

4- S'explota l'aigua del subsòl a Aiguadolç?

Crec que no però no tinc gaire coneixement. Tampoc de l'existència de pous. Però si existissin un problema seria la salinització dels pous.

Despesa econòmica i actuacions per la gestió

5- Quins problemes solen estar associats a la gestió de platges, i més en concret a Aiguadolç?

El problema més greu és la quantitat de sorra. L'usuari vol una platja amb sorra i gaudir-ne amb comoditat. Amb la dinàmica costanera la sorra s'ha anat erosionant i hi ha episodis en que hi ha molt poca sorra a la platja i això és un problema. També ens hem trobat amb problemes d'algues mortes que queden residus a la platja, però això es un problema generalitzat a la costa, no només a Aiguadolç

6- Aquests problemes com es gestionen?

A través de la gestió de platges. S'aprofita la sorra que queda acumulada a l'entrada del port per portar-la a la platja. La qualitat d'aquesta sorra de vegades no es la millor qualitat per una platja de banyistes. Amb el temps s'adapta (color, humitat,...)

7- Quin pressupost es destina manteniment i recuperació de platges?

Té un cost molt elevat 200 o 300 mil euros

8- Quina part d'aquest pressupost depara a Aiguadolç?

En concret ho desconec

9- Amb quina freqüència es realitzen dragatges per recuperar la platja?
10- Quina part del pressupost es destina a això?
11- S'han detectat algun tipus de problemes a la platja o al port pel que fa a eutrofització de les aigües o males olors?

Sí. A la falconera aquest estiu han sigut terribles. Gairebé dia rere dia. Degut als lixiviats dels abocadors del Garraf. La gestió de l'abocador (clausurat) la porta l'entitat metropolitana de BCN. Tenen un projecte de 20-25 anys de tapar-ho. Estan fent estudis d'isòtops amb sofre. Pensen que hi ha reducció de sulfats que fan molta pudor.

Percepció de la SGD

12- A tot això creieu que els fenòmens anteriorment descrits es relacionen d'alguna manera amb la descàrrega d'aigua subterrània? Quins impactes o repercussions creieu que pot generar?

Em dóna d'impressió que no. Crec que una surgència d'aquestes es una surgència que "permea" amb la capa de sediment. No arrossega ni te cap tracció. És aigua que passa a través dels porus del sediment. No se si m'atreviria a dir que es perd línia de costa per aquest tipus d'erosió. Però la sorra si que es mou. L'erosió general de la platja existeix sempre però les surgències aquestes em semblen molt puntuals com per vincular-les a l'erosió de la platja. Tot i que jo no sé molt del tema i no sabria dir-te. Jo no tinc aquesta percepció. A nivell micro segur però que això sigui un factor que alteri la línia de costa...no t'ho se dir, no estaria segur.

És un fenomen natural. Sempre ha passat i poca cosa podem fer. No crec que ho haguem d'aturar, al contrari. El que passa és que la gent de vegades no ho entén o ho percep, per tant hauríem de conscienciar i informar a la gent per que la gent en sigui conscient. La gent ha d'entendre el que esta passant. Li hem de donar el valor d'ecosistema natural que té i mantenir-lo intacte. Si surt aigua, surt aigua. Però potser hem de ser més comunicatius perquè de vegades no ho som prou. Però tampoc veig una situació molt dramàtica.

13- Qui es veu majorment afectat i de quina manera (positiva / negativa)? Té algun efecte en els usuaris / residents d'Aiguadolç?

Veïns i banyistes. Però no és tant grau com per no anar a banyar-se. Inclús pot ser divertit pels nens. És un problema menor.

14- Ha tingut alguna queixa del veïnat a causa d'això?
15- Existeix alguna plataforma que defensi aquesta causa?
16- Si haguessis de presentar un manual de bones pràctiques pel que fa a la gestió de platges, que proposaríeu?

