DESSIN

DEMONSTRATE ECOSYSTEM SERVICES ENABLING INNOVATION IN THE WATER SECTOR

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D35.2– Llobregat Demonstration

Economic analysis and proposed payment regulation of the identified ecosystem services – a methodological approach

Amphos 21 Consulting, February 2018

The research leading to these results has received funding from the European Union Seventh Framework Programme (FP7/2007-2013) under grant agreement no. 619039

TITLE OF THE REPORT

D35.2 Llobregat Demonstration: Economic analysis and proposed payment regulation of the identified ecosystem services in the Barcelona demo site – a methodological approach.

SUMMARY

This document presents the Llobregat case ESS Evaluation following the DESSIN methodology.
The drivers and pressures in the Llobregat delta are described together with their influence on the ecosystem state. The changes of ecosystem state that the implementation of the deep recharge would bring are identified and quantified. The main changes are observed in the groundwater quality and quantity (decrease of contaminants and increase of potentiometric levels) but the analysis also reveals the importance of the increased groundwater storage which gives to the water managers more security for water supply to the population. The costs of the technology are lower than the saving costs estimated using the ESS approach. Main savings are related with less energetic costs for pumping and treating the water. But the most relevant saving is the fact that groundwater storage can offer an additional water resource for drought periods. Cultural services are also estimated and monetized. New cultural services, as research opportunities or education, are estimated together with improved cultural services (as landscape) to estimate the economic impact. As a result, in total, it is estimated that the implementation of the measure would bring savings higher than 4.3 million €/year.
Additionally, different approaches to evaluate the best scheme for payment regulation based on ESS are presented and compared. A survey done in this project is evaluated as a tool to estimate the citizens' willingness to pay.

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Amphos 21 Consulting	Vilanova, Ester (A21); Bayer, Martí (A21); Font, Jordi (A21), Guimerà, Jordi (A21).

QUALITY ASSURANCE
Georgios Karakatsanis (NTUA), Salvador Jordana (Amphos 21), David Schwesig (IWW)

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List of Acronyms and Abbreviations

AB	Aigües de Barcelona
ACA	Catalan Water Agency
ADIF	Administrator of Railway Infrastructures
ASR	Aquifer Storage and Recovery
CUADLL	Association of groundwater users in the Llobregat aquifer
CUACSA	Water users' community of Castellbisbal
ESS	Ecosystem Services
MAR	Managed Aquifer Recharge
PCE	Tetrachloroethylene
PES	Payment for Ecosystem Services
PET	Polyethylene-terephthalate
SA	Sustainability Analysis
SCC	Santa Coloma de Cervelló
SGAB	Barcelona's Water Supply Company
SVH	Sant Vicenç dels Horts
TCE	Trichloroethylene
WFD	Water Framework Directive

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Introduction

Water scarcity and quality issues are a concern in many regions in and outside of Europe. New technologies may provide solutions for these issues. If the benefits of technical solutions are clear, they are more likely to be implemented.

The European water research project DESSIN demonstrates and promotes innovative solutions for water scarcity and water quality related challenges, and demonstrates a methodology for the evaluation of ecosystem services (ESS). Innovative solutions are tested at five demo sites across Europe.

Within the DESSIN project, a framework has been developed for the evaluation of changes in ecosystem services (ESS) and sustainability as a result of the implementation of new technical or management solutions (D11.2). This framework is applied at five European demo cases. It is one of the first times that an evaluation framework has been applied on several international cases at once.

This document contains the ESS evaluation report of one of the demo cases, more specifically, the Llobregat demo case where deep injection of pre-potable water is planned.

The objective of this report is to show how the technical solution(s) affect ecosystem services, and to perform an (economic) evaluation of the changes in ESS provision and use. Furthermore, the sustainability of the measure(s) is assessed and implications regarding governance and policy are discussed. After that, opportunities and challenges related to governance and policy are discussed, and novel financing mechanisms are proposed together with a comparative analysis of payment regulation schemes.

PART I – Study description

Step 0. Setting the scene

Administrative details

Llobregat river is located in the North-East of Spain and has a typical Mediterranean climate regime. As a consequence, the river basin is characterized by irregular and heavy rain periods, followed by periods of severe droughts which occur in intervals of 8 – 10 years. The lower part of the river is located in the most densely populated area of Catalonia, the metropolitan Barcelona area, where several and diverse anthropogenic activities have worsened the status of the basin (Sánchez-Vila et al., 2012). The deltaic area holds the LLobregat aquifer, close to Barcelona, which is a key element for the urban and industrial water supply of Barcelona Metropolitan Area. The water demand of the area is historically very high relative to the small and highly variable water resources under the Mediterranean climate conditions.
Since 1955, the joint use of surface and groundwater has improved the guaranty of availability.
Catalan Water Agency (ACA), along with government agencies operating in the same area, Agbar S.A. and the Association of groundwater users in the Llobregat aquifer (CUADLL), have carried out different actions to improve groundwater chemical and quantitative status.
The Catalan Water Agency (ACA), under the Department of Territory and Sustainability of the Catalonia Government, is the public company responsible for planning and managing the complete water cycle in Catalonia. Their main goals are:

- Execute the Water Framework Directive (WFD).
- Protect the aquatic environment and authorize river works.
- Plan and manage water supply and water treatment to the inland basins of Catalonia.
- Build and operate water treatment plants.
- Compose flooding studies.
- Make inspections and monitoring.
- Develop laws in water issues.

The public-private company Aigües de Barcelona, Empresa Metropolitana de Gestió del Cicle Integral de l'Aigua, SA, of which Aigües de Barcelona has a 70% share and Àrea Metropolitana de Barcelona (AMB) and Criteria a 15% share each, handles the efficient management of the complete water cycle, from catchment to drinking water treatment, transport and distribution. Furthermore, it is in charge of sewerage and wastewater treatment services, ensuring that this water is suitable for its return to the environment or reuse. It provides service to almost 2 million people in the towns of the Barcelona metropolitan area.

The "Community of users of the waters of the low valley and the river Llobregat delta" (CUADLL) is a Public Law Corporation under the present water legislation in force and protected by the Agència Catalana de l'Aigua (ACA).

The CUADLL groups the users, owners and irrigators who have the rights to use groundwater and surface water. Water utilities, industrial users, local services and agricultural activities are represented in this Community.

Main objectives of CUADLL are:

- To solve potential problems related to overexploitation, pollution and marine intrusion in surface and groundwater in the territory of the Community.
- Avoid and, if applicable, resolve issues or litigation among users.
- Manage the common interests of the water users.
- Inform, about changes and new concessions..
- Manage the services delegated by the Administration.
- Encourage users to introduce new mechanisms for saving and rationalizing the use of water.
- To promote the reuse of reclaimed water.

Llobregat aquifer is a very important strategic water resource in this area. The Cornellà pumping station, operated by Agbar, pumps water from the Llobregat aquifers to the city of Barcelona and was constructed completely in 1909 and still provides water to Barcelona metropolitan area at present.

Objectives of the assessment

Barcelona is one of the most populated cities in the north bank of the Mediterranean with precipitation values oscillating around 500-700 mm a year. 83% of the water input for purification comes from surface sources, 40% (78 Mm^3) comes from the Llobregat river and 43% (83 Mm^3) from the Ter river (DESSIN deliverable 22.4).

The economic development of the Barcelona metropolitan area caused several pressures in the low course of the Llobregat River and the delta of the Llobregat River. Several factors related with urban and industrial development have caused a hydrogeological direct impact on the aquifers resulting in decreased groundwater availability, increase of saline intrusion processes and groundwater pollution along the urbanized area.

One of the problems in the area is the aquifer overexploitation. Recent studies have shown that the groundwater withdrawals should be less than 40 Hm^3 a year to ensure a good quantitative status (Vázquez-Suñé et al., 2006; ACA, 2010). Nowadays the extractions are around 55 Hm^3 but in the 1970's, when the saline intrusion began, the total abstraction was higher than 100 Hm^3 (Figure 1). The peak of the extractions was in 1973, a very dry year, with a total of 130 Hm^3 (Matia and Bruno, 2010). Changes in industrial demands in the late 1980's allowed an important decrease in the extractions but they remained still too high and saline intrusion problem continued to grow. Population water supply, on the other hand, has increased in the last recent years.

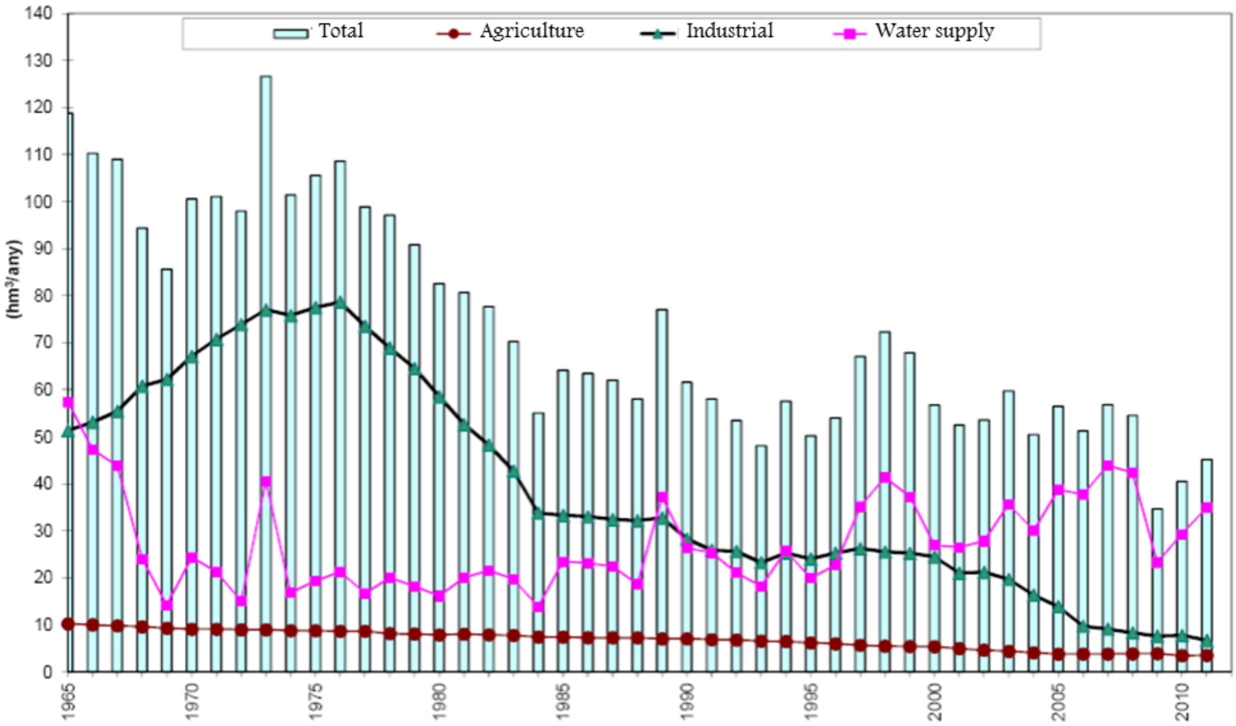


Figure 1: Withdrawals evolution on the Llobregat Delta area (Source: CUADLL)

The solution to these problems was not simple and consisted in a package of measures to assure the sustainability of the area in terms of hydraulic resources. In this context, Catalan Water Agency (ACA) limited water concessions, reduced withdrawals, constructed new water management structures and proposed water reuse schemes. It has to be pointed out that ACA also promoted the implementation of different recharge measures. On one hand, ACA constructed and maintained from 2007 to 2011 a Hydraulic barrier against saline intrusion. Additionally, local water users' associations with the ACA support, universities and Agbar implemented and tested different infiltration ponds (Sant Vicenç dels Horts, Cubeta d'Abrera and Santa Coloma de Cervelló) (see Deliverable 13.1), injection wells or other recharge actions as river bed scarification.

The hydraulic barrier consists of 15 wells into which highly treated reclaimed water from the waste water treatment plant of the Baix Llobregat is injected to the aquifer. Injected water is previously treated with secondary and tertiary treatments (with ultrafiltration, UV disinfection without chlorination, and salinity reduction through reverse osmosis). Hydrogeological and hydrochemical monitoring data indicate an efficient performance and aquifer improvement. The evaluation of such efficiency and operational costs has been analyzed and discussed.

Late in the 1960's SGAB built a treatment plant whose surpluses were used to be deeply injected into the aquifer. Hence, in 1969 seven extraction wells of 40 m depth belonging to Aigües de Barcelona were adapted for recharging treated drinking water being the design injection flow of 50 L/s (Armenter, 2008). In a second stage, five more wells were drilled specifically for recharging purposes. Nowadays, these wells are still in use to inject treated potable water if they have surpluses. Specifically, there are 12 injection wells with a maximum recharge capacity of 75.000 m^3/d. New wells were equipped with a 15 to 20 m deep screen, which allowed increasing the injected water flow from 50 L/s to 100 L/s (Armenter, 2008). Optimum operation of these wells requires periodical unclogging by pumping a flow of 200 or 400 L/s, depending on the well, for 10 minutes, every 15 days of continuous operation. The amount of recharged water by deep injection ranges from 0 to 14 hm^3/year, as it depends on the availability of the

resources. The results have been very good but due to the increase of purification costs of the water to be injected, the injected volume has decreased drastically in the last years.
Therefore, the Barcelona system has an important water stress and water scarcity risk as safety supply margins do not meet desirable levels resulting in a water deficit that is likely to become significant. To reduce this risk, and to help in the improvement of water resources status, another measure implemented by ACA was the construction of a desalination plant. This was installed in Barcelona in 2009 with a capacity of 60 Mm3/year. The plant offers guarantee of supply and assures drinking water availability for the metropolitan area in case of drought periods or when there is an increase of the water demand. However, the cost of the desalinized water is more expensive than surface water or groundwater and improvement of natural resources is often preferred among users. In this last years the desalination plant has been running just in the maintenance operation most of its lifetime.

Due to this current situation of groundwater status and the recurrent drought episodes, Agbar is evaluating in the Cornellà Pumping Station, the use of the ASR wells to inject prepotable water in the (deep) Llobregat aquifer with the aim to improve local groundwater water status, water availability and taking advantage of the additional treatment that the aquifer offers.

In this context, the DESSIN project has evaluated the technical, economical and sustainable feasibility of deep injection of other water sources in order to recover the sustainability of the existing ASR system.
In DESSIN project, the specific evaluated solution consists in the injection of 15 Hm^3 of prepotable water, which is water from the Llobregat river with only a conventional treatment (Figure 2) (coagulation-flocculation, sedimentation and sand filtration) in Cornellà wells. With the DESSIN scheme, prepotable water is going to be injected in the aquifer and later it will be recovered at the same point of the groundwater catchment input in the treatment plant. One of the goals of the DESSIN project in Llobregat site has been to analyse if it is possible to inject surface river water without disinfection without having clogging problems in the well and studying the effects of this kind of water in the aquifer. This aspect has been evaluated in the deliverable 22.4.

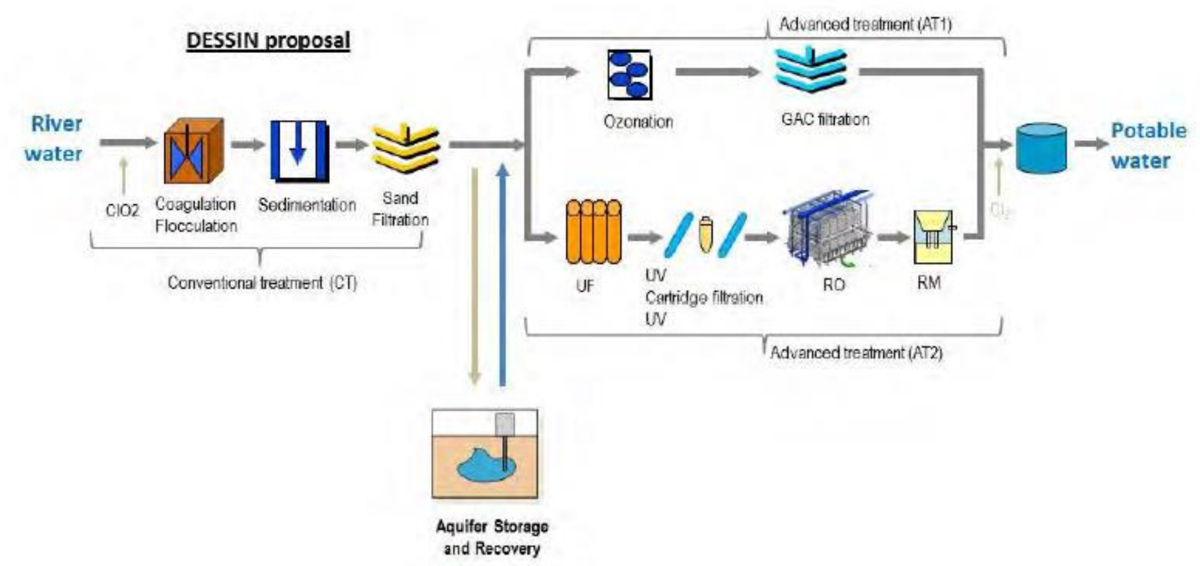


Figure 2: DESSIN scheme proposal for ASR operation (Source: deliverable 22.4)

In deliverable 22.4 a local numerical model has been implemented to evaluate the impacts in nearby wells of a pilot injection. Instead, in the present task (T35.6), to evaluate the impacts and the related changes in ESS due a full scale injection, a regional numerical model has been run by CUADLL. This model simulates the water level increase and salinity decrease along Llobregat delta in main beneficiaries' points when different volumes (from 2 to 16 Hm3) of prepotable water are injected in the aquifer.
The model reproduces the change in the aquifer related to a punctual increase of groundwater volume and considers that there are no changes in abstraction volumes. The model also allows estimating the increase of local discharges in nearby areas and in underground structures, in a general view. These impacts are related to ESS changes and estimated using economic approaches.

Overview of the study area

The Llobregat Delta is located at the SW of the densely populated area of Barcelona City, in the NE of Spain (Figure 3).