Conscienciar a la gent. Vivim en una societat molt tecnològica i de vegades hi ha fenòmens naturals que passen de tota la vida i s'han de valoritzar més. Potser fa falta més informació per la població per que entenguin que no és una canonada trencada, etc.

17- Creieu que la població està ben informada?

No, fa falta més informació i conscienciació.

18- Es porta a terme algun tipus de gestió o està prevista en un futur?

No. Som poc intervencionistes. Si hi hagués alguna actuació ho hauríem de mirar amb molta cura. No ens agrada la intervenció sobre el medi natural. També perquè l'impacte sobre els usuaris és mínim.

5/Octubre/2018

Entrevista a Aurora Carbonell i Abella, regidora de platges de l'Ajuntament de Sitges

Registre sobre l'aigua subterrània i la costa

1- Sabeu de l'existència de surgències d'aigua dolça a la platja d'Aiguadolç?

Sí. De fet el 2015 va començar a sortir aigua una altra vegada. La gent que viu aquí diu que de tant en tant surt aigua. A partir del 2015 ha començat a sortir molta aigua (excepte aquest any que ha sigut especial). El temps que no va sortir aigua ha estat al voltant d'una dècada.

2- Des de quan es coneix?
3- Com era la platja en el passat?

Era de pedra. No sé quan es va posar sorra. Aquí els romans venien a buscar aigua dolça

4- S'explota l'aigua del subsòl a Aiguadolç?

No s'explota i no existeixen pous. Antigament es veu que existia un

Despesa econòmica i actuacions per la gestió

5- Quins problemes solen estar associats a la gestió de platges, i més en concret a Aiguadolç?

Molèstia per platges humides i males olors associades a estancaments, queixes dels veïns. El problema més gran que hi ha es el tema administratiu. Costa molt fer procediments perquè hi ha moltes administracions diferents (ajuntament, generalitat, port, ministeri. Molta burocràcia per arreglar-ho

6- Aquests problemes com es gestionen?

Prospeccions de geòlegs. Possibilitat de fer panells informatius.

Dragatges de sorra del mar, manteniment de platges, neteja,...

7- Quin pressupost es destina manteniment i recuperació de platges?

Aquest any hem invertit gairebé 1 milió d'euros en arreglar platges (sorra, arreglar accessos, manteniment, personal, ...). Ja us passaré el pressupost

8- Quina part d'aquest pressupost depara a Aiguadolç?
9- Amb quina freqüència es realitzen dragatges per recuperar la platja?

Els que calguin, però s'intenten fer abans del juny o a finals de Setembre-Octubre

10- Quina part del pressupost es destina a això?

Només la draga ja val 350mil euros

11- S'han detectat algun tipus de problemes a la platja o al port pel que fa a eutrofització de les aigües o males olors?

Males olors per eutrofització no. A la Falconera hi ha males olors des de fa uns anys. Afecta al poble del Garraf. Sembla ser que es molt greu i s'estan posant en marxa per fer alguna cosa.

Percepció de la SGD

12- A tot això creieu que els fenòmens anteriorment descrits es relacionen d'alguna manera amb la descàrrega d'aigua subterrània? Quins impactes o repercussions creieu que pot generar?
13- Qui es veu majorment afectat i de quina manera (positiva / negativa)? Té algun efecte en els usuaris / residents d'Aiguadolç?

Veïns, gremi d'hoteleria, manteniment de platges (costa mes netejar), lloguer d'hamaques, escola de surf (usuaris poden veure la platja deixada).

14- Ha tingut alguna queixa del veïnat a causa d'això?

Si, fa uns anys va ser horrible. Queixes per humitat de la sorra, estancament de l'aigua i males olors, "forats que xuclen"...Els veïns diuen que hi ha gent que ha marxat a causa d'això però jo no en tinc constància

15- Existeix alguna plataforma que defensi aquesta causa?

No, però ens van comentar que estaven disposats a crear-la.

16- Si haguessis de presentar un manual de bones pràctiques pel que fa a la gestió de platges, que proposaríeu?