Figure 3: Location of Llobregat Deltaic area.

The Llobregat delta consists of an extensive plain that occupies 98 km^2 between the Garraf massif (in the south), Montjuïc hill (in the northeast) and the Sant Andreu de la Barca gorge in the northwest. It is formed at a recent time: it appears at Roman times and is has been growing until the nineteenth century. It has had different river mouths that over time have created the coastal lagoons and present wetlands area.

Due to its location, several infrastructures occupy the Llobregat Delta (Figure 4). The most important are the harbor and the airport but there also industrial areas, urbanized land, train lines and roads, together with agricultural uses, pine forest and the wetlands.

Coastal wetlands are connected to and dependent on the aquifer. The Llobregat delta is the second delta in the extension of Catalonia and conserves one of the most important wetlands in the country. The main lagoons are called Ricarda, Murtra, Remolar, Filipines, Cal Tet and Magarola.

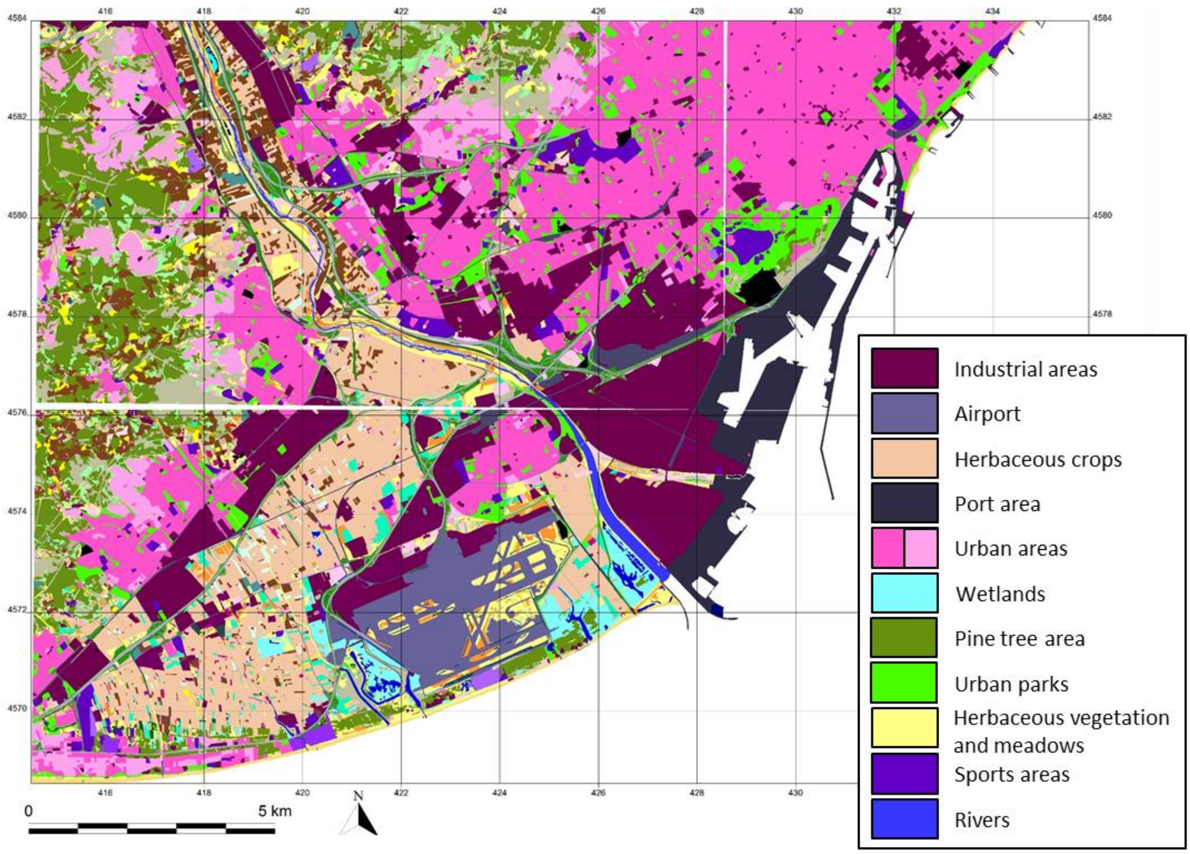


Figure 4: Different soil uses in the Llobregat Delta (CREAF, 2012).

The aquifer of the Llobregat Delta is a sedimentary hydrogeological formation stretching from Martorell to the sea, widening progressively from a few hundred meters to several kilometers along a total length of 110 km^2.

In the upper reaches (between Pallejà and Cornellà), and where the injection is planned, the aquifer is unconfined and up to 2100 wide and over 40 m thick. From Cornellà to the sea, the aquifer splits into two: an upper unconfined aquifer and a confined and deeper one. The latter is the most important and it is called the main aquifer. Its thickness ranges from 30 to 45 m. The main abstractions of the aquifer are located in this deep aquifer.

The salinity intrusion showed a slight decrease after the hydraulic barrier, but present salinity values in the area are too high for direct human consumption.

Stakeholder list

The main stakeholders in this area can be classified according to their water use:

- Water utilities that have their main wells in the Delta area:
    - Aigües de Barcelona (Agbar)
    - Aigües del Prat
- Industries (that use groundwater)
    - Damm
    - Clariant
    - Total
    - Gearbox
    - Achroma
    - Other minor industries with less water use
- General population (both inhabitants that consume local water and visitors of the area)
    - Inhabitants of the urban areas (El Prat de Llobregat)
    - Visitors to the natural area of the Llobregat Park
    - Inhabitants of the agricultural zones (agriculture use surface water but most of them have private wells)
- Consortium for the Delta Natural Area protection
- Catalan Water Agency (ACA)
- El Prat de Llobregat Council
- CUADLL

PART II – Problem characterization

DRIVERS

STEP 1. Defining drivers

In DESSIN project, a driver is defined as a human activity that may produce an environmental effect on the ecosystem (Figure 5).

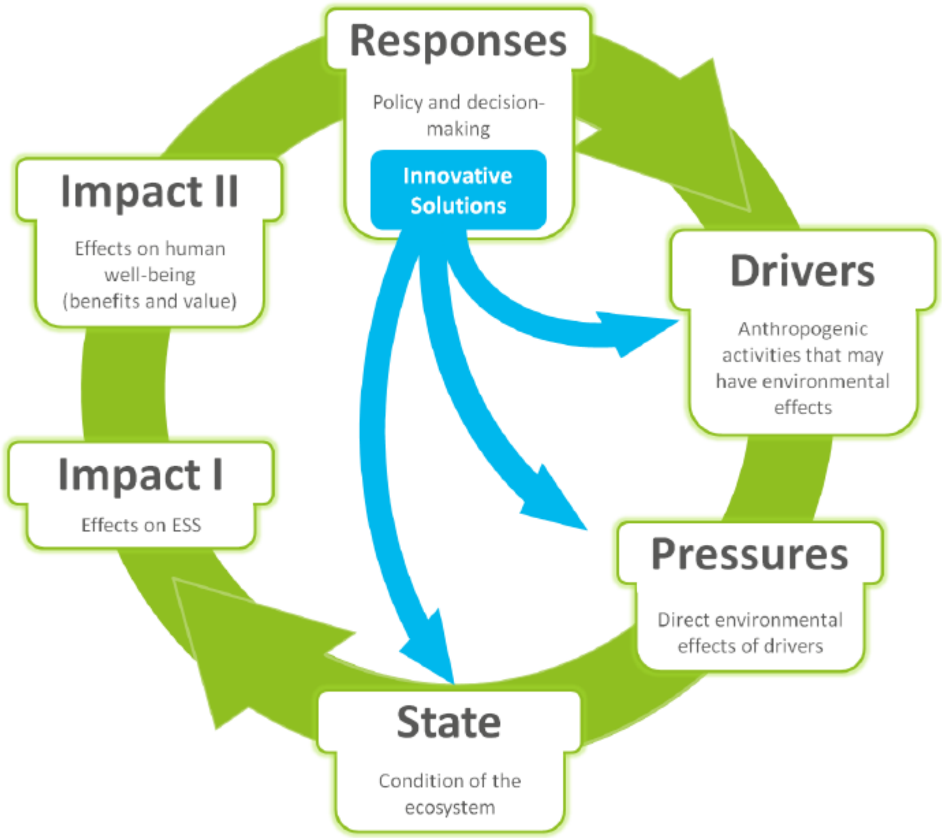


Figure 5: Conceptual approach of the DESSIN ESS Evaluation Framework (based on (Müller and Burkhard, 2012; van Oudenhoven et al. (2012); Haines-Young and Potschin (2011)). Extracted from deliverable D11.2

In the study area, the presence of river water, the existence of fertile soils, the proximity to Barcelona city and Barcelona harbor, the easy access by road, the flat topography, etc. have facilitated the urban, industrial and agricultural development of this area. Additionally, the Llobregat Delta Aquifer has historically been a strategic water supply resource to the Barcelona metropolitan area.

Therefore, the main drivers that have acted in the Llobregat Delta producing impacts over groundwater resources are the industry and the urban development. Agriculture is also an important actor of this area. Nevertheless, they consume only river water, which is diverted along different channels, and therefore they are not considered drivers that may produce environmental effect on the aquifer. Bad agricultural practices can have impacts on groundwater, but nowadays these do not limit present water uses.

Main groundwater users are industries with extract high water volumes. Although this demand has decreased in the recent years is still the most important in this area. Additionally water demand for population supply has increased in recent years and the aquifer becomes strategic in summer and drought periods. Regarding water quality, the urban grown and development in this area, together with past industrial activity (and related bad practices) has caused a persistent groundwater and soils contamination that is still affecting nowadays groundwater quality.

These drivers have been extensively described in the Llobregat mature case report (Deliverable 13.1).

DRIVER 1: INDUSTRY

The location of the Llobregat Delta, in a plain area, near the river and the sea, and close to an important metropolis has propitiated the industrial development of this area.

For many centuries, it was an inhospitable land, with a precarious and scattered settlement subject to the harsh conditions of the territory. As of the fifteenth century, the territory is occupied continuously: agriculture of the dry land, first, and that of irrigation, then, will be the dominant economic activities until in the 20th century they will leave the industry and, finally, tertiary activities.

The Llobregat River was in the last century, the axis of development of the Catalan industry, especially paper and textile.

The arrival of the train in the mid-1850s led to the first initial industrialization of this area, especially in the left side of the delta. In the Prat de Llobregat area, the first industries date from the beginning of the XXth century (Papelera Española, 1917; La Seda de Barcelona, 1926), thanks to the presence of groundwater. The massive industrialization of this zone took place after the Stabilization Plan which was launched in 1959. The main industry of this plan was the SEAT, which was installed in the middle of the Delta.

With the economic recovery of the 1960es, numerous industries settled there, some coming from neighboring Barcelona where industrial land was scarce. Also, in parallel, these areas attracted large waves of immigrants due to the possibility of work that the industry offered. This also entailed a rapid and unplanned growth of urban land.

During the seventies, there were all kinds of industries in the delta area e.g., chemical, paper, metallurgical, textile, automotive, construction, glass and food industries. Until the arrival of the global economic crisis in 1973 there was a great concentration of industrial zones like the Zona Franca (which occupied most of the left side of the delta).

Around 1980, as a result of the crisis and together with a new distribution of the production system, the industry began to lose weight. The groundwater withdrawals also decreased to less than 40 Hm^3/year (Figure 1).

These industries discharged most of their residual water, without treatments, to the river impacting in their water quality. Bad management practices in these areas left also punctual soil contamination with hydrocarbons and other solvents.

Another phenomenon linked to the industrial and urban expansion of the 1960s and 1070s was the proliferation and intensification of sand and gravel extractions (from the alluvial materials). Unfortunately, the practices that were carried out were not sustainable and the remaining holes from the extraction of these materials were refilled with waste, often of industrial origin, and contaminants.

Another industry that must be taken into account in this area is the extraction of potash in the upper part of the basin. The flow of the river through salt beds and the lack of brine management for some years explain the high salinization of the river that enters the delta with concentrations of salts higher than those recommended. Currently, the brines are properly managed with a collector.

DRIVER 2: URBAN DEVELOPMENT

The current delta is a space transformed by human action. The different stages have left a mark on the territory, which has become a mosaic of landscapes: natural spaces, crops, urban areas, industrial and services, road and rail networks, and infrastructures such as the Port and the Airport.

Along the low course of the river, Baix Llobregat region is a fast growing area in terms of population since XIXth century. The population grow is related with the industrial development of this area (immigrants from other parts of Spain settled close to the Llobregat production centers) and the increase of living costs in Barcelona city. Actually, from 1975 to 2014 the population has increased by more than 50% (Hernández el al., 2017 - DESSIN report 13.1-).

As a direct result of this population increase there is an increase of drinking water demand .This also means that waste water production has increased in this period, following the same relation as for drinking water. Land use has undergone important changes as there is a substitution from the agricultural uses to urbanized uses. Agricultural surface has decreased by more than 3.000ha that were transformed to urban areas which are mostly pavement.

It has to be noticed also that groundwater in the nearby Barcelona city cannot be used for drinking purposes due to its bad chemical status. Barcelona population relies mainly on Llobregat basin resources and on other artificially interconnected networks.

As a result of the urbanization, this area suffers and important stress over water resources. The water demand is increasing and the permeable surface water and the natural recharge is decreasing resulting in affections over the natural equilibrium of the coastal zones between land and sea.

PRESSURES

STEP 2. Defining pressures

Following the DPSIR scheme (Figure 5, DESSIN deliverable 11.2), the pressures are directly related with the drivers (defined as the direct environmental effects) and they produce impacts that can affect the state.

The following table (Table 1) indicates the main pressures that results from each of the identified drivers. In following chapters, the impacts that can produce these pressures are identified with different indicators.

Table 1: Description of the drivers and related pressures

Drivers	Pressures
Industry	• Point source: contaminated (abandoned) industrial soils; bad management of industrial contaminants (activities using specific substances: solvents, PAHs, metals, …); Industrial wastewater spills; refilling of sand and gravels extractions with industrial wastes. • Abstraction: Water abstraction from industry.
Urban development	• Diffuse source: Runoff and infiltration of surface urban water; sewerage system below the urban areas, river water pollution (pesticides, pharmaceuticals, ammonium, chloride, TOC, sulphates). • Point source: Urban waste water spills; Discharges not connected to sewerage network • Abstraction: Water abstraction for water demand; construction of urban underground structures in the saturated zone (that needs pumping). • Morphological and hydrological alteration: Reduction of permeable surface for precipitation infiltration.

Point source pressure from industrial activity

Industrial activities can generate pressure over both groundwater qualitative and quantitative status, the first one mainly through point source pressures, the latter one mostly through abstraction pressures.

In the point source pressures present and past industrial activities have to be taken into account. This is the cause of Chromium, Trichloroethylene, Perchloroethylene, mercury concentration and heavy metals in general in groundwater.

In this area there are several places with polluted soils, with ancient industrial activities and bad practices being the main problem. The input of contaminants was punctual and no longer exists, but the problem remains there (Figure 6). Therefore, this soil contamination is a source for groundwater contamination and an important pressure (metals and volatile compounds). This source has to be added to the contamination that reached groundwater in the past and has not been remediated yet.

Present bad management (mainly accidentally) of industrial contaminants is also a pressure to take into account. Nowadays this is a minor cause of contamination and if such incidents happen, remediation actions are implemented.

Wastewater of industrial activities is nowadays treated in the same plant or transported to a centralized treatment plant. This treated or raw water is discharged to the river and therefore, it is finally infiltrated to the aquifer downward. In the case of transport of wastewater, potential leakages from this network can bring also contaminants to the environment (soil and aquifer).

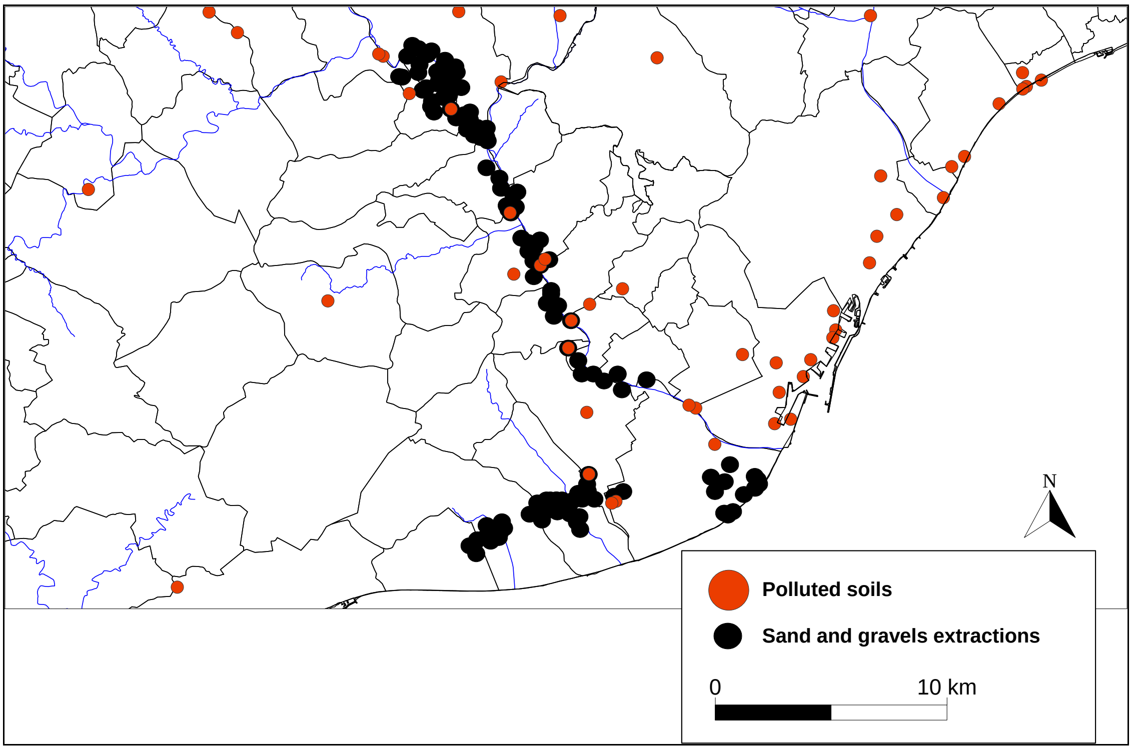


Figure 6: Polluted soils identified by ACA (2005) due to industrial activities and location of areas with past and present extraction of sand and gravels.

Another important industrial activity in this area is the extraction of sands and gravel in old river beds (Figure 7). This activity can affect water potentiometric level but the main problem (there are more than 60 areas of extraction) in this area is that in the past, the holes that the extraction left were filled with industrial waste. The water percolation through these materials is a source of contaminants, mainly metals, to groundwater.

Another side industry that has to be mentioned is the potash mining in the upper part of the basin. Before 2009 the brine collector did not work properly and most of the waste salt of the mine ended up in the river: increasing its natural salinity values and affecting the quality of the aquifers along the course of the river. In 2009 this infrastructure was fixed and is now in a phase of further improvement.

Table 2 describes the characteristics of this pressure indicator, the VOCs.

Figure 7: Image of a sand extraction exploitation.

Table 2: Organic Volatile compounds indicator

INDICATOR	Organic volatile compounds
Description	• VOC's represent the most relevant industrial pollution in delta soil and aquifer. The largest utilized compound was Trichloroethane which is proposed as an indicator compound of punctual industrial pollution. This contaminant was used in the past as a solvent to remove grease in metal production activities; in textile fabrication it is present in different aerosols. The remediation of this compound is very difficult, hence it can persist for many years in the aquifer.
Units	• µg/L of trichloroethane
Reference value (before the measure)	• 500 µg/L of trichloroethane (only in the areas with punctual contamination)
Objective	• To reduce the concentration below 25 µg/L of trichloroethane

Point source pressure from industrial waste water

In Catalonia most of river water comes from industrial and urban wastewater treatment plants effluents. In fact, this water is required in most of the rivers to maintain environmental river discharge. The volume of these effluents can be used as indicators (Table 3)

In the Barcelona area there is a high concentration of discharge points both of biodegradable and non-biodegradable effluents (ACA, 2005). The implementation of WFD Directive considered that the pressure over this groundwater body due to wastewater spills was high.

Table 3: Volume of industrial effluents indicator

INDICATOR	Volume of industrial effluents in Llobregat river
Description	• Treatment of industrial water has improved significantly the water quality around industries. This water is mainly discharged to rivers and in this area the main receptors is Llobregat river.
Units	• m^3/year
Reference value (before the measure)	• 875 m^3/year
Objective	• This volume is not expected to change as a result of the measure implementation.

Abstraction pressure from industrial activity

Water abstraction is one of the most important pressures in this area (Table 4). The volume of water abstracted for each industry is a private information and we did not have access to it. In this study the data we have used to evaluate the industrial abstraction is a sum of the extractions of different nearby companies which are water utilities and industries. This sum of different wells is the same value used in each cell of the CUADLL numerical model. The total water abstraction is 45,47 Hm^3/year. This value represents the withdrawals in an average year.

Water utilities, Agbar and Aigües del Prat, are the main consumers of this area, representing 92% of the main extractions.

The main problems or impacts related with water abstraction are the decrease of water levels and the advance of water saline intrusion. Overexploitation breaks the natural equilibrium of aquifer or land water with seawater of the coastal zones favouring the advance of the saline plume into the aquifer. Once the aquifer is salinized, the remediation is not easy and long. It is a long-term and demanding process and often some wells have to be abandoned. The most effective and economically reasonable method of groundwater quality improvement is the reduction of the groundwater pumping rate. Other available methods such as underground barriers, the artificial recharge of aquifers, hydraulic barriers relocation of pumping wells, can be expensive and not always effective. In the case of Llobregat Delta, implemented measures have demonstrated a notable effectivity which is described in this report.

Table 4: Industrial abstractions indicator

INDICATOR	Industrial abstractions
Description	• Total annual volume of water extractions for industial use
Units	• Hm^3/y
Reference value (before the measure)	• 10 Hm^3/y
Objective	• The total industrial extraction is not expected to change as a result of the measure implementation.

Diffuse source pressure from urban development

Urban areas occupy large areas in this area. Runoff of precipitation water over these pavement areas generates polluted water that can arrive to the aquifer in those areas without pavement. Additionally and similarly, leakage from sewerage system is another source of urban contaminants to the aquifer. The Spanish Association of Water Supply and Sanitation (AEAS) has made a diagnosis of the sewerage system situation in Spain and has detected a general and progressive aging of the sewerage network, especially in metropolitan areas and in cities of between 50,000 and 100,000 inhabitants. The maintenance of these systems use to be minimum implying potential media contamination.

The urban pavement is directly related with urban population and, therefore, population is used as indicator (Table 5)

In this category also the recharge from the river has to be included, as this water has pesticides, TOC, ammonium, chloride, phosphates, organics of emerging concern.

Table 5: Urban population indicator

INDICATOR	Population in the urban areas
Description	• Runoff and pavements areas together with amount of residual water are related to the total population in the urban areas
Units	• Population in Baix Llobregat (inhabitants)
Reference value (before the measure)	• 771.516 inhabitants
Objective	• This indicator will not change with the measure implementation

Punctual source pressure from urban development

The punctual pressures that are typical in urban areas are the discharges of urban wastewater treatment plants. These discharges can bring some nutrients and contaminants to the river and therefore, to the aquifers. These contaminants are mainly nutrients, pathogens and organic contaminants of emerging concern (micropollutants). Additionally, also scattered houses without connection to the sewage network can pour domestic water into the environment.

In this area there are 6 water treatment plants to treat the residual water generated by Baix Llobregat population. The total treatment capacity of this area is 594.000 m3/day which has an equivalent population of 3.215.000.

The indicators in this case are the same as for diffuse pressures for urban development (Table 5). Both pressures can bring the same type of contaminants, as the origin of the water is the same.

Abstraction source pressure from urban development

The population growth in this area has also increased the water demand. Water consumption is not very high in this area (less than 150 l/person/day) but all metropolitan area relies on the groundwater resource which can be around 30% of the total water supply. Nowadays the groundwater abstraction for domestic uses is between 30 and 40 Hm^3/y.

As explained before, the main problems related with water abstraction are the aquifer overexploitation and the saline intrusion.

Seawater intrusion is a widespread contamination phenomenon affecting most coastal semiarid areas. In the main Llobregat delta aquifer seawater intrusion processes have been observed since the 1960s (Iribar & Custodio, 1992). The intensive exploitation of groundwater resources, along with the excavation of part of the confining layer in the eastern coastal corner, has led to the progressive deterioration of groundwater quality (Custodio, 1981; Iribar et al., 1997; Abarca et al., 2006).

Figure 8 shows the chloride distribution in the aquifer in 2017, before any measure implementation in the Llobregat Delta. Cl concentration was over 250 mg/l in most of the delta area limiting the drinking of this water without treatment.

Table 6 describes the indicators of the pressure of water abstraction for domestic purposes, this is water population supply.

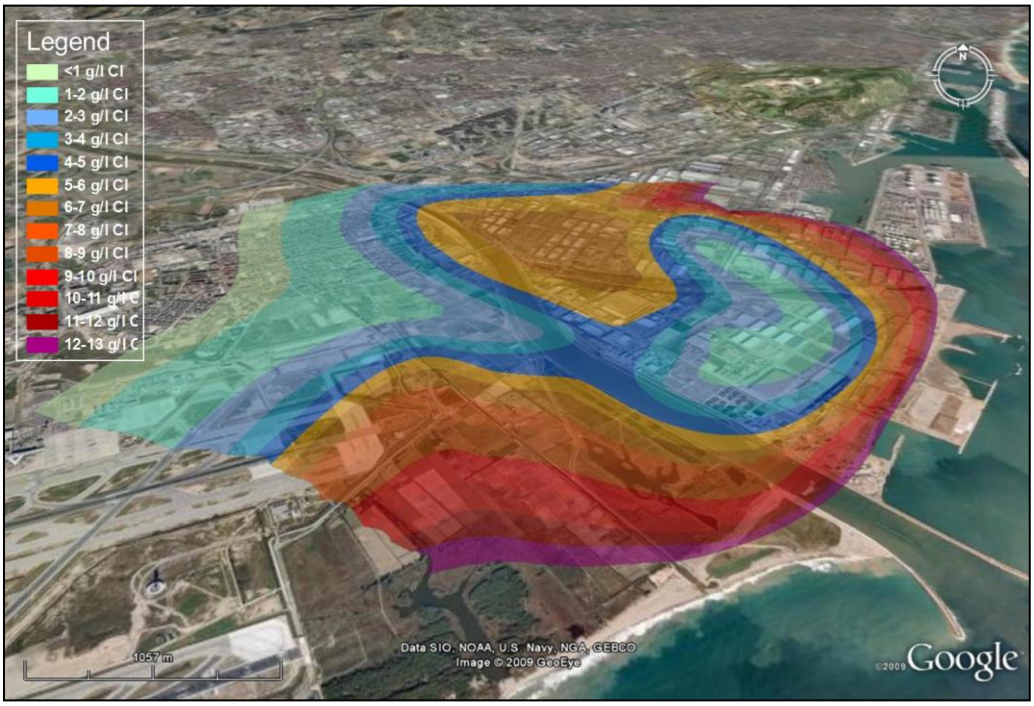


Figure 8: Chloride concentration in que Llobregat aquifer in 2007 (ACA, 2011).

Groundwater quantitative status is also affected by the construction of underground structures like metro, train, parking and others. These infrastructures, depending on the groundwater level position, need water pumping to avoid the flooding of these spaces to keep the water level below the infrastructures.

Table 6: Domestic abstractions indicator

INDICATOR	**Domestic abstractions**
Description	• Total annual volume of water extractions for supply drinking water
Units	• Hm^3/y
Reference value (before the measure)	• 37,68 Hm^3/y
Objective	• The total extraction for population supply is not expected to change as a result of the measure implementation.

Morphological alteration pressure from urban development

Urban zones increase the area of pavement. This usually is a non-permeable material and hence, the available surface for infiltration is drastically reduced. As a result, the total recharge value in the aquifer is diminished and, at the same time, the runoff increases with water that acquires contaminants during this surface transport.

As it can be observed in Figure 4, Industrial and urban areas are surrounded by crops and agricultural areas which were more important in the past. The differences are evident in Figure 9 and Figure 10. In the second one, which is from 1947, there was more area used for crop cultivations than in the present.

Figure 9: Satellite view of present Llobregat Delta (www.icgc.cat)

Figure 10: Satellite image of Llobregat Delta in 1947 (www.icgc.cat).

A more detailed look at these land use changes is shown in Figure 11 and Figure 12. The first one shows the small size the El Prat de Llobregat urban area had in 1947, while Figure 12 displays how this urban area is nowadays practically connected with El Prat airport.

Figure 11: Satellite view of El Prat de Llobregat (in the Llobregat Delta) in 1947 (www.icgc.cat).

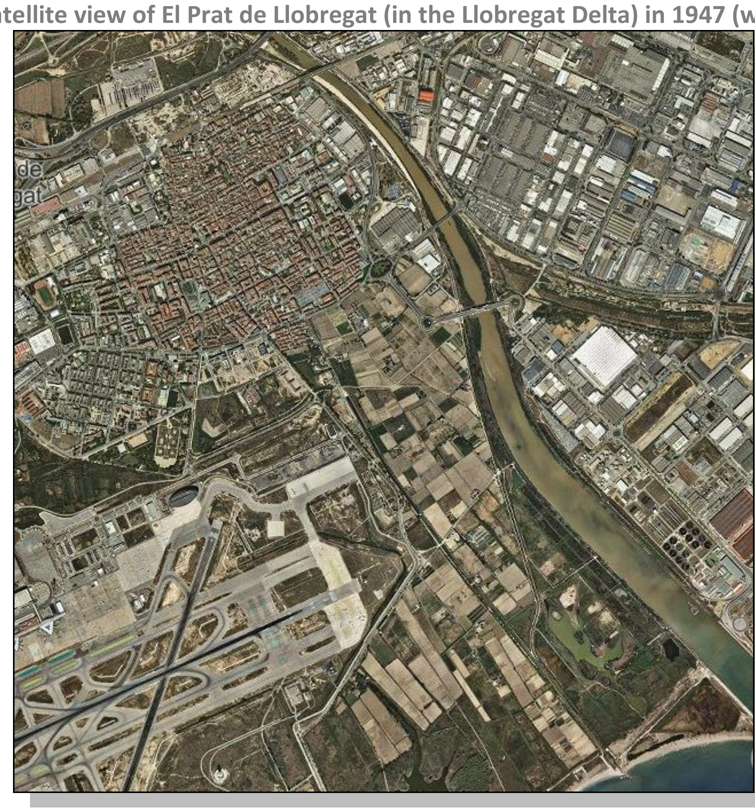


Figure 12: Satellite view of present El Prat de Llobregat area (in the Llobregat Delta area) (www.icgc.cat)

Note in previous figures that the river was displaced from its initial course due to industrial and urban needs. As a result, the recharge area has decreased considerably between both Figures. Deliverable 13.1 indicates that the agricultural surface has decreased by a 35% in the last 20 years (Source of data: Idescat).

Table 7: Surface of urbanized land indicator

INDICATOR	Surface of urbanized land
Description	• Total of urbanized land in Llobregat Delta area
Units	• Hectares (Ha)
Reference value (before the measure)	• 14.200 Ha
Objective	• The total area urbanized is not expected to change as a result of the measure implementation.

PART III – Description of responses & identification of potential beneficiaries

STEP 3. The measure

3.1 – Description of the proposed measure

With the aim to improve groundwater quantitative and qualitative status and, at the same time, to increase the groundwater reservoir, in case of drought, it is planned to implement a Managed Aquifer Recharge (MAR) installation of injection wells using pre-potable water from the Llobregat river. An annual recharge volume of 15 Hm^3 is foreseen.
Nowadays, water from population supply comes from the river and from the aquifer. Agbar purification plant treats this water before distribution for water supply. In case of surplus, this potable water is returned to the aquifer by different wells. Thus, several expensive and energy consuming processes are applied to this water that is being recharged without taking into account that non-saturated zone and aquifer itself can remove most of the river contaminants.

MAR facilities comprise a wide variety of systems in which water is intentionally introduced into an aquifer. In general terms, this groundwater recharge can be performed in two ways: through soil and subsoil passage or by direct entrance (injection) into the aquifer. In the first case, the system uses the favourable characteristics of soil, subsoil and aquifer for further treatment of the infiltrated water, which is called SAT (Soil Aquifer Treatment). This is an advanced treatment process that is done in three steps: Surface infiltration, percolation through the unsaturated zone (vadose zone) and slow transport through the aquifer. SAT uses the soil and groundwater as treatment and seasonal or longer-term storage (Bouwer and Rice, 1984).
Water can be also introduced by wells directly to the aquifer, without passage through the unsaturated zone. This water can be recovered in the same point (ASR, Aquifer Storage and Recovery) or in another well (ASTR, Aquifer Storage Transport and Recovery). In the latter, treatment processes are favoured by transport through the aquifer.
MAR is used to store and treat water in an appropriate aquifer from a variety of sources. Recharging water can be rainwater, river water, reclaimed water, desalinated seawater, stormwater or even groundwater from other aquifers. MAR is a technology widely applied and with an important increase in the recent years due to its double capability: storage and treatment of water for a potential final drinking water use. In case of recharging wastewater natural aquifer treatment can be easily combined with engineered treatment systems. With an appropriate pre-treatment prior to recharge and post-treatment after recovery (if necessary), MAR may be used for several different water demands: drinking water, water for industry, for agriculture, municipal uses, environmental uses and for sustaining groundwater dependent ecosystems.
Managed Aquifer Recharge (MAR) with reclaimed waste water combines natural water treatment during infiltration with subsurface storage and has shown to be a cost-effective wastewater reclamation technology that can improve water quality to drinking water quality levels (Kazner et al., 2012). However,

there are still concerns about some contaminants like trace organics or emerging contaminants and this is probably one of the main drawbacks of this technology. These characteristics are evaluated in Deliverable 35.1

Another barrier is or can be the legislation. There is not a European legislation regarding to MAR activities. The EU Water Framework Directive (2000/06/EC) stipulates that MAR can be a supplementary measure to reach good quantitative and qualitative water status by regulating the water cycle on basin scale within an integrated water resource management. On the other hand, the EU Groundwater Directive prohibits any actions that may deteriorate groundwater quality – a demand that needs to be evaluated site-specifically. Some countries like Switzerland, Netherlands or Spain count on specific regulations that consider some of the contaminants of emerging concern. When recharge is done using wastewater, JRC has recently published a guide that refers to “Minimum quality requirements for water reuse in agricultural irrigation and aquifer recharge - Towards a water reuse regulatory instrument at EU level”. This report aims to become an input to the design of a Legal Instrument on Water Reuse in Europe. It recommends minimum quality requirements for water reuse in agricultural irrigation and aquifer recharge based on a risk management approach (Alcalde-Sanz and Gawlik (2017)). When recharging aquifers with reclaimed water, member states authorities use to follow a conservative approach denying authorization of new sites due to the lack of information related to impacts on groundwater quality. Another reference document in MAR activities are the Australian regulations that provide minimum removal guidelines for drinking water augmentation for several microbial parameters as well as an extensive list of chemical contaminants with typical and guideline values (NRMMC-EPHC-NHMRC, 2008).