Jo sóc molt partidària de valoritzar el fenomen aquest. Explicar-ho i informar a la població amb panells informatius. Igualment si es posa un pou perquè la platja no estigui sempre mullada...

17- Creieu que la població està ben informada?

No, segurament no esta prou informada. Fa un parell d'anys si que vam intentar informar més a la gent, quan va venir el col·legi de geòlegs. La gent ho veu com una cosa dolenta, no com un fenomen natural. Aquesta és la feina més gran, canviar la mentalitat de la gent.

18- Es porta a terme algun tipus de gestió o està prevista en un futur?

Ha sortit el tema als plens municipals. Els diferents grups municipals en general es queixen però sense proposar cap tipus d'acció.

L'ultima proposta va ser fer un pou que podria canalitzar l'aigua. Fins i tot hi ha un pressupost

14/Desembre/2018

Entrevista a Oscar Villas García, técnico del Ayuntamiento de Sitges

Registro sobre el agua subterránea y la costa

1- ¿Sabéis de la existencia de surgencias de agua dulce en la playa de Aiguadolç?

Sí

2- ¿Desde cuándo se conoce?

En Aiguadolç de toda la vida está registrado. De hecho había una fuente antiguamente. Hablando con un pescador nos cuenta que sus padres paraban en Aiguadolç a repostar agua.

Hacía muchos años que no salía agua, pero desde hace 3 años hemos tenido problemas con las surgencias, aunque este verano 2018 no ha salido ni gota de agua pese a ser un año lluvioso. No hemos puesto ni los postes de protección.

En el pasado esta playa era de roca caliza, como toda la costa de Sitges. La piedra aparece a unos 20 cm en la parte trasera de la playa. En mitad de la playa hay 40 cm de arena mezclada con cantos traídos por la riera antiguamente.

3- ¿Se ha llevado alguna acción a cabo para identificarlas o caracterizarlas?

Sí. Pedimos a la compañía que lleva el mantenimiento de la red de agua potable (SOREA) unas analíticas y vimos que el agua no era potable pero casi.

Intentamos localizar el punto de surgencia en el lado de la playa que toca a Barcelona, donde veíamos las descargas más significativas, pero excavamos y no encontramos nada. Luego hicimos una zanga longitudinal a la playa y la sensación que daba era que entraba agua desde el lado montaña, con lo que entraba agua por toda la playa.

4- ¿Tenéis constancia de la presencia de pozos en las inmediaciones de Aiguadolç?

No. Ni en la playa ni cerca

5- ¿Tenéis un registro? ¿Conocéis su evolución (si ha variado el nivel piezométrico)?

No

Gasto económico y actuaciones para la gestión

6- ¿Qué problemas suelen estar asociados a la gestión de playas, y más en concreto en Aiguadolç?
El dragado y el mantenimiento de desperfectos.

7- ¿Qué parte de este presupuesto depara en Aiguadolç?
Una parte muy pequeña respecto del total.

8- ¿De dónde se extrae la arena?
Llevamos 5 años que dragamos en la bocana de los puertos. Analizamos la arena, comprobamos que no tiene materia orgánica y la traemos a las playas donde hemos perdido la arena por los temporales.

En Aiguadolç actuamos el año pasado, solo una vez. Es una playa donde la arena no se va de forma significativa. Intentamos subir el nivel de la playa tirando arena para que no hubiera subidas de agua por capilaridad y conseguimos generar más superficie seca que el año pasado.

Se gasta poco dinero en Aiguadolç en cuanto a acondicionamiento porque se autogestiona por si sola. Otras playas son más costosas de acondicionar porque en algunas se va la arena y en otras se forman dunas. Aquí la playa esta perfecta durante. El temporal se lleva arena pero luego el mar la vuelve a traer.

9- A todo esto ¿Creéis que los fenómenos anteriormente descritos se relacionan de alguna manera con la descarga de agua subterránea? ¿Qué impactos o repercusiones creéis que puede generar?