3.2 - Claimed/expected capabilities of the proposed measure:

As it has been mentioned, MAR techniques are able to improve groundwater status both in qualitative and quantitative terms. In the case of Llobregat delta, the main capabilities of ASR that are the reason for its implementation are:

- 1) To increase water quantitative status
  Overexploitation of the aquifer has decreased the water level and facilitated the saline intrusion in the lower part of the delta. When injecting water to the aquifer, the differences between the water inputs and water output decrease, thus helping to maintain the aquifer equilibrium in a coastal zone. The quantitative status of the aquifer is expected to improve with the increase of freshwater input. This will result in a rise of potentiometric levels around the injections points. The area that will be affected by this increase will depend on volume of injected water and the hydraulic properties of the aquifer.
- 2) To increase water availability for drought periods. Groundwater is a strategic resource in this area to supply Barcelona metropolitan area. The volume of abstracted water depends on the demand and in periods when surface water is scarce and not available, the amount of groundwater abstraction is increased (together with the increase of desalinized water production). This happened in 2007 and recently, in 2018, due to a significant drought, government has recently announced the increase in groundwater exploitation (Figure 13).


LAVANGUARDIA

TU HUELLA | CAMBIO CLIMÁTICO | ACTUALIDAD | HÉROES Y VILLANOS | ANIMALADAS | SÍ, EXISTE | ECOGALLEGO |

SITUACIÓN PREOCUPANTE

Las reservas subterráneas se activan para combatir la sequía

Los acuíferos del delta del Llobregat y del Besòs deben frenar la caída de los caudales en los ríos

ACTUACIONES EN MARCHA PARA OBTENER CAUDALES ADICIONALES CONTRA LA SEQUÍA EN LA REGIÓN DE BARCELONA

1. DESALINIZADORA DE EL PRAT
Amplía su nivel de explotación. Trabaja al 70% de su capacidad mientras que antes, con los embalses llenos, operaba al 20%

2. DESALINIZADORA DEL TORDERA
Trabaja al 75% de su capacidad. Desde noviembre pasado una conducción transporta el agua hasta la potabilizadora de Cardedeu, desde donde la lleva al depósito de Trinitat

3. AGUA REGENERADA EN LA DEPURADORA DE EL PRAT
Servirá para inyectar agua en el acuífero del Delta (y evitar la entrada de aguas salinas), en la industria, para dar caudal ecológico al tramo final del Llobregat y transportarla aguas arriba, hasta Sant Joan Despí, para obtener nuevos caudales potables

4. ACUÍFERO PROFUNDO DEL DELTA
Empieza ahora su explotación. Se extrae más de 1 m³/segundo. Tiene una capacidad de 80 hm³. Se utiliza como reserva estratégica

EVOLUCIÓN DEL NIVEL DE LOS EMBALSES

Embalses de cuencas internas de más de 2hm³, en porcentaje

	HACE 1 AÑO	8 ENERO
Darnius Boadella 61,10 Hm³	45%	36%
Sau 165,26 Hm³	53%	39%
Susqueda 233,0 Hm³	55%	48%
La Baells 109,43 Hm³	74%	49%
La Llosa del Cavall 80,0 Hm³	67%	35%
Sant Ponç 24,38 Hm³	91%	91%

Figure 13: News on catalan newspaper detailing that groundwater will be exploited to face drought problems (la Vanguardia, 12/01/2018, http://www.lavanguardia.com/natural/20180112/434229816938/ reservas-subteraneas-llobregat-besos-sequia.html)

- 3) To increase water quality. Nowadays groundwater has very low qualitative status and implementation of WFD 2000/60/CE has identified this groundwater body as being at risk. The main contaminants in the water are the organic pollutants of industrial origin and the saline intrusion. As it shown in Figure 6, most of the groundwater in the delta presents Cl^- concentration above 250 mg/l, which is the limit value for drinking water. Thus, nowadays, groundwater is not suitable for drinking production neither for most of industrial processes requiring different treatments depending on the final use.
- 4) Another aspect that has to be taken into account is the fact that aquifers offer additional treatment to the water. Managed Aquifer Recharge combines natural water treatment during aquifer passage and storage and has shown to be a cost-effective treatment technology that can improve water quality to drinking water quality levels (Kazner *et al.,* 2012). This capability of the measure allows introducing non-potable water to the aquifer. The quality of the injection water

can be lower of that water that is being injected nowadays. The aquifer can treat most of the contaminants. The only concern is about some of the micropollutants, which have been investigated separately. As aquifer water has very high salinity, it is possible also to introduce water with high chloride contents but lower than those of the aquifer. This characteristic will allow decreasing present treatment cost of the abstracted water.

- 5) The Llobregat Delta is one of Catalonia's most important wetland zones (Figure 14). It is home to 20 natural habitats which have been designated special areas of conservation by the EU, and has an extraordinary diversity of plant species. It encompasses more than 900 hectares over the right margin of the river that have been declared a Special Protection Area as a designation under the European Union Directive on the Conservation of Wild Birds. Coastal wetlands depend on groundwater and at the present, as groundwater quantitative status is not good, some wetlands receive water from nearby wells. The increase of water level can help in the maintenance of this areas status increasing the input of water. Furthermore, if the groundwater quality is improved due to this MAR facility, also the quality of this ecosystem could be improved increasing the amount of fauna and flora.

Figure 14: Wetlands in the coastal zone

3.3 - Driver, Pressure, and/or State Based affected by the measure capabilities

In previous chapters it has been described the main drivers and the area and the related pressures. The capabilities of the measure, the MAR, will only affect some of these pressures (Table 8). In summary, the main pressures are point source from industrial activities, industrial water abstraction, diffuse pressure from urban development, point pressure related with urban development, water abstraction du to urban development and morphological alterations related also with urban development.

Table 8: Effects of the measure on pressures

		Effect on DRIVER		Effect on PRESSURE								
Proposed measure	Claimed / expected capability	Industrial bad activities (mainly past bad practices)	Urban development:	Point source groundwater pollution	Point source industrial waste water	Abstraction from industry (Abstraction).	Point source industrial refill of sands and gravels extractions	Diffuse source of runoff of contaminated water	Point source urban discharges not connected to WWTPs	Point source urban waste water	Abstraction for urban uses & development	Reduction of permeable surface
Injection of 15 Hm3 of prepotable water to the aquifer through wells.	Improving water quantitative status	X	X			X					X	
	Increasing water availability for drought periods		X								X	
	Improving water quality in the aquifer (reduction of contaminants)	X	X	X	X		X	X	X	X		
	Improving water quality of injection water via aquifer passage	X										
	Improvement of ecosystem related status		X									X

Previous tables have indicated the relation between the measure capabilities and the existing pressures. It has to be noticed that the abstraction for industrial and urban demands it is not expected to change with the measure implementation. The injection will increase the water level only if the abstractions do not change. The objective of the injection is not to allow major abstraction volumes but to increase the present depleted water levels. Nevertheless, both groundwater uses will benefit from groundwater level increase, as they will need less energy consumption in wells pumping. This is the reason why it has been indicated that the water abstraction will be improved with this measure implementation.

Similarly, it has to be pointed out that the improvement in the quality of water injection will not cause any change in the pressures, as we are also considering separately the improvement of water quality itself. But, the water utility that is nowadays in charge of the water supply and is recharging potable water in the aquifer, will have less costs in the recharging systems as some treatments will be not necessary.

The following table (Table 9) indicates the state parameters that are influenced by the measure (from S catalogue) considering the capability of the measure previously identified. :

Table 9: Effects of the measure on pressures

Capability of the measure	State parameters
Improving water quantitative status	Groundwater level, volume of groundwater replenishment by surface infiltration
Increasing water availability for drought periods	Groundwater level
Improving water quality in the aquifer (reduction of contaminants)	Salinity (Cl), Electrical Conductivity, Nitrates, Chlorinated compounds
Improving water quality of injection water via aquifer passage	Natural attenuation
Improvement of ecosystem related status	Water volume

3.4 – State parameters and related ESS

These state parameters identified that are expected to be affected by the implementation of MAR can be related to an ecosystem service. The following table (Table 10) relates the state parameters and the corresponding ESS from the CICES list.

Table 10: ESS associated to the affected state parameters

STATE Parameter influenced by measure	CICES Class *(restricted to ecosystem type)*	CICES Group	CICES Division	CICES Section
Biological	*Maintaining nursery populations and habitats*	*Lifecycle maintenance, habitat and gene pool protection*	*Maintenance of physical, chemical, biological conditions*	*Regulation & Maintenance*
Hydrology	*Hydrological cycle and water flow maintenance*	*Liquid flows*	*Mediation of flows*	*Regulation & Maintenance*
Physiochemical	*Surface water for drinking*	*Water*	*Nutrition*	*Provisioning*
	Surface water for non-drinking purposes	*Water*	*Materials*	*Provisioning*

STATE Parameter influenced by measure	**CICES Class** *(restricted to ecosystem type)*	**CICES Group**	**CICES Division**	**CICES Section**
	Bio-remediation by micro-organisms, algae, plants, and animals	*Mediation by biota*	*Mediation of waste, toxics and other nuisances*	*Regulation & Maintenance*
	Filtration/ sequestration/ storage/ accumulation by micro-organisms, algae, plants, and animals	*Mediation by biota*	*Mediation of waste, toxics and other nuisances*	*Regulation & Maintenance*
	Filtration/ sequestration/ storage/ accumulation by ecosystems	*Mediation by ecosystems*	*Mediation of waste, toxics and other nuisances*	*Regulation & Maintenance*
	Dilution by atmosphere, freshwater and marine ecosystems	*Mediation by ecosystems*	*Mediation of waste, toxics and other nuisances*	*Regulation & Maintenance*
	Maintaining nursery populations and habitats	*Lifecycle maintenance, habitat and gene pool protection* …	*Maintenance of physical, chemical, biological conditions* …	*Regulation & Maintenance*

3.5 – Identification of expected beneficiaries:

To finally estimate the economic impacts of the measure it is necessary to identify those local stakeholders that will become beneficiaries of the MAR implementation (Table 11).

Main beneficiaries can be linked to the measures capabilities. These beneficiaries are those industries that extract water from the aquifer; the water utilities that pump groundwater to be distributed; the operators of the treatment plants (can be the same water utilities that do the water supply); investigators that develop research projects; students that participate in these projects; and people that visit the wetlands of the coastal zone and those that enjoy the area by bike, walking, … (experiencers and viewers).

Table 11: beneficiaries of each measure capability

Proposed measure	Claimed / expected capability	Municipal drinking water treatment plant operators	Local water utility	Industries	Researchers	Experienced and viewers
Injection of 15 Hm3 of prepotable water to the aquifer through wells.	Improving water quantitative status	X	X	x	x	
	Increasing water availability for drought periods	X	X			
	Improving water quality in the aquifer (reduction of contaminants)	X	X	X	X	
	Improving water quality of injection water via aquifer passage (*)					
	Improvement of ecosystem related status					X

(*) Intermediate ESS that do not have direct beneficiaries

The aquifer passage offers an additional treatment to injected water. The beneficiary of this ESS will depend on the responsible of the injection and on the water type used in the injection (if the injected water was used for other purposes before the MAR implementation). Nowadays the system is being done with water from the river which is not treated and, therefore, there is not a direct beneficiary of the treatment that the aquifer offers.

PART IV – Response evaluation

To evaluate the response it is necessary firstly, to quantify the impacts generated with the implementation of the measure, in this case the deep injection of water in the aquifer.

There are two types of impacts resulting from changes in ecosystem state: Impact I are those effects over the ecosystem services while Impact II are the impacts on human well-being.

STATE

STEP 4. Identification of state variables

The implementation of the deep recharge will change the state of the ecosystem and there are some indicators that can give insights into these changes. These are the indicators of state.

It is expected that the implementation of a MAR facility will improve the groundwater quality, the groundwater quantity and the wetlands status. It has been pointed out that groundwater recharge will increase also the volume of stored water available for droughts periods. The indicator of this capability is the same as for groundwater quantitative status.

Table 12 includes all state variables that are relevant in the implementation of MAR in Llobregat Deltaic Area.

Table 12: State variables

Parameter	State parameters	Units
Quantitative status	Groundwater level	m
Qualitative status	Chloride concentration (directly related to Electrical Conductivity)	mg/l
	Chlorinated compounds	mg/l
	Nitrates	mg/l
Wetlands status	Groundwater input	Hm^3/y

STEP 5. Identification of Indicators of Impact I and Impact II

Impact I measures the change of biophysical indicators without taking into account the beneficiaries of these changes. These impacts are summarized in Table 13.

Table 13: State parameters and corresponding Impact I indicator

Parameter	State parameters	Impact I Indicator
Quantitative status	Groundwater level	Increase of groundwater level in the influence zone
Qualitative status	Chloride concentration (directly related to Electrical Conductivity)	Decrease in Cl^- concentration in groundwater (depending in distance to injection area and quality of injection water)
	Chlorinated compounds	Reduction of selected chlorinated compounds due to dilution with injection water
	Nitrates	Reduction of selected chlorinated compounds due to dilution with injection water
Wetlands status	Groundwater input	Increase of groundwater input to wetlands zone (and therefore, increase of the wetlands area)

Impact II measures the change of human wellbeing after the implementation of the MAR facility. Therefore, these impacts are related with the beneficiaries of the impact I and the related ESS (Table 14 and Table 15).

Table 14: State parameters, beneficiaries and Impact II

Parameter	State parameters	Beneficiaries	Impact II
Quantitative status	Groundwater level	Drinking water treatment plant operators Water utilities Water administration Industrial processors Researchers	Energy costs for pumping Energy costs for membrane system Guarantee of supply costs Research studies (PhDs, visits, budget of projects…)
Qualitative status	Chloride concentration (directly related to Electrical Conductivity). Chlorinated compounds. Nitrates	Drinking water treatment plant operators Water utilities Industrial processors Researchers	Energy costs for membrane system Membrane maintenance Research studies (PhDs, visits, budget of projects…)
Wetlands status	Groundwater input	Experiencers and viewers Schools	Visitor's value

The ecosystem services related with the measure can be divided into three groups of CICES (Common International Classification of Ecosystem Services) classes: Provisioning, Regulation & Maintenance and Cultural. These ESS can change as a result of measure impacts and therefore the benefits of these ESS can increase or decrease. These changes are evaluated using Impact indicators in the following chapters. Table 15 relates the ESS with the beneficiaries.

Table 15: ESS and related beneficiaries

ESS	CICES section	CICES Class	Beneficiaries
Water suitable for being treated in water utilities	Provisioning	Groundwater for drinking	Drinking water treatment plant operators Water utilities Researchers
Water suitable for industrial processes	Provisioning	Groundwater for non-drinking purposes	Industrial processors Researchers
Landscape and sounds that provides sensory experience; opportunity to view the environment and organisms	Cultural	Experiential use of plants, animals and land-/seascapes in different environmental settings	Experiencers and viewers
Research opportunities	Cultural	Scientific	Researchers
Students formation	Cultural	Educational	Students
Storage of groundwater in an aquifer as a reservoir	Regulation & Maintenance	Hydrological cycle and water flow maintenance	Water administration
Groundwater purification during aquifer passage (organic pollurtants, N retention rate, pesticides, pharmaceuticals)	Regulation & Maintenance	Filtration/sequestration/storage/accumulation by ecosystems	Intermediate ESS

STEP 6. Quantification of changes in impact I

Most important changes will be on groundwater quantity and quality. To evaluate the changes in the aquifer due to deep recharge of 15 Hm3 a regional flow numerical model with conservative transport has been implemented. This model has been developed by CUADLL and described in deliverable D22.4, Chapter C.

A regional model has been developed using VISUAL TRANSIN (Galarza *et al.,* 1995). The existing numerical model of "Vall Baixa" (Lower Valley) and Llobregat Delta has been adapted to simulate the impact of ASR operation at full scale (15 Hm^3). The model has 129 km^2 of surface. In the delta there are two layers (superficial and deep aquifer) and in the rest one layer (main aquifer). The main aquifer is formed by Cubeta Sant Andreu de la Barca aquifer (9 km^2), low Valley aquifer (20 km^2) and finally deep delta aquifer (100 km^2) (Figure 15). The model is built by finite elements and it has more than 10.000 cells. In the delta zone there are two layers because in this area there are two aquifers separated by an aquitard. This aquitard is thicker in the centre of the delta area

The unit of time used for model simulations is monthly and the working period stretches from 1965 to 2013. In consequence there are 576 stress periods. In the model there are 96 wells groups. The average extraction rate in the last twenty years is about 50 hm^3 /year. The model data comes from 2011 year as this year represents mean values in precipitation and abstractions.

In this aquifer, the transport model of chloride is very important as it has been used historically to simulate the saline intrusion in the Delta. In 2014, the model has been updated until 2013 with a new calibration that correlates satisfactorily.

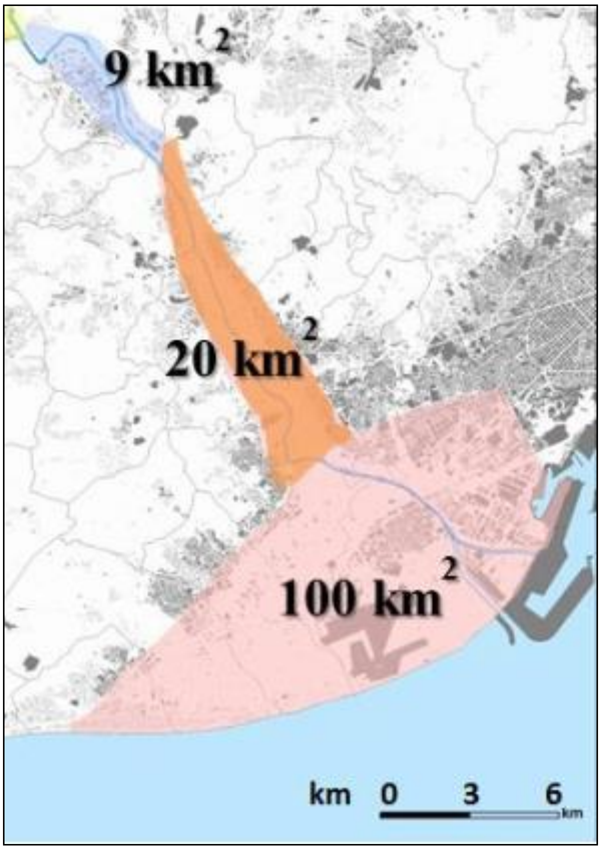


Figure 15: Modelled area (Source: deliverable 22.4)

The numerical model is a simulation of the aquifer where several cells (more than 10.000) represent the total aquifer surface. Each cell can contain zero, one or more than one well. In the latter case it is not possible to distinguish between different wells and the total abstraction of the wells located in that cell are attributed to the node of the cell. Therefore, the model and the changes in state are not evaluated for each single well but for a group of wells (Table 16 and Figure 16).

Table 16: Wells and corresponding cells (nodes) of the model

<table>
<tr><th>Group</th><th>Node</th><th>Wells</th><th>Name well in model</th><th>Volume of abstraction</th></tr>
<tr><td>1</td><td>2780</td><td>Pou 14</td><td>266</td><td>0,00</td></tr>
<tr><td>2</td><td>2781</td><td>Pou 15</td><td></td><td>-1,54</td></tr>
<tr><td>3</td><td>2782</td><td>Pou 16</td><td>267</td><td>-0,44</td></tr>
<tr><td>4</td><td>2806</td><td>Pou 11</td><td>273</td><td>-1,65</td></tr>
<tr><td rowspan="2">5</td><td rowspan="2">2808</td><td>Pou 10</td><td></td><td rowspan="2">-4,99</td></tr>
<tr><td>Pou 18</td><td>276</td></tr>
<tr><td rowspan="2">6</td><td rowspan="2">2857</td><td>Pou 17</td><td>272</td><td rowspan="2">-1,87</td></tr>
<tr><td>Pou 4</td><td>270</td></tr>
<tr><td rowspan="2">7</td><td rowspan="2">2871</td><td>Pou 13</td><td>275</td><td rowspan="2">-2,64</td></tr>
<tr><td>Pou 19</td><td>277</td></tr>
<tr><td>8</td><td>2872</td><td>Pou 20</td><td>278</td><td>-1,10</td></tr>
<tr><td rowspan="2">9</td><td rowspan="2">2927</td><td>Pou 5</td><td>261</td><td rowspan="2">-1,10</td></tr>
<tr><td>Pou 3</td><td>269</td></tr>
<tr><td rowspan="3">10</td><td rowspan="3">2928</td><td>Pou 1</td><td>268</td><td rowspan="3">-2,75</td></tr>
<tr><td>Pou 12</td><td>274</td></tr>
<tr><td>Pou 21</td><td>279</td></tr>
<tr><td rowspan="8">11</td><td rowspan="8">3007</td><td>Pou 8</td><td>264</td><td rowspan="8">-11,77</td></tr>
<tr><td>Pou I</td><td>257</td></tr>
<tr><td>Pou II</td><td>258</td></tr>
<tr><td>Pou III</td><td>259</td></tr>
<tr><td>Pou 2</td><td>260</td></tr>
<tr><td>Pou 6</td><td>262</td></tr>
<tr><td>Pou 7</td><td>263</td></tr>
<tr><td>Pou 9</td><td>265</td></tr>
<tr><td>12</td><td>3009</td><td>Pou 22</td><td>280</td><td>0,00</td></tr>
<tr><td>vb5</td><td>4265</td><td>vb5</td><td></td><td>1,62</td></tr>
<tr><td>vb6</td><td>4259</td><td>vb6</td><td></td><td>1</td></tr>
<tr><td rowspan="4">VB8</td><td>3894</td><td colspan="2">VB8 - Estrella 1</td><td>1,75</td></tr>
<tr><td>3946</td><td colspan="2">VB8 - Estrella 2</td><td>0,7</td></tr>
<tr><td>4073</td><td colspan="2">VB8 - Estrella 5</td><td>0,6</td></tr>
<tr><td>4038</td><td colspan="2">VB8 - Estrella 6</td><td>1,95</td></tr>
<tr><td>P4</td><td>2190</td><td>P4</td><td>P4</td><td>1,25</td></tr>
<tr><td>P9</td><td>2081</td><td>P9</td><td>P9</td><td>3,25</td></tr>
<tr><td>P22</td><td>2191</td><td>P22</td><td>P22</td><td>2,6</td></tr>
<tr><td>P32</td><td>2418</td><td>P32</td><td>P32</td><td>1</td></tr>
</table>

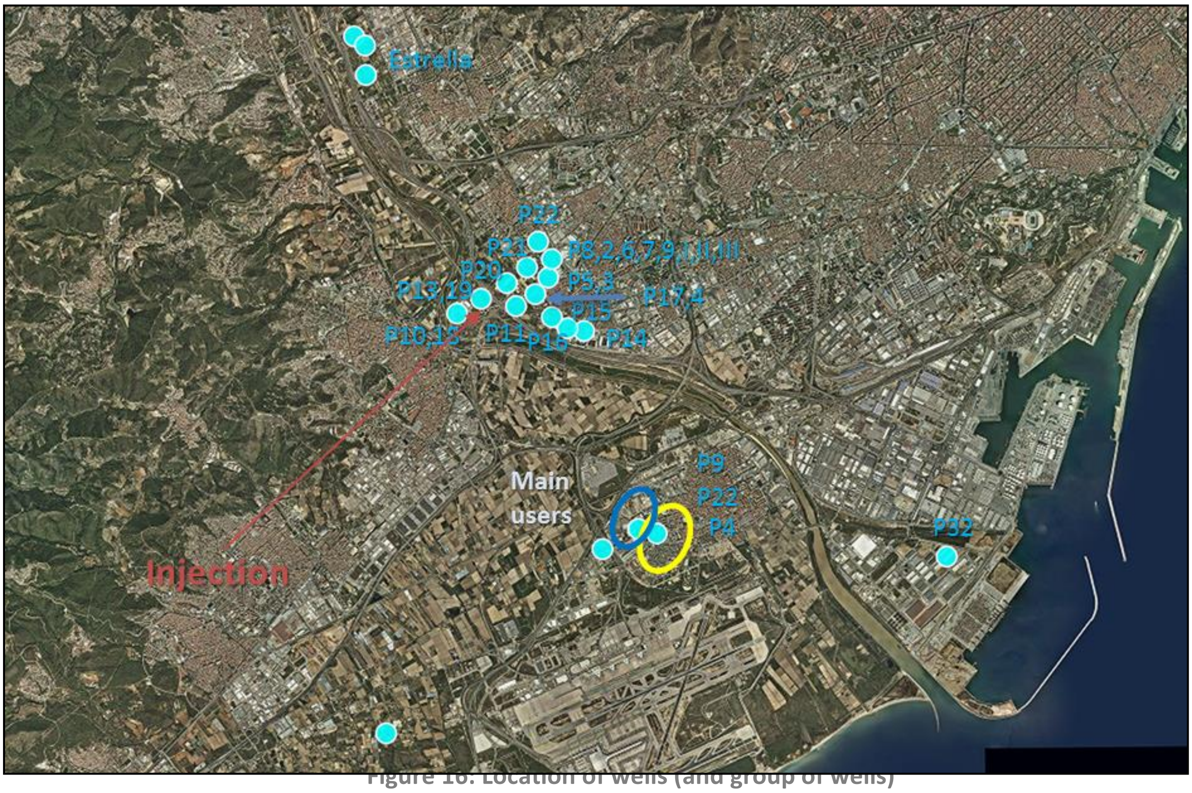


Figure 16: Location of wells (and group of wells)

The parameters considered in the model are:

- All the temporal functions of prescribed flow are constant and its value is an average result of the mass balance model.
- The extraction is supposed as a constant value, based on last years' exploitation (50 Mm^3/year)
- The injection is done in a single point: Group 5 of Table 16 (Well 18 and 10).
- Alternating injection/extraction of 15 Mm3/is implemented with a frequency of the alternation of fourteen days
- To evaluate the impact, static conditions have been sought, corresponding to a simulation period of 30 years to assure equilibrium.
- The plume of mixed water has been evaluated using a conservative tracer (starting in the injection water with 100 units).

The deliverable 22.4 concluded that although VISUAL TRANSIN model allows the simulation of injection and recovery processes with medium resolution (sometimes it integrates several real wells in a single node), its mesh has the adequate geographical dimension to present clearly the results. This means that numerical model is a powerful tool to present results to local stakeholders which are familiar with the use of this tool to evaluate the impact of hydrogeological in the Llobregat area. Therefore, the results of this model have been used to evaluate the state changes in ESS due to measure implementation.

The main changes that the model shows are: increase of water levels and dilution of contamination

Increase of groundwater levels

The injection and replenishment of the Llobregat aquifer results in an increase of water heads. This increase is directly related to the injected volume (Figure 17) and depends on the distance to the injection point. The closest wells to the injection area show an increase of between 7 and 9 meters. In wells located at more than 4 km from the injection area, the increase is less, around 5-6 m (Table 17).

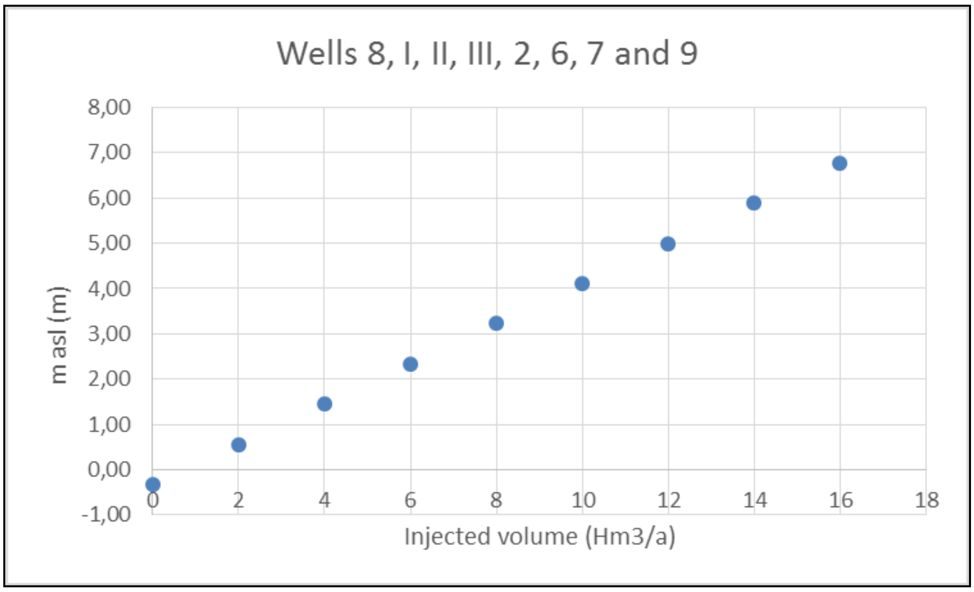


Figure 17: Increase of water heads in a group of wells at different injection volumes

Table 17: Increase of groundwater level as a result of the measure

Well	Initial head (m)	Final head (15 Hm^3 injection) (m)	Head increase (m)
Pou 8 / Pou I / Pou II / Pou III / Pou 2 / Pou 6 / Pou 7 /Pou 9	-0.34	6.78	7.12
Pou 10 / Pou 18	0.38	10.05	9.66
Pou 1 / Pou 12 / Pou 21	-0.01	7.18	7.19
Pou 13 / Pou 19	0.23	7.76	7.53
Pou 17 / Pou 4	-0.11	7.01	7.12
Pou 11	0.01	7.21	7.20
Pou 15	-0.17	6.72	6.89
Pou 20	0.14	7.43	7.29

Pou 5 / Pou 3	-0.19	6.91	7.10
Pou 16	-0.12	6.86	6.98
Pou 14	-0.15	6.66	6.82
Pou 22	0.13	7.30	7.17
Pou 32	-1.92	3.12	5.04

As the water level increase depends on the location, it is not possible to identify a general baseline value before the measure implementation and a general head value after the implementation. Instead, we have to consider a range of values taking into account the distance from the injection point ranging from an increase of 5 m to 9 m.

In the Llobregat coastal area there are several wetlands where the increase of water level will increase the outputs or groundwater discharges to this area. The numerical model has allowed the calculation of these changes in the outputs. As the result, the wetlands will have a bigger area and a more constant value. The model indicates that the most relevant increases will be in La Murtra and El Remolar wetlands. In the first the increase will be of 3953 m^3/d (1, Hm^3/y) while in El Remolar it will be of 695 m^3/d (0.25 Hm^3/y) (Figure 18).

Figure 18: Increase of discharges (in red) in coastal wetlands

Dilution of contamination

As it has been explained, groundwater in this area contain different contaminants: chloride, COVs, nitrates, ammonia, …

The numerical model allows simulating the transport of a conservative tracer. The baseline in the model is the present chloride concentrations while the chloride concentration in injecting water has been set to 240 mg/l, which is the mean concentration of present river water. The model gives the final chloride concentration in each observation point after 30 years injecting 15 Hm^3 a year.

The rest of contaminants do not have a conservative behaviour but we can assume a similar dilution factor of that estimated with chloride concentration.

The results of the chloride distribution after the injection are presented in Figure 19. It can be seen that most of the delta still presents values above 575 mg/l but from the injection area to the main users in Prat del Llobregat, this concentration is lower. If we analyse the change in the concentration if the main user's wells we can see that major dilution factors (and therefore major decreases in Chloride concentration) are at around 6-7 km of the injection area (Figure 20). This is because initial Cl^- concentration in the injection area is quite similar to that of injecting water and at certain distance the injected water is too diluted to decrease the baseline concentration.

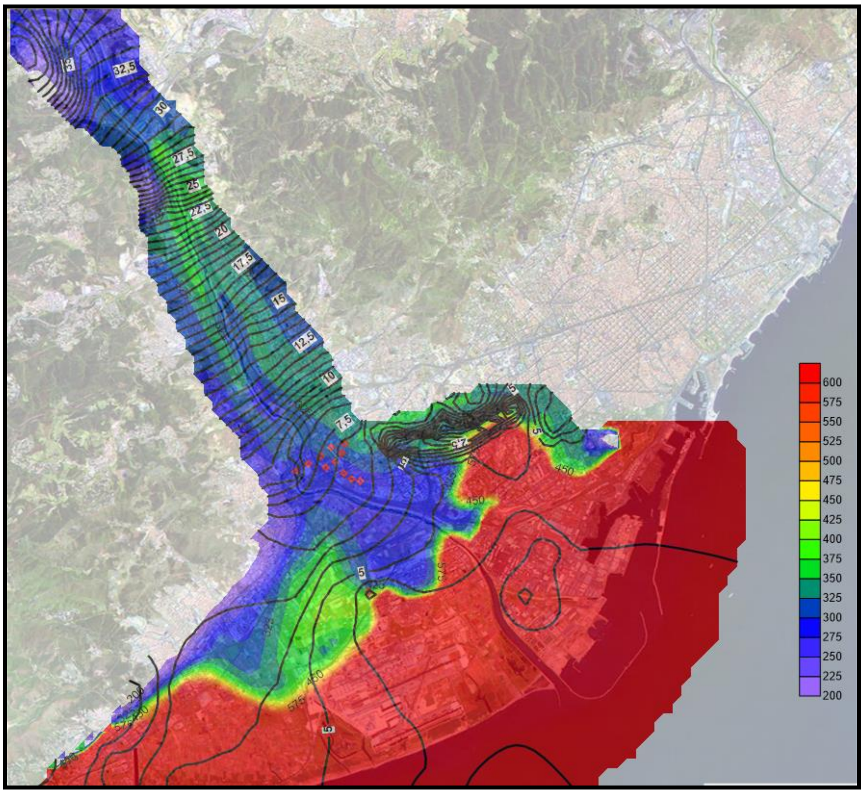
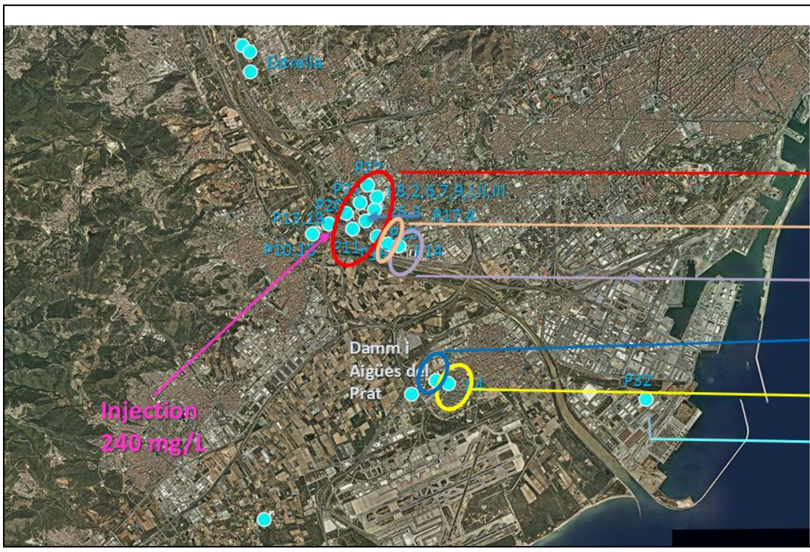


Figure 19: Chloride concentration distribution when injecting 15 Hm^3/y



Cl CONCENTRATION (mg/L)

Before recharge	After	Decrease
318	304	14
337	293	44
456	296	161
587	302	285
952	302	650
1804	1871	-67

Figure 20: Chloride decrease in observation wells

Based on modelling results we can establish an area of influence of around 8 km downstream of injection point where more of the 40% of the abstracted groundwater comes from the injection. It has to be noted that final concentration depends on the concentration in the recharging water, which is not going to be constant over the injecting period. For this reason we opt for indicating the final value together with the % of injection water (Table 18)

Nitrate concentration in the aquifer is not a pollutant of concern but is highly variable in time and space depending on the zone and the main activity. The implementation of the WFD in this groundwater body characterized the quality of the aquifer. Nitrates mean concentration was set as 4.3 mg/l (using 23 punctual data) with a maximum of 42 mg/l. Recharging water has a mean concentration in nitrate of 6 mg/l with a range between 5 and 15 mg/l. In the areas close to recharging water and in the main influence area nitrate concentration is almost the same as in recharge water. Thus, no changes in nitrate concentration are expected in the injection influence area.