Percepcion de la SGD

10- ¿Quién se ve mayormente afectado y de qué manera (positiva/negativa)? ¿Tiene algún efecto en los usuarios/residentes de Aiguadolç?
La repercusión que tiene son las quejas vecinales. Los vecinos quieren bajar con toalla y se les moja porque la arena esta mojada. Desde el chiringuito también hay quejas porque la gente se va a otras playas. Se han presentado incluso algunos vecinos con propuestas para la gestión.

11- ¿Ha tenido alguna queja del vecindario debido a esto?
En las viviendas cercanas no se han detectado problemas pero si hay preocupación por si puede afectar a las edificaciones cercanas.

12- ¿Si tuvieses que presentar un manual de buenas prácticas respecto a la gestión de playas, que propondríais?
Dado que es una playa con mucha extensión, la zona donde las surgencias son evidentes la cerraría al uso público y le daría un valor medioambiental. El resto de playa seguiría haciendo lo mismo. Si hay que poner arena para conseguir que esté seca pues se hace. Si no se puede, pues la naturaleza es la naturaleza, que en este pueblo tenemos 5 km de playas

Entrevista a Victor Torrent López, President de l'associació de veïns del Port d'Aiguadolç (Via email)

Registre sobre l'aigua subterrània i la costa

1- Des de l'AVV coneixeu l'existència de surgències d'aigua dolça a la platja d'Aiguadolç? Des de quan es coneix?

Sí. En menor o major mesura, des de fa molt de temps. De fet el barri i la platja es diuen d'Aiguadolç per la surgència d'aigua de la riera. Fa tres o quatre anys que va créixer en intensitat, però de forma petita des de que jo recordo.

2- Hi ha algun tipus de recurrència o patró que s'hagi observat respecte a la sortida d'aigua dolça?

En els darrers 12 anys, des de que jo hi visc a Sitges, els primers 6-7 en forma de petites surgències (2006-2013 podríem dir), a partir del 2014 aprox. es va incrementar, amb un màxim potser del 2015-17. Ara sembla que ha tornar a afluixar la cosa, el darrer any.

3- Com era la platja en el passat?

Només puc parlar des del 2006.

4- Heu percebut canvis substancials en la platja al llarg dels anys?

Només el que he explicat abans.

5- I en la urbanització i el port (durant la darrera dècada)?

S'ha urbanitzat la rotonda d'accés al Port, just davant de l'hotel Estela. Abans era un descampat. Es va urbanitzar, convertir en zona blava d'aparcament, crear la rotonda abans de les barreres d'accés al Port. Potser sobre el 2010 o així. El carrer Meravelles, just a sobre del Poblat Mariner del Port, s'ha obert, abans estava restringida la circulació. Ara permet la sortida cap al Melià des del camp de futbol sense tenir que arribar al Port o realitzar cap infracció. Sobre el 2010 també aprox. El Port també va urbanitzar la zona al darrera de la caseta d'accés, posant-hi els contenidors de reciclatge i escombraries, sobre el 2013 aprox. i va tancar la zona de carena (tallers navals), sobre el 2011 o així.

6- S'explota l'aigua del subsòl a Aiguadolç (hi ha algun pou en el veïnat)?

Que jo sàpiga, no.

7- A l'AVV teniu constància d'alguna mena de problemàtica que hagi sigut detectada a la platja d'Aiguadolç? Quan es dóna amb major freqüència?

Sobre els anys 2015-2017, la platja era un fangar, per surgències d'aigua o falta d'aportació de sorra.

Actuacions i relació amb administració

8- La comunitat de propietàries de la Marina d'Aiguadolç va demanar, al novembre de 2016, un estudi de detall al Col·legi de geòlegs de Catalunya (COLGEOCAT) per tal d'avaluar la possible causa i evolució d'aquest fenomen natural amb les conseqüències referents a l'afectació a la platja. Que ens podeu explicar respecte a aquest procediment, va resultar en algun tipus d'informe o actuació?

Desconec aquest estudi.

9- Heu contactat amb l'Ajuntament de Sitges?