Chlorinated compounds are one of the main problems in groundwater of the lower Llobregat delta valley. These are related with historical industrial bad practices. The quantification of this pressure has indicated a value of 500 µg/L of Trichloroethane but locally it may reach peaks of 700-900 µg/L. The characterization of the groundwater body done with the implementation of the WFD (ACA, 2005) reported that 52% of the ACA monitoring points had trichloroethylene (TCE) and perchloroethylene (PCE) concentrations above drinking water standards.

As recharge water do not contain PCE neither TCE, the aquifer recharge can dilute the concentration of this chlorinated compounds. Nevertheless, it has to be pointed out that the transport of these contaminants is not conservative and their degradation generates other sub products contaminants. In general, it can be assumed that in the injection influence are the contaminants will be diluted depending their distance to the injection point. At less than 8 km, concentrations can show a 40% of decrease.

Table 18: Change of state variables because of the measure

Parameter	State parameters	Units	Without measure	With measure
Quantitative status	Groundwater level	m	Values between -2 and + 0.5 m above sea level	Values between 3 and 10 m above sea level (Increase between 5 and 9 m)
Qualitative status	Chloride concentration (directly related to Electrical Conductivity)	mg/l	Values between 250 and 650 mg/l	Depends on injecting water. River water: decrease between 14 and 650 mg/l – depends on the location- More than 40% of abstracted water comes from injection at less than 8 km
	Chlorinated compounds	µg/l	500	A decrease of around 40%
	Nitrates	mg/l	4.3	No changes are expected

STEP 7. Quantification of changes in impact II

Impact II measures the change of human wellbeing after the implementation of the measure. Therefore, the quantification is done by means of changes to end users. These beneficiaries have been linked to state parameters in Table 14 and to ESS in Table 15.

In Llobregat Delta there are two drinking water operators: Aigües de Barcelona and Aigües del Prat. Aigües de Barcelona is the biggest water utility in Catalana supplying water to more than 3 million of people in metropolitan area. The water that Aigües de Barcelona distributes comes mainly from rivers but it is complemented with Llobregat groundwater, especially during drought periods and when river water is not suitable for treatment. Instead, Aigües del Prat is smaller and supplies to 60.000 inhabitants of El Prat de Llobregat city. Aigües del Prat relies only on Llobregat groundwater through different wells. The mean annual volume abstracted by Aigües de Barcelona is 16.3 Mm^3 while Aigües del Prat is around 1 Mm^3.

Other important users of groundwater are the industrial processors. Most of them pump groundwater that is finally used both in their industrial processes and for plant maintenance works. As groundwater quality is not enough for most of industrial uses, they treat the water by different technologies.

Agricultural use is not considered here as they mainly use surface water for irrigation. Moreover, groundwater salinity is too high in some places for irrigation purposes.

Barcelona metropolitan area is placed in a Mediterranean area with habitual drought periods. One of the concerns of the Catalan Water administration is to guarantee the water supply to all these inhabitants during drought periods. As groundwater is not enough to complement surface water supply, in 2009 the Catalan Water Agency built a big desalinization plant. This plant can supply around 4.5 million people and generate an additional resource of 60 Hm^3/y supplying around 24% of the metropolitan water demand. Due to the cost of this water, when surface water is enough the plant works at its 10% of capacity. The water production increases in drought periods when other water sources are not available.

Groundwater discharges to the sea, to underground structures and to coastal wetlands. The rise of groundwater levels will increase also the outputs to these wetlands, helping to maintain biodiversity. The human beneficiaries of this improvement will be the visitors.

On the other side, the rise of levels will increase also the groundwater outputs to underground infrastructures as train tunnels and underground parking lots. Therefore, this water will need to be pumped out of these structures.

Managed aquifer recharge with non-potable water is a novel technology that is being studied by several research projects and researchers. The implementation of this technology will allow the development of research projects to bring more insights on the benefits of these technologies.

Monetization of Impact II for drinking purposes

The main beneficiaries of changes in drinking water production are the water utilities Aigües de Barcelona and Aigües del Prat. We consider only the changes in the provision of water for drinking purposes. We do not take into account here the costs of the injection and the different costs related with different types of injection.

The main changes that will bring benefits to these users are the increase of water levels and the quality improvement.

The monetization of water level increase is done through the avoided costs in energy for water pumping while the estimation in quality improvement is done by the avoided costs of water treatment.

It has to be pointed out that the main objective of groundwater recharge is to push back the effects of the overexploitation. Hence, the numerical model considers that the abstractions will not increase, the groundwater use will be the same as now. Therefore, the water utilities will not change their present abstraction infrastructures.

<u>Water for drinking purposes</u>

The injection of 15 Hm^3 of water will increase the groundwater levels between 4 and 10 m depending on the distance to the injection area (more increase in closer areas). The mean value of water level increase in Aigües de Barcelona is 5.5 m. The energy consumption of the water pump depends on pumping height, engine yield and discharge. Aigües the Barcelona has several wells but they are not working all together during the whole time. It can be assumed that the performance of each individual well can represent in total a constant 24h pumping of three wells. The difference in energy consumption in these wells working full time is of 54 kW/m^3. To estimate the total savings for pumping a higher water levels heights we have to consider 8760 hours year (for each well). This difference in energy consumption during these days gives that the annual avoided costs in energy for pumping is 22,341 €/year (the cost of the energy paid by water facility is 0.091 €/kWh. This calculation results in a total annual avoided costs in energy for **pumping of 22,341 €.**

Aigües del Prat withdrawals are less than Aigües de Barcelona. In this case the increase of water level is of 5.8 m (from -2.24 to 3.59 m asl). The difference in energy consumption at this higher level is of 56.9 Kwh/m^3. Their wells do not work continuously and it can be assumed that the total annual working hours are 4,975, based on their information. Considering that the cost of the energy in this use is 0.091 €/kWh, the calculation gives an annual **avoided cost of 1,445 €/year**.

Salinity does not change considerably in wells of Aigües de Barcelona, as the injecting values are quite similar to those of the aquifer in wells area. Instead, other contaminants like PCE and TCE will be diluted by the injecting water. Nevertheless, groundwater is only used by Aigües de Barcelona as a supplementary resource and it volume is much lower than river volume. Therefore the treatment plant is designed to eliminate main river contaminants and the proportion of groundwater is too small to change current water treatments.

Instead, Aigües del Prat relies only in groundwater. The decrease in salinity and other contaminants may change water treatments. Nowadays, treatment of Aigües del Prat consists in a filtration, a stripping tower and a reverse osmosis.

The decrease in organic contaminants is not enough to eliminate the stripping tower. The salinity decrease is more important in one well rather in the other[1]. In one case the decrease is from 453 to 363 mg/l of Cl^- while in the other one it is from 952 to 302 mg/l of Cl^-. In the first case the reduction is not enough to introduce changes in treatment options, it is only a 20% decrease. In the second well, the decrease is important, of about 68%. The mix of both water gives a mean chloride decrease of 41% and consequently, the company foresee changes in the reverse osmosis system. Nowadays Aigües del Prat count with 2 treatment plants where they could change membranes type and using new membranes where the energy consume would be the half (from present 19 bars to 10 bars). In this case, the avoided costs are: less energy composition and more economic membranes. The membranes consumption decrease from 0.9 to 0.5 Kwh/m^3 for a discharge of 100 m^3/h which results in 4 € less at hour giving savings **of 33,816 €.** Additionally the purchasing cost will be also lower. Each plant counts with 120 membrane units with a cost of 625 €. These membranes could be changes for other membranes of 400 € each. Considering changes in both plants the savings will be of 54,000 for each 5 years of lifetime. **Annually the savings would be of 10,800 €.**

<u>Water for non drinking purposes</u>

The total industrial demand for groundwater is around 3.2 Hm^3/year. More than half of this demand belongs to a unique company, which fabricate beverages. This company pump local groundwater and purify it through an intensive reverse osmosis system. They are not going to introduce changes in the treatment systems unless the salinity change is higher than 20% and this change is maintained for a remarkable period of time. In summary, they do not plan to change the treatment system unless these changes are evident and constant along time.

Deliverable 13.1 described the savings in this industry of beverages if the water level increases and the salinity decreases.

[1] Note that we are not really referring to the amount of wells they use but the groups of wells. In Aigües del Prat wells have been grouped in 2 different cells of the model and therefore we can differentiate characteristics of both groups.

In the case of savings for increase of water level, the numerical model indicates that the increase will be around 8 meters. The pumps consumption will reduce significantly, as the water level will be close to the surface, in 78.5 Kw/m3. Considering the total water abstraction the total savings **are of 4,585 €.** Deliverable 13.1 has estimated the savings related with the decrease of salinity. The changes of the membranes type (from DESAL-CE8040-F to DowBW30HR-440i) will suppose a lower energy consume (from 1.10 to 0.57 kWh/m^3) for a water flow of 250 m^3/h. As a result, **the estimated cost are of 112,016 €**.

Another saving in this company is related with the fact that the new membranes will be more economic as the deliverable 13.1 describes (525€ each instead of 1,100 €). The present system counts with 696 membranes with an expected lifetime of 5 years. Following the recommendations of Cookbook Step 8, a discount rate of 3% is applied. It is a final decrease of 52% of the annual cost respect to original membranes. The annual avoided **cost is 87,385 €**

The rest of industries will have also savings related both with the increase of the water level and the quality improvement. Due to the lack of data, a benefit transfer using beverage company estimations is calculated. In order to use a mean value of increase of all these industries, a mean value of 6 m has been considered. Then, the avoided costs for energy consuming for **pumping is 1,346 €.** These industries will introduce changes in the treatment only if salinity decrease is higher than 20%. Industrial wells located in El Prat de Llobregat area will be benefited of this change. Approximately half of these industries are influenced significantly from the recharge or groundwater quality and are proactive. Therefore if the same costs of beverage industry are assumed these avoided costs will be around **52,000 € for pumping and 40,000 for membranes system purchasing** (half of beverage industry savings),

Table 19 includes all these described avoided cost of the provisioning services.

Table 19: Total of avoided costs in provisioning services

Provisioning services	Avoided costs in pumping (€/year)	Avoided costs in treatment (€/year)		
Water for drinking purposes	22,341 (Aigües de Barcelona) 1,445 (Aigües del PratP)	33,816 + 10,800 (Aigües del Prat)		
Water for non drinking purposes	4,585 (Beverages company) 1,346 Other industries	112,016 + 87,385 (Beverage company) 52,000 + 40,000 (other industries)		

In the monetization process, it has to be taken into account also a side negative effect, which is the entrance of water in underground human structures. This is underground parking, houses and train tunnels. The numerical model has estimated the outputs to the tunnels they have implemented in the model. These outputs have increase with the injection in 1.02 Hm^3/y. This volume will have to be evacuated from underground structures and discharged to other water body. The cost of this pumping that would be carried out by two water pumps would **be of 8,770 €.**

Storage of groundwater

This service is very important in this area. During drought periods, when surface water is scarce, water supply has to be done with other water sources. As aquifer is overexploited in 2009 Catalan Water Agency built the desalinization plant of El Prat. This plant can provide 60 Hm^3 a year of potable water. This means both an increased water supply to the city of Barcelona and surrounding districts incorporated into the regional ATLL (Aigües Ter-Llobregat) network. The plant, which is located beside the mouth of the River Llobregat, can provide a maximum flow of 0.2 Hm^3 of potable water per day, and in terms of water supply is the biggest of its kind in Europe. Sea water is collected 2.2 km out to sea at a depth of 30 metres off Prat del Llobregat beach then piped to the desalination plant.

The installation has complete pre-treatment facilities for sea water, including flotation, open filtration, closed filtration and cartridge filters to ensure that the water that reaches the osmosis membranes is of the best quality possible. For the desalination process itself, the plant has ten sets of membranes that can function independently. Among the newer elements incorporated in this installation are its pressure exchange systems, which provide a 50% saving in electricity consumption. After the water leaves the membranes it is remineralised and disinfected, then pumped to the tanks at Fontsanta in Sant Joan Despí (www.pemb.cat). The plant was originally conceived in the Spanish National Hydrological Plan and a strategic plan of Catalonia. In 2005 the Catalan Government assigned the project to ATLL. In response to the assignment, ATLL awarded a €159m contract to Degramont and Aguas de Barcelona (Agbar) in 2007 to design, construct, and operate the plant for two years.

In periods with low demand, in non-droughts periods the plant produces 10 Hm^3/y mainly for maintenance purposes. When water resources in rivers and dams are not enough the plant increases its production.

This plant has been built to ensure supply to Barcelona Metropolitan area. If groundwater would have a good quantitative status, this plant could have been avoided. Aquifer is overexploited causing an important saline intrusion. In drought periods groundwater abstraction can be increased but it has a limit as the aquifer is already supplying more water than the recommended.

Therefore, the groundwater recharge would improve the aquifer quantitative status. By injecting 15 Hm^3 yearly, the aquifer could reach a sustainable quantitative state. This activity could increase the storage of water, which could be available for exploitation in periods of high demands or drought.

Figure 21: Llobregat desalinization plant (source: www.ATLL.cat)

Consequently, the monetization of the ESS of Storage of groundwater can be calculated by the avoiding costs of desalinated water production. The cost of the water depends on the production being between 0.35 and 0.60€/m^3 (Barriola, 2012) These costs include construction, production and maintenance (Montano-Sanz, 2011). As the energetic consume has been improved, we consider the lower costs, 0.35, for a production of 10 Hm^3/year. This gives a total of savings **of 3.5 milion €.**

Cultural services: research and education

Both Llobregat infiltration ponds and hydraulic barrier against saline intrusion have been visited by scientifics, students and research and have been included in different research projects (national and international).

This is because this kind of projects attracts an interest of foreigners as students, scientific and water managers. In fact Llobregat Delta is focus of several publications every year related with water resources and management.

It is expected that a deep recharge of 15 Hm^3 would generate similar scientific interest of these other MAR projects.

The monetization of cultural services of 15 Hm^3 of direct recharge has been estimated considering the budget of the research projects conducted annually, the visits to the wetlands and the technical visits to the facilities. As this MAR installation is not yet constructed, this estimation has to be done assuming that the cultural services are going to be the same as the other MAR activities of the Delta area: the past hydraulic barrier and infiltration ponds. Deliverable 13.1 has estimated the cultural services of the infiltration ponds and these calculations will be also used here. The details of the calculations can be found in this report D13.1 elaborated by Cetaqua.

- Technical visits. Infiltration ponds received 232 visitors during 8 years. The only way to reach it is by car or by private bus specially hired to visit the ponds. The cost of the bus, from Barcelona to the ponds, for each of the visitors, is 13 €. This individual cost has been used to estimate that the annual value of the technical visits is 412 € (which includes an annual increase of 2%).
- PhD conduction: these projects give an excellent opportunity to develop research studies and therefore PhD investigations. The total value of PhD conducted at the ponds amounted 369,264 € since its constructions. The total annual value of these PHDs studies is 50,408 €.
- Research projects have allocated different budgets to develop research activities in these Llobregat sites. Considering only the studies of the hydrogeology and water quality related with MAR the total value of investment is 3,173,777 € that corresponds an annual value of 433,215 € a year.
- Another more difficult aspect is to estimate the value of these wetlands for the experiencers and viewers. The wetlands already exists and there many visitors interested in weekend activities, biodiversity watching, etc. Deliverable 13.1 has evaluated the number of visitors (more than 5,000 a year) and the monetization has been done using the Travel Cost Method (ICTM) of the widely applied methodology of Langemeyer (2015). Data from an exhaustive survey is used to estimate the precedence of the visitors. D13.1 concluded that the annual value of visitors is 20,477 €/year. But these wetlands already exist and the MAR activity can help to improve the qualitative and specially the quantitative state of this natural area. Thus, an increase of the visitors to these areas can be expected when the status is better. Internal studies of Park Managers and the surveys conducted in this project suggest an increase of visits between 5 and 10%. An increase by a mean value of 7.5% would mean an additional value of 1536 € per year.

All these costs are summarized in Table 20 indicating the type of the ESS. This table also includes the negative costs which have to be also taken into account in the final calculation.

Table 20: Summary of monetization

ESS	Avoided costs in pumping (€/year)	Avoided costs in treatment (€/year)	Travel costs	Studies costs
Water for drinking purposes	22,341 (Aigües de Barcelona) 1,445 (Aigües del Prat)	33,816 + 10,800 (Aigües del Prat)		
Water for non drinking purposes	4,585 (Beverages company) 1,346 Other industries	112,016 + 87,385 (Beverage company) 52,000 + 40,000 (other industries)		
	-8,770 (costs of pumping out water in underground structures)			
Storage of groundwater		3,5 million		
Cultural services (scientific, educational and Experiential use of plants, animals and land-/seascapes in different environmental settings)			412 (Technical visits) 1,536 (experiencers and viewers)	50,408 (PhD studies) 433,215 (research projects)
TOTAL = 4,341,189	**19,601**	**3,836,017**	**1,948**	**483,623**

In summary, Table 20, shows that the total of savings are higher than 4.3 millions of €. The most influencing parameter is the ESS storage of groundwater, because if the system had enough groundwater to be supplied in periods of drought, the desalinization plant would not have been necessary.

Intermediate ESS

In this study case we identified only one intermediate ESS which is the additional treatment that the aquifer offers.

Table 21: Intermediate ESS

Section	Division	Group	Class	Class type
Regulation & Maintenance	Mediation of waste, toxics and other nuisances	Mediation by biota	Filtration/sequestration/storage/accumulation by micro-organisms, algae, plants, and animals	By amount, type, use, media (land, soil, freshwater, marine)
Examples				
Biological filtration/sequestration/storage/accumulation of pollutants in land/soil, freshwater and marine biota, adsorption and binding of heavy metals and organic compounds in biota				

This ESS as it has been explained before, cannot be related directly with a beneficiary as depends on the injection water and on the implementer. This intermediate ESS can become final if the implementer obtains some benefit from the injection of non-potable water. This can happens if the implementer can save some treatment that is nowadays applied. At the present stage, there is not a direct beneficiary of this ESS and it is out of scope of this report to evaluate future changes in water management that could bring additional benefits.