Per aquest motiu, no.

10- Que reclameu a l'administració?

Nosaltres com AVV Port d'Aiguadolç? Rescatar la concessió administrativa i sortir del règim del Port d'Aiguadolç, per a passar a ser terreny municipal com els altres. Si no és possible aquest "deslinde", que entenem que és un procediment complicat, intentem aconseguir la renovació de les concessions administratives, que caduquen l'any 2022.

11- Quina ha sigut la resposta per part d'aquesta?

Que és complicat, que ja veurem, que depèn de Madrid (el "deslinde"), i de la concessió que depèn de la Generalitat.

12- Quines mesures heu pres en conseqüència a la resposta de l'administració?

Cap. Seguim esperant.

Percepció de la SGD

13- Creieu que els problemes de la platja anteriorment esmentats es relacionen d'alguna manera amb la descàrrega d'aigua subterrània?

Sí, possiblement, però és un fenomen natural que ha de seguir els seus ritmes. Amb aportació de sorra suficient a la temporada d'estiu seria prou bé.

14- Creieu que aquest fenomen podria resultar en algun tipus d'impacte econòmic, o si pot afectar a l'ús de la platja?

Els darrers anys 2015-2017 l'afluència a la platja va baixar molt. Era un fangar.

15- En quin sector o col·lectiu té o tindria conseqüències?

Entenc que les explotacions del xiringuito i les tumbones ho deuen haver notat. Però aquest 2018 ha millorat molt la situació.

16- Que en pensen les veïnes de la urbanització i com les afecta actualment?

No agrada trobar la teva platja convertida en fangar, tot mullat, evidentment.

17- Existeix alguna plataforma que defensi aquesta causa?

Des de AVV Port d'Aiguadolç no. Desconec si AVV Marina s'ha mogut, suposo que sí.

18- Creieu que la població està ben informada sobre aquest fenomen natural i els seus impactes?

Els veïns que hi viuen saben que sempre ha sortit aigua, potser no tant com darrerament. Els que vénen els caps de setmana no crec que ho tinguin present.

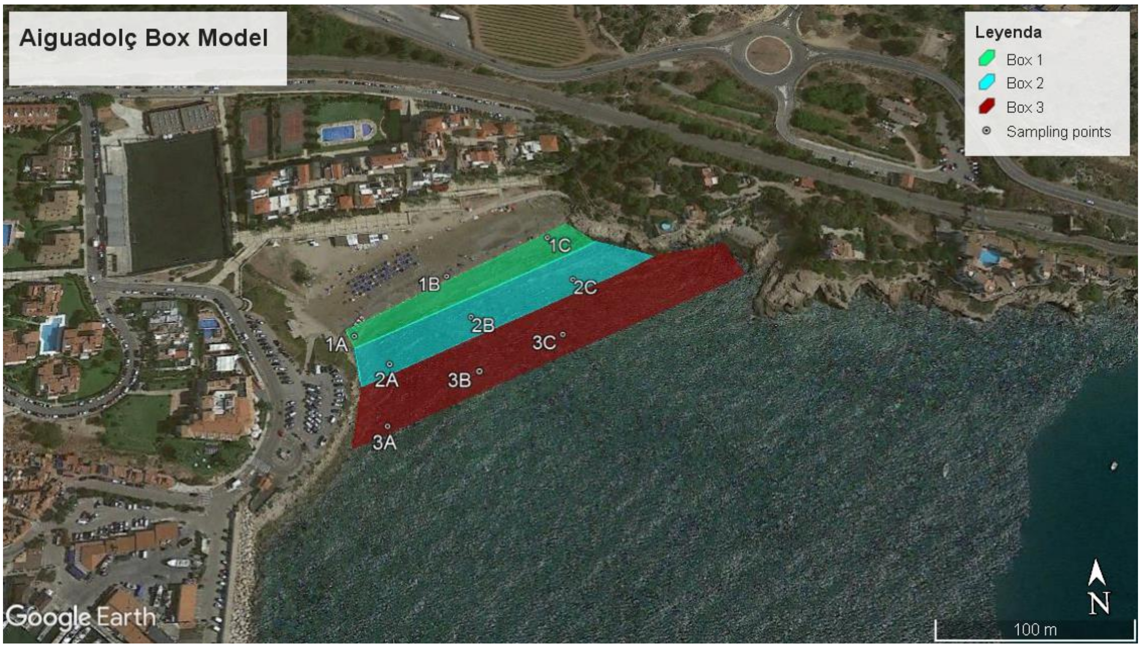
19- Quina creieu que hauria de ser la postura de l'administració respecte a la gestió de la platja?