PART V – Sustainability Assessment

Step A: Definition of the assessment and decision case

This sustainability assessment (SA) follows the ESS analysis conducted in the Llobregat Demo case with the deep injection of 15 Hm^3/y in the aquifer. The SA allows to widen the analysis, putting the evaluated changes in ESS into perspective by considering multiple dimensions. These multiple dimensions include wider social, environmental, financial, governmental, and asset performance aspects of the examined solution. This allows for the consideration of potential disadvantages like costs and environmental effects and their comparison with the advantages in terms of benefits expected from implementing the solution (Figure 22).

The SA uses different indicators to compare results. In this report the two compared cases are the status with or without the implementation of deep aquifer recharge. This analysis takes place in the Vall Baixa of Llobregat Delta.

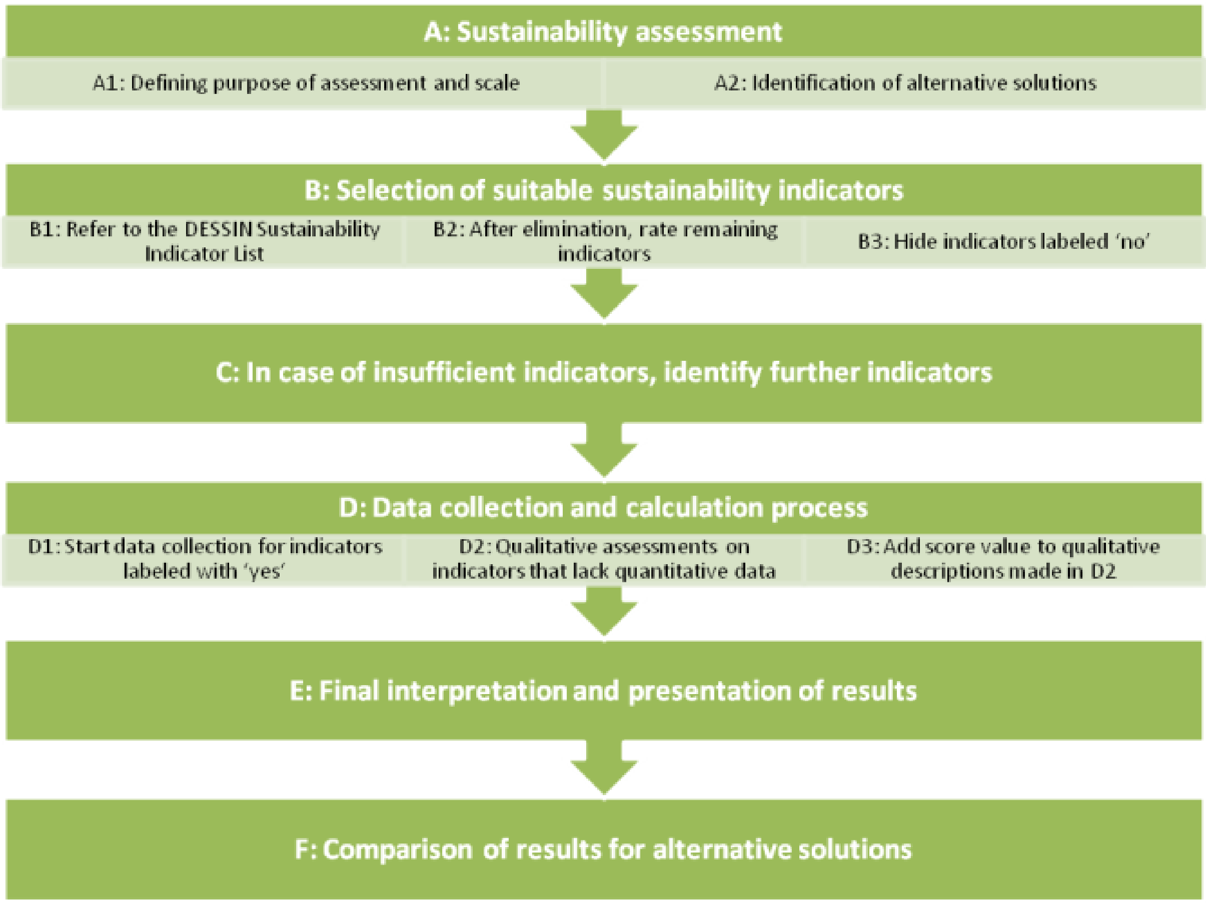


Figure 22: Procedures for SA conduction (Source: deliverable 11.2)

Step B: Selection of indicators

The sustainability indicators for each sustainability dimension are identified according to the list developed in DESSIN project as indicated in Figure 22.

Social

The social dimension covers effects of the solution on society and how it influences the quality of life.

It was found that the deep aquifer recharge does not involve significant changes in job creation and social equity. Instead, in the criteria of health and safety, MAR will change the presence of toxic chemicals (S113). The technology would have also a relevant economic impact (more than 3 million €) (S121) and the cultural services will be enhanced but to a lesser extent.

The numerical model (and studies developed in other sites) shows that the recharge of groundwater with river water can reduce some contaminants nowadays present in the aquifer as the salinity or organic compounds in less extent. The salinity is reduced from a 20% to 60% depending on the distance to the injection area.

From the impact II assessment, the economic savings for water provisioning services have been estimated. These values come from the energy savings in water pumping and in water treatment as well as in water treatment equipment. The groundwater level will be closer to the surface and thus the energy for pumping will be considerably lower. If salinity and contaminants are reduced, then the energy and equipment for treatment can be cheaper. Additionally, the increase of stored water would make unnecessary the desalination plant which was built for water supply during scarce water periods.

On the other side, the increase of water levels will increase the discharge and outputs to underground structures. This water will have to be pumped out of the tunnels or parkings, which is a negative side effect for the population. But this water can be also used for environmental purposes, regenerated or returned to the aquifer downstream.

Similarly, impact II assessment has estimated the annual value of the cultural services. These are economically much lower than those described before but they will have a more impact on the population, as this is something that most people can visit. The increase of water level in coastal wetlands can enhance and increase the visitors to this area. A survey conducted among the local population (see following chapter) showed that people really appreciate the changes in the environment conducted in the last years, and a high percentage enjoy walking in that area.

Environmental dimension

The environmental dimension of MAR consists mainly in local change of water quality. The situation modelled in this case is the increase of water resources but not the increase in abstractions and hence, there is not an increase in groundwater resources availability for pumping.

The indicators to be considered here are the efficiency use of energy (En124) and the efficient use of materials and consumables (En 131). It has been described that the increase of water levels will decrease the energy needed for pumping. On the other side, the decrease of salinity will decrease the energy required for reverse osmosis systems and, at the same time, the materials of the water treatment, the membranes, could have a lower cost.

Financial dimension

The financial dimension is the total cost of the implementation of this system. This cost if different if new wells have to be constructed or if it is only necessary to adapt the present wells. Nowadays Aigües de Barcelona counts with several wells ready for injection but these are not prepared to inject pre-potable water. This investment cost depends on the typology of injecting water and the wells to be used.

The cost of the deep injection was calculated as 0.09 €/m^3 (Mesa, 2014). By injecting 15 Hm^3/y, the total cost of the system would be 1.3 M€.

Governance

In this dimension, compliance with European and national legislation of water recharge, groundwater and water reuse is ensured. The stakeholders' involvement it is not expected to change with the measure implementation as other recharge activities are being conducted in this area.

Assets dimension

By implementing the MAR with deep injection some additional assets have to be considered. These are not very relevant as few indicators are expected to be different before and after of the technology implementation.

The available data allows estimating that the expected lifetime (with a correct maintenance activities) is 20 years.

Step C: Indicators

Sustainability indicators have been quantified in previous chapters.

Table 22: Data derived from SA

SA metric /indicators	DESSIN ESS	unit	before	after	Comments
S113	Water for drinking and non drinking purposes	Mg/L Cl	400-1000	200-600	This value is very variable and depends on the location and distance to the injection point
S121	Economic impact creation	€	0	20.000	Only cultural economic services approach
En124	Efficiency in energy consumed	€		-20,000	The initial consume of energy is a private information of local water user's
En121	Efficiency in the use of materials	€		-300,000	

PART VI – Payment for ecosystem services

6.1 Introduction

This report describe different kinds of services that contribute to human wellbeing or system regulation.

Sustainability assessment has pointed out the environmental aspects of the measure considering the life cycle assessment.

One of the mechanisms that can better recognise the value of ecosystem services is the Payment for Ecosystem Services (PES). PES can be defined within market-based approaches as PES help to link up those services supplied by the ecosystem and those benefiting from the same ecosystem services. Therefore, it is necessary to identify "beneficiaries" and "suppliers".

The PES approach recognises the important role that the environment plays in contributing to human wellbeing and economic prosperity, and the potential of market-based approaches to promote conservation and address environment-related market failures. In most PES schemes, people managing and using natural resources, are paid to manage their resources and to protect the ecosystem status. In doing so, PES compensates the owners and/or managers of ecosystem services for the positive externalities (Engel et al., 2008). There are different approaches for these payments. These can be made by the beneficiaries of the environmental services, such as, for example, water users and hydropower companies. This is possible when users are associated or where there are big water users. In other cases, national or local governments pay on behalf of their citizens, who are indirect beneficiaries (IIED, 2017). The role of the private sector is typically growing among PES schemes at both international and local levels. But the role of the government or public institutions is crucial to ensure the engagement of this private sector. Consequently PES can only be effective under certain social and institutional circumstances and therefore should not be regarded as a panacea or a blueprint for environmental conservation (McCauley, 2006). When the obstacle for the provision of ecosystem services is mostly economic and other institutional, social or political barriers do not act as an impediment for environmental conservation, PES can be both efficient and successful in achieving their stated goals. (Russi et al., 2011)

There are however many open questions with regard to the scope of PES, their cost-effectiveness in addressing the growing global challenges of climate change and food security, and the theoretical baseline assumptions, largely derived from neoclassical economics.

The answers to such questions can often be found in lessons learned from existing projects, and they have to be taken into account in future designs of PES schemes.

6.2 PES experiences

Private and public sector PES implementation models emerge, co-exist and cooperate worldwide. Private PES are usually negotiated and customized to local conditions, including so that ES buyers can directly sanction any non-compliance by ES providers (Sattler and Matzdorf, 2013). In publicly financed PES, the service buyers are a third party, typically a local or national governments act to congregate Ecosystem Services user interests by levying taxes or fees on end users or tax payers and earmarking revenues for conditional payments to ES providers (Dobbs and Pretty, 2008; Norgaard, 2010; Tuner and Daily, 2008). User-financed programs are fully voluntary for both ES providers and users. In contrast, government financed programs are typically only voluntary on the provider side (Wunder et al., 2008). There are also less cases of public-private PES hybrids with sequential sector leadership and some municipal local-scale PES (e.g. watershed schemes).

More than 300 PES schemes have been inventoried in the world. Most of them are recentor have been running for a few years only, and several PES schemes remain experimental in scope or are still in their pilot phase. Ezzine et al. (2016) analysed the different types of existing PES. While hundreds of PES schemes are reported loosely upon in the literature, most contributions do not provide sufficient in-depth information to be useful for quantitative analysis. This study found 584 of which they select 55 cases with enough data to be analysed. This chosen 55 PES are mapped in Figure 23.

Figure 23: Location of selected PES (Ezzine et al., 2016)

Industrialised countries have less PES cases, though some are huge government schemes that outsize small-scale initiatives by orders of magnitude. Instead, PES are more frequent in countries with emerging economies, especially Latin America. Among different types of PES, the most frequent are the payments for the protection and restoration of watersheds (water) and for and for multiple services from agriculturally dominated systems. Other PES are payments for biodiversity conservation and for climate change mitigation through carbon sequestration or avoided deforestation (Figure 23). Few PES schemes in developing countries aim to reduce tropical deforestation per se (Valatin and Coull, 2008). PES schemes encompassing multiple ecosystem services are rare (Costa Rica and US –Oregon-)

The same study identified substantial differences between the characteristics of public vs. privately funded PES schemes and these can be categorized geographically. In Latin America most of the cases (65%) are publicly funded cases but display a large variety of arrangements. Europe, North America and Asia present a slightly higher frequency of publicly funded PES (70%). In Africa, privately funded schemes clearly predominate (85%). Half of these private schemes are run by the private commercial sector, especially for eco-tourism and wildlife. It also has to be taken into account that public schemes feature larger in area and are more costly schemes. Public sector PES participation is high in Europe and Asia due to its tradition for public-sector environmental management. Instead, public participation is yet very low in Sub-Saharan Africa, where public sector institutions have lower capacity to organize PES schemes.

6.2 PES examples in water

Following, some examples of water PES in Europe are detailed.

Case study: Romagna Acque S.p.a.

This is one of the most developed PES in Europe. Romagna Acque S.p.a. is a consortium of municipalities which manages water resources in the Romagna area of north-east Italy, transferring tap water from the Apennines to cities along the coast. The most important water source of the company is a dam-basin in the central Apennines (Ridracoli, municipality of Bagno di Romagna), which covers 50% of the entire Romagna tap-water demand (108 M m^3/year).

In 1993, the company invested in research to understand the link between forest management and soil erosion as well as water quality stabilization.

One of the problems of the basin is the soil erosion. Romagna Acque Spa conducted a study that concluded that the soil erosion could be reduced with certain forest management practices resulting in an overall benefit of 10,000m^3/year in terms of avoided soil erosion (originally 42,000m3/year), besides improving water quality.

In 2001, a PES was implemented with the aim to preserve the forest management practices. Forest owners were encouraged (public and private) to adopt these forest management practices. The initial payment amount was around 200 €/ha decreasing to 100 €/ha after a couple of years, corresponding to 7% and 3% of the water bill revenues. Today, almost all the surface of the catchment area (5,200 ha) is covered by the scheme, which involves the majority of forest owners in the region. It generates an annual monetary flow of 0.5 – 1M€.

In terms of performance both Romagna Acque S.p.A. and the landowners have increased their utility: the company has reduced its costs for water purification and assured longer dam life, while the landowners have increased or maintained their annual forest revenue.

Case study: Piedmont (Pettenella, 2012)

Piedmont Region (Regional Act 13/1997, art. 14) built up a structural fund with 3-8% of extra-charge on water bills to compensate mountain areas in terms of projects or infrastructure aimed to improve local land management practices.

Case study: Vittel (Pettenella, 2012)

Vittel (Nestlé Waters) is located in north-eastern France. In order to address the risk of nitrate contamination in the aquifer caused by agricultural intensification, the world leader in the mineral water bottling business is financing farmers in the catchment to change their farming practices and technology.

Water comes from a 6,000 ha aquifer 80m below ground and is lifted naturally to the surface through a natural geological fault (Perrot-Maitre, 2006).

In 1988, Vittel proposed to farmers with land in the protection perimeter that they transform their land into grassland, a solution outlined by a group of experts in the French Committee for the Reduction of Water Pollution by Nitrates. Farmers felt the proposal was not adapted to their production system and rejected it (Déprés et al. 2005). Only one alternative was left: to convince farmers to change their farming practices, and develop a system of incentives attractive enough for them to want to do so.

Case study: Veneto region (Pettenella, 2012)

The Veneto Regional Decree no. 3483 of 10th December 2010 set up a financial tool for mountain areas (3% of the water bill) partially covering the costs of new hydraulic infrastructure or forest operations close to areas of slope instability, in order to protect the downstream population.

Case Study: Other Mineral water supply

Italy has been one of the first five consumers of bottled mineral water in the world since 2002. This is an important market in Italy and since the 1980s bottled water has been promoted by several industries due also to the introduction of new plastic polymers like polyethylene terephthalate (PET) instead of the traditional glass.

Bottled water production is a concession-based business where a given company applies for the extraction license of a particular spring. The fee considers the compensation to the local municipality for the land that is covered by the mineral water plant and a general production fee based on the water extracted in the power plant, but no compensation is addressed by law to the surrounding catchment areas.

Two singular cases in Italy involve two Nestlé-controlled water companies: Levissima, which is using large plastic sheets during summer time to reduce the glacier melting in its Alpine catchment area; and Acqua

Panna, which is promoting natural evolution of forestland to enhance biodiversity around the spring. Unfortunately, specific data and reports are lacking, and information is still incomplete.

Case Study: Others

An historical example is the payment mechanism promoted by the New York City Council to enhance water quality, compensating landowners in the catchment area when they improve their management practices (NYC-DEP, 2010). Several public authorities in France have also encouraged the production of forest drinking water by drafting a similar compensation scheme.

6.3 Lessons learned

Nowadays a multiplicity of models coexists and no single one has so far emerged as a standard. Moreover, PES schemes are usually adapted to the very specific conditions under which they are established and to the specific characteristics of Markets for different environmental services.

The United Nations Environment Programme (UNEP) breaks the implementation of PES schemes into different points (PACE, 2011).

1) Identifying ecosystem service prospects and potential buyers or sellers.

The first step in preparing a PES scheme is to identify what ecosystem service you wish to buy or sell.

Once an ecosystem service and potential buyers and sellers have been identified, negotiations over price can begin. Furthermore, it is crucial that payments actually result in an improvement of the ecosystem service and it is therefore necessary to ensure the ecosystem service will be monitored.

Given PES are voluntary, service providers may offer land areas where no real environmental threats exist. It is important to develop a spatially explicit baseline – where environmental threats or opportunities for improvement in the absence of PES would occur – and to spatially target PES using that baseline to achieve additionality. Many environmental services are unevenly distributed in the landscape (e.g., watershed protection demand near large cities). It is important to map their supply and demand, and target high priority areas for PES inclusion.

Service provision costs can vary dramatically across resource owners, as some areas are much more valuable for alternative uses. Paying all service providers the same per-hectare rate may exclude resource owners with high opportunity costs, so PES rates could be customized.