Aportació de sorra a la temporada d'estiu (com a la resta de platges de Sitges), senyalització i tancat suau de la zona on surt més aigua, com el realitzat els anys 2016-17 aproximadament, amb una corda i pals de fusta. Quedava molt bé.

20- Es porta a terme algun tipus de gestió o està prevista en un futur?

Ni idea.

Appendix 7: *Aiguadolç box model used to calculate SGD flows.*



Appendix 8: *Aiguadolç study Carbon Footprint*

To calculate Aiguadolç Carbon Footprint, the *"Guia pràctica per al càlcul d'emissions de gasos amb efecte hivernacle"* (2018) of Oficina Catalana del Canvi Climatic (OCCC) was used. This document specifies that units of equivalent CO_2 (eq.CO_2) are used to refer to greenhouse gases, which includes the six polluntants included in the Kyoto Protocol: carbon dioxide (CO_2), methane (CH_4), Nitrogen Oxide (N_2O), Hydrofluorocarbons (HFC), Perfluorocarbons (PFC) and Sulfur Hexafluoride (SF_6).

Emissions derived from mobility and transport

The calculation of the emissions derived from mobility and transport will be done by using travelled distance, wasted fuel and vehicle model. To calculate the $gCO_2 \cdot km^{-1}$, the conversion factor of Instituto para la Diversificación y Ahorro de Energia has been used. The results obtained are presented below, in *Table I*.

Table I: *Emissions derived from mobility and transport.*

Transport	Combustible	Model	Distance (km)	Emission factor ($g\ CO_2 \cdot km^{-1}$)	Generated emissions (eq. kg CO_2)
Car	Gasoline	Volkswagen Touran	178,7	126	22,51
Car	Gasoline	Seat Altea XL	89,3	120	10,72
Van	Gasoline	Volkswagen T3 Multivan	357,4	198	70,76
Train (Rodalies Renfe)			446,7	0,06	0,03
				Total emissions:	**103,99**

Emissions derived from electrical consumption

The emissions derived from the electric consumption have been calculated by employing hours of use and emission factor calculated by the OCCC of 392 g $CO_2 \cdot kW^{-1}\ h^{-1}$. Results obtained are presented in *Table II*.

Table II: *Emissions derived from electrical consumption.*

Tool	Use time (h)	Electrical power (W)	Emission factor ($g\ CO_2 \cdot kW^{-1} \cdot h^{-1}$)	Generated emissions (eq. kg CO_2)
Computer 1	400	65	392	10,2
Computer 2	400	65	392	10,2
Computer 3	816	65	392	20,8
Computer 4	36	65	392	0,9
RaDecc	816	100	392	32,0
RAD7	6	30	392	0,1
Gamma detector	1152	400	392	180,6
Illumination	400	100	392	15,7
ERT	5	350	392	0,7
EI	3	65	392	0,1
CTD	24	45	392	0,4
			Total emissions:	**271,7**

Emissions derived from project printing

The conversion factor used to calculate the emissions derived from the project printing was obtained from Logic Palet Spain (2015). Results are presented in *Table III*.

Table III: *Emissions derived from project printing.*

Material	Nº pages	Emission factor ($g\ CO_2 \cdot page^{-1}$)	Generated emissions (eq. kg CO_2)
Pages	480	3	**1,44**

RESULT: The final result, obtained by the amount of Kg CO_2 eq. calculated previously, is 103.99 + 271.7 + 1.44 = **377.08 kg CO_2 eq**.