2) Assess Institutional and Technical Capacity. Secondly, it is necessary to check the legal context of the proposed PES deal.

3) Structure Agreements. The structuring of agreements may take time, but it is important to ensure both parties (landowner and ecosystem service buyer) understand the terms of the agreement.

4) Implement the PES agreement. The monitoring is essential during the implementation. Some PES schemes lack adequate monitoring and sanctions, resulting in reduced compliance and low

additionality. Compliance to land-use management changes and also actual service(s) provision should be assessed, to be able to claim that the programmes are effective.

5) Ensure institutional coordination of policies It is crucial that all institutions involved in the implementation of PES components like financing, contracting and monitoring are coordinated. Government involvement is often necessary to guarantee PES objectives are not compromised by contradictory policies.

6) Limit transaction costs. These include set-up, communication, negotiation, monitoring and enforcement costs, and all other costs beyond the actual payments. High transaction costs may reduce the budget available for paying for service provision. Innovative technologies like remote sensing technology for monitoring, sanctioning systems to enhance compliance, bundling or layering of ecosystem services, broker-based exchange mechanisms, or building on existing community development programmes can reduce costs.

However, PES schemes may not constitute a cost-optimal instrument in all circumstances. Indeed, their success depends in great part on preexisting conditions. PES systems work best when services are visible and beneficiaries are well organized, and when land user communities are well structured, have clear and secure property rights, strong legal frameworks, and are relatively wealthy or have access to resources (Mayrand, 2006). Local, regional or national governments play essential roles in promoting a more effective system based on defined, defendable and divestible economic property rights as well as embodying supply-demand coordination.

6.4 Spanish regulation framework

In Spain there are very few cases of PES systems and most of them are related to forests or, to a lesser extent, to wetlands. The PES schemes in Spain have been developed in the national legislative framework on the basis of the principle of keeping the ownership of the resources in public hands.

The regulation of environmental services through tools and legal mechanisms in Catalonia could be regulated by multiple ways. Spanish law 42/2007, of natural heritage and biodiversity, specifically the article number 73, mentions the need to find mechanisms and policies to encourage positive externalities in conservation, restoration and improvement the natural, fixing carbon dioxide, soil conservation and hydrological regime and groundwater recharge. This article refers to “environmental services” and the possible compensation (it does not refer specifically to PES but can be interpreted like this).

Catalan law 8/2005, of protection, management and planning of the landscape, provides a fund or the protection, management and planning of landscape, specifically in article number 16. Hence, this funds could finance PES programs.

The programs of measures to be elaborated with the implementation of the Water Framework Directive (2000/60/CE) can be considered the main mechanisms for the implementation of the environmental objectives of WFD. The EU Water Framework Directive (WFD - Directive 60/ 2000) enforced a regulatory system of the entire water cycle, especially in terms of water quality maintenance. This issue has been considered in national legislation affirming that (i) the “full-cost-recovery principle”; (ii) “polluter-pays-principle”; and (iii) “access-right-guarantee principle”. The “full-recovery-cost” key-concept has been an important step to recognize the role and costs of ES on water supply quality, recently withdrawn in a national referendum.

Therefore, the existing legal framework provides regulatory pathways for the management of environmental services. But do not exists a specific legislation for PES practices.

6.5 Deep recharge case

To evaluate the PES in the Llobregat case, as it has been mentioned, it is very important to identify ecosystem service prospects and potential buyers or sellers.

In this case for one side there is the implementer of the measure. This can be the Water Administration Agency (as happened with other recharge facilities of the area) or the water utility (which will ask to the water administration for economic support). These kind of activities, to be funded by public investment, need to have a public service.

The implementer of the measure will be the entity (water agency or water utility) who will put more water in the system and therefore, the seller of this water.

The injection will increase the water storage in the aquifer, the water levels and the water quality.

The main beneficiary of the water storage is the water administration itself as it is the final responsible one for ensuring water supply to the population. Nevertheless, water administration paid the construction of the desalinization plant to have enough water volume available in case of drought. Therefore, the supply of the demand is a need that was already paid by public funds (Spanish and European).

The improvement of water quality and the increase of water levels will be to the benefit of industrial users and water utilities. The monetization of ESS has shown that Aigües del Prat would have savings around 45,000 €/year, Aigües de Barcelona of 22,000 and all industries together around 300,000 €. As there are direct beneficiaries of the measure, these can become buyers of the improvements (for each volume of water).

To find buyers for Cultural and environmental services is more difficult. The experiencer's and visitors of the site are not paying anything right now to visit the wetlands. The beneficiaries of the improvement of these area are the visitors and also the local inhabitants in general. The same can be applied to the students and researchers. In fact, the public administration is, at the end, a beneficiary of the research studies in the site.

Table 23: ESS, beneficiaries, potential buyers and sellers

ESS	Beneficiaries	Potential buyers	Potential sellers
Water suitable for being treated in water utilities	Drinking water treatment plant operators Water utilities Researchers	Water utilities Water administration	Water administration
Water suitable for industrial processes	Industrial processors Researchers	Industrial processors Water administration	Water administration
Landscape and sounds that provides sensory experience; opportunity to view the environment and organisms	Experiencers and viewers	Water administration	Water administration
Research opportunities	Researchers	Water administration	Water administration
Students formation	Students	Water administration	Water administration
Storage of groundwater in an aquifer as a reservoir	Water administration		Water administration
Groundwater purification during aquifer passage (organic pollutants, N retention rate, pesticides, pharmaceuticals)	Intermediate ESS	Water utilities	Water administration

6.6 Willingness to pay

In order to evaluate the willingness to pay of the local population for having a cleaner river, a nicer coastal area, a bigger wetlands etc., a specific survey was conducted.

The first task was to elaborate the stakeholders map. This map included 165 actors (Figure 24):

- 11 council towns
- 7 water utilities

- 16 industries
- 10 agricultural associations
- 21 environmental associations
- 100 cultural and neighbourhood associations

All these stakeholders were contacted at least by email informing about the project and the survey.

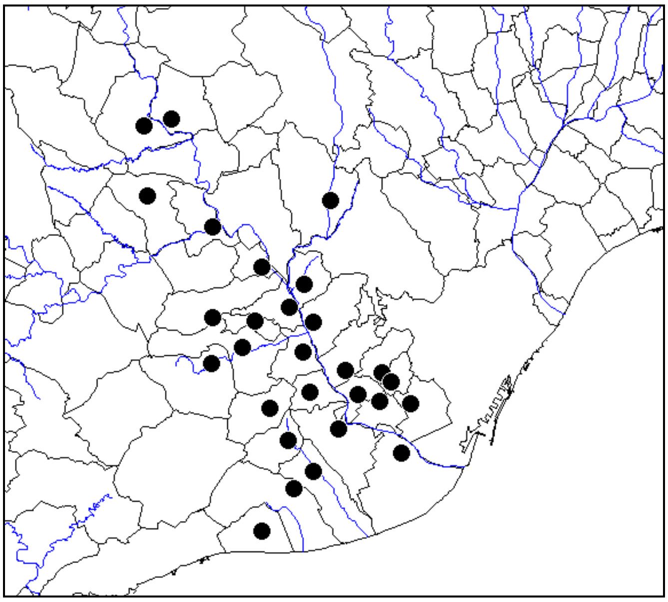


Figure 24: Distribution of local actors

The survey was conducted in 3 ways:

- Web survey: an on-line questionnaire was designed (in Spanish) with an easy interface of the Google Platform (Figure 25).

- Semi structured interviews. Several questionnaires were filled by face-to-face interviews with local inhabitants of El Prat de Llobregat.

- Paper interviews distributed to all attendants to technical water events in Catalonia.

Some of the questions were closed with tabulated answers while others were open to allow additional comments and opinions. The questionnaire included a total of 24 questions.

Figure 25: Screen capture of on-line **questionnaire** first page

The questionnaire asked firstly about the person (age, gender, formation and location) and then about the level of knowledge on delta water management and ecosystem characteristics. There are also some questions regarding the environmental evolution of the delta in the recent years. Finally, when the interviewee has analysed all the good and bad environmental aspects of the delta, he/she was asked about the willingness to pay for having a good status of the resources.

In total, 110 surveys were conducted. Most of the people were of middle age, from 25 to 45 years and of higher education (Figure 28). This is due to the fact that several questionnaires were filled-in during technical workshops. 61% of the answers are from people that live or work in the Llobregat delta.

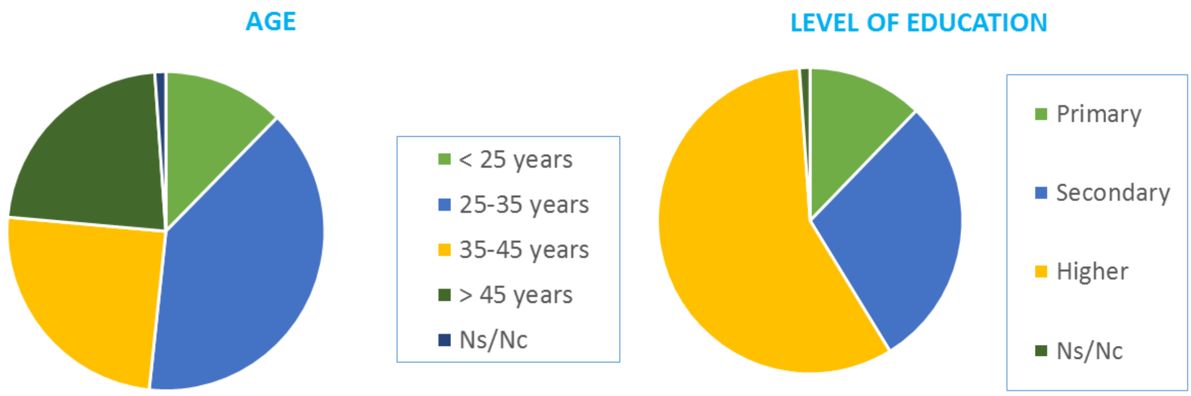


Figure 26: Age and level of education of interviewed people

People were asked from one side about their knowledge of water supply precedence. Most of them affirmed to know the origin but when they had to answer about these water origins most of them failed and were forgetting, in most of the cases, groundwater.

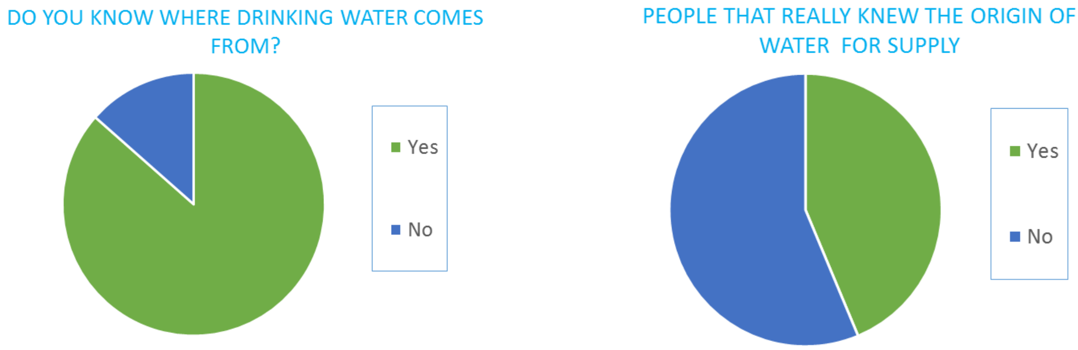


Figure 27: Answers to water supply origin

Half of the people that live or work in the study area drink tap water. This means that there is a still long way to convince people that tap water is safe. Regarding the environmental status of the area, around 75% of the interviewed people agreed that during the last 10 years the environment has improved noticeably (Figure 28). The list of the best aspects of the present delta was large but most of them include the beach and the landscape in general. The most appreciated activities of the area were walking, birdwatching and biking.

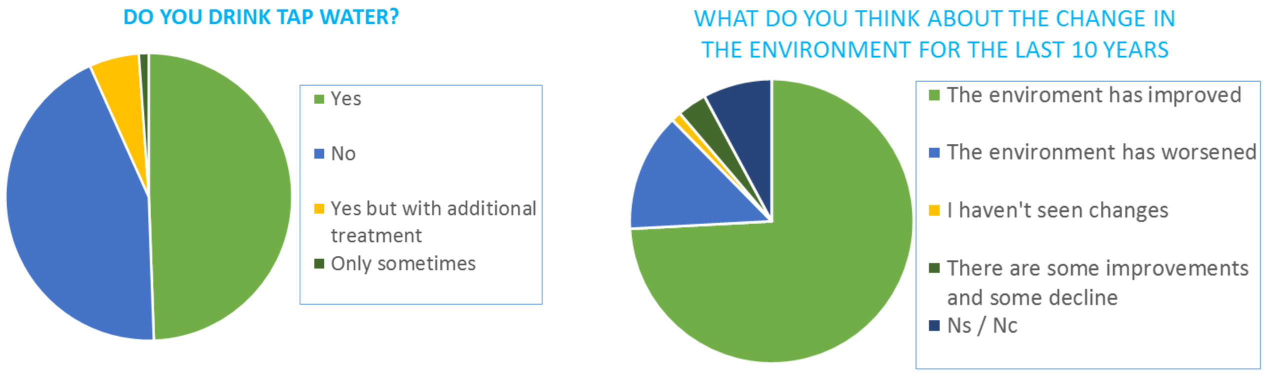


Figure 28: Answers to environment conditions

Finally the questionnaire asked about who should pay the delta aquifer restoration. About 65% of the people agreed that the regional administration (not the local one) should pay for it but in second term, people answered that also local industries that use water should pay for the restoration of the aquifer. Finally, they were asked about the amount they think that the bill could increase to pay the environmental restoration. Just few people replied 0 €, only 9%, and all these persons were those with a lower level of education. 32% of the people thought that an annual increase of between 1 and 6 € in the bill would be fair and 31% increased this amount to 12€. Around 17% of the persons mentioned that they would pay an increase of between 13 and 24 €.

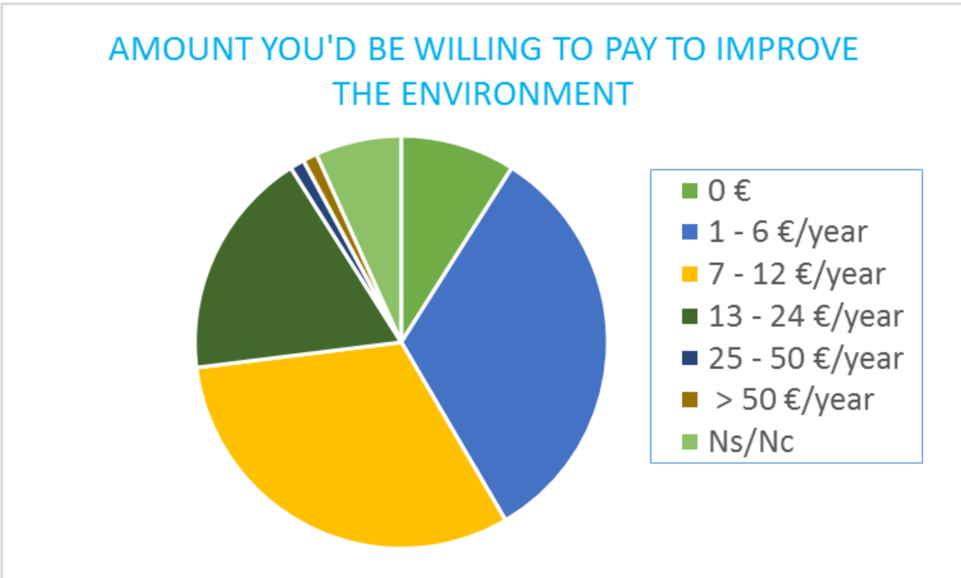


Figure 29: Answers to the amount that one would pay

6.2 Conclusions

In general and independent of the particular context and the targeted ecosystem service(s), an effective PES project needs to have all the information on the table from the beginning to establish clear rules for all actors. Additionally, these projects have to be based on incentives that help to better align the private interests of the local actors with the general public interest of preserving the environment while increasing food security. This is often achieved through public private partnerships that result in innovative practices, institutions and products that make PES schemes financially sustainable and generate positive externalities on their own.

PES schemes requires the consideration of scientific but also social, economic, political, institutional, and power relationships (Perrot, 2006).

Estimating costs and benefits of PES is not always possible. Not all information is public knowledge, and costs are not broken down in a way that allows the separation of costs associated with the PES scheme from others.

Although most of PES conditions are more likely to be found in industrialized countries (Nestlé Waters has used a similar approach with Perrier and Contrex in France), it could be applicable to a developing country context and, in fact, there are more PES in developing countries rather than in industrial ones.

Finally, the study clearly concludes that there is a strong business case for private sector participation in water-related PES (particularly in terms of water quality, as the link with ecosystem protection is more easily demonstrated than is the case for water quantity). Care needs to be taken in order to ensure that PES does not lead to a de facto privatization of the water resource. But the participation of each sector will depend on the type of ecosystem services previously identified. In case of environmental services administration will have an important role in the scheme.

As it has been shown, Llobregat Delta has an evident problem of water supply during drought periods. Water administration has develop different solutions such as the construction of a desalinization plant. Present research in other water managing strategies such as MAR is evaluating the feasibility of using these more natural solutions to restore water environments. Additionally to technical benefits of this technology, the ESS approach developed in DESSIN project has put the numbers on the table to show the savings that the deep recharge would bring in economic terms. The savings are important and relevant both for private water users and for the administration. Nevertheless, some of water supply measures have been already implemented by the administration and the economical inversion has been done. But the results of this project can be also applied or used in other areas with similar problems and where are in phase of solution evaluations, as is happening in other areas of Catalonia.

The PES scheme in this area would need a public finance as there are public benefits related with the implementation of the measure.

Ecosystem services approach is a god tool to evaluate the beneficiaries and the savings from another point of view taking into account local population and environmental solutions. The survey conducted with local inhabitants has shown that there is an important percentage of people that would understand a reasonable increase in their annual bill to pay for a better local environment.

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