Appendix 9: *Information panel proposal for Aiguadolç beach (DIN-A4 and DIN-A3).*

PUNT D'INTERÈS NATURAL

PLATJA D'AIGUADOLÇ

PLAYA DE AIGUADOLÇ

AIGUADOLÇ BEACH

La platja d'Aiguadolç es troba a l'extrem sud del massís del Garraf, un massís calcari de materials juràssics i cretàcics. El massís és reconegut per les abundants surgències d'aigua dolça tant en la superfície com submergides en el mar. Aquest fenomen molt característic del Garraf es deu a la seva carstificació. La dissolució de les calcàries i dolomies que el conformen degut a l'acció hídrica permet el flux i l'emmagatzematge de l'aigua dolça.

La playa de Aiguadolç se encuentra en el extremo sur del macizo del Garraf, un macizo calcáreo de materiales jurásicos y cretácicos. El macizo es reconocido por las abundantes surgencias de agua dulce tanto en la superficie como sumergidas en el mar. Este fenómeno muy característico del Garraf se debe a su karstificación. La disolución de las calizas y dolomías que lo conforman debido a la acción hídrica permite el flujo y el almacenamiento del agua dulce.

Aiguadolç beach is located at the southern tip of the Garraf massif, a limestone massif of Jurassic and Cretaceous materials. The massif is recognized for the abundant freshwater springs on the surface as well as submerged in the sea. This phenomenon very characteristic of Garraf is due to its karstification. The dissolution of the limestone and dolomite that make up it due to the water action allows the flow and storage of fresh water.

Figura 1

El topònim Aiguadolç es deu la surgència que descarrega a l'extrem est de la platja. L'aigua descàrrega des del massís a través de diversos conductes subterranis. Un estudi de la UAB ha estimat el flux d'aigua dolça que descarrega en el mar entre 2500-3900 m^3/dia. Aquesta aigua és molt rica en soluts com nutrients i enriqueix l'ecosistema costaner. També transporta sediments, en la Figura 1 es pot observar la ploma d'aigua amb sediments que sorgeix de la Falconera. La sortida d'aquesta aigua pot provocar que la sorra de la platja quedi humida i fins i tot, en episodis de gran cabal de sortida, que s'erosioni com a la Figura 2.

El topónimo Aiguadolç ("Aguadulce") se debe la surgencia que descarga en el extremo este de la playa. El agua descarga desde el macizo a través de varios conductos subterráneos. Un estudio de la UAB ha estimado el flujo de agua dulce que descarga en el mar entre 2500-3900 m^3/día. Esta agua es muy rica en solutos como nutrientes y enriquece el ecosistema costero. También transporta sedimentos, en la Figura 1 se puede observar la pluma de agua con sedimentos que surge de la Falconera. La salida de esta agua puede provocar que la arena de la playa quede húmeda e incluso, en episodios de gran caudal de salida, que se erosione como en la Figura 2.

The place name Aiguadolç ("Sweetwater", which is the Spanish way to say freshwater) is due to the spring that discharges at the east of the beach. This water discharge from the massif through several underground ducts. A study by the UAB has estimated the subterranean fresh groundwater discharge (SGD) between 2500-3900 m^3/day. This water is very rich in solutes as nutrients and enriches the coastal ecosystem. It also transports sediments, in Figura 1 you can see the water plume with sediments that emerges from la Falconera. The emerging of this water can cause that the beach sand become wet and even being eroded in episodes of large flow discharge, as in the Figura 2.

Aquest procés natural i innocu està sotmès a diferents variables que fan complex predir el seu comportament. Degut a la dinàmica "sifonal" del carst, a la variabilitat de les pluges i a les accions humanes en el massís com les pedreres o les vies de comunicació, el volum d'aigua que descarrega per Aiguadolç pot variar molt en el temps. En la Figura 3 es pot veure a través d'una tomografia de resistivitat elèctrica (↓ resistivitat = aigua salada, ↑ resistivitat = aigua dolça) la situació de la ploma d'aigua dolça en una secció perpendicular a la línia de costa a Aiguadolç del dia 18 d'abril de 2018.

Este proceso natural e inocuo está sometido a diferentes variables que hacen complejo predecir su comportamiento. Debido a la dinámica "sifonal" del Karst, a la variabilidad de las lluvias y a las acciones humanas en el macizo como las canteras o las vías de comunicación, el volumen de agua que descarga por Aiguadolç puede variar mucho en el tiempo. En la Figura 3 se puede ver a través de una tomografía de resistividad eléctrica (↓ resistividad = agua salada, ↑ resistividad = agua dulce) la situación de la pluma de agua dulce en una sección perpendicular a la línea de costa en Aiguadolç del día 18 de abril de 2018.

This natural and innocuous process is subject to different variables that make it difficult to predict its behaviour. Due to the "siphon" like dynamics of the karst, the variability of rains and the human actions in the massif as well as the quarries or the routes of transport, the volume of water that discharges Aiguadolç can vary greatly in time. The situation of the freshwater plume in a perpendicular section to the coastline in Aiguadolç on April ,18th 2018, can be seen through a electrical resistivity tomography (↓ resistivity = saline water, ↑ resistivity = freshwater) in Figure 3.

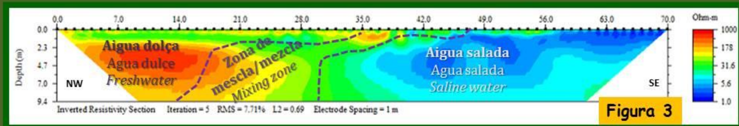


Figura 3

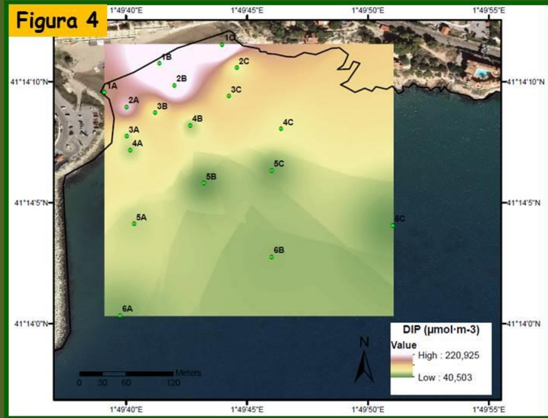
Figura 2

L'aigua que prové del continent està carregada amb compostos químics com nutrients (*Figura 4*) i metalls traça que són vitals per el manteniment de l'ecosistema marí. Tanmateix un excés d'aquest compostos per la contaminació de l'aigua subterrània pot tenir implicacions molt perjudicials per la qualitat de les aigües tant des del punt de vista de bany com des del punt de vista ecològic.

El agua que proviene del continente está cargada con algunos compuestos químicos como nutrientes (*Figura 4*) y metales traza que son vitales para el mantenimiento del ecosistema marino. Así mismo, un exceso de estos compuestos por la contaminación de las aguas subterráneas puede tener implicaciones muy perjudiciales para la calidad de las aguas desde el punto un vista de baño como desde un punto de vista ecológico.

The water that comes from the continent is loaded with some chemical compounds such as nutrients (*Figure 4*) and trace metals that are vital for the maintenance of the marine ecosystem. Likewise, an excess of these compounds due to the contamination of groundwater can have very detrimental implications for the quality of the water from the point of view of a bath as from an ecological point of view.

Figura 4



Dades extretes de: Navarro, P., Navarro, D., Garcia-Orellana, J., Alorda, A., Diego, M. (2019). Assessment of SGD in coastal karstic massif: Aiguadolç beach (Garraf). Bellaterra.

geoWASU
Environmental and water surveys

Universitat Autònoma de Barcelona

Ajuntament de Sitges