

Workshop on Artificial Groundwater Recharge in the Júcar River Basin District

The workshop was held within the framework of the European research project **AGREEMAR** on Managed Aquifer Recharge (**MAR**), in which the Water Resources Engineering Group (**GIRH**) of the Institute of Water Engineering and Environment (**IIAMA**) of the Technical University of Valencia (**UPV**) participates.

The workshop's main objective was to discuss the complex aspects of groundwater recharge (technical and non-technical) and their influence on the implementation of MAR in the Júcar Hydrographic District (**DHJ**), which is one of the four case studies of the AGREEMAR project. Different aspects of the ongoing MAR actions in the DHJ were highlighted with special emphasis on the non-technical aspects that affect the sustainability of their implementation: Belcaire pond, Algar dam (Palancia), and other cases in the DHJ.

The workshop began with a welcome speech delivered by **Joaquín Andreu** (GIRH, IIAMA (UPV)), in which he addressed different topics such as the importance of the joint use of surface and groundwater resources along with artificial recharge in the world in general and in Spain in particular. He also presented the AGREEMAR project and its main targets.

Immediately afterward, the participants presented a first round of talks regarding their vision for MAR.

In the following table, a summary of the different important points discussed by each participant will be presented.

Participant	Vision
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<p>Marc García The water commissar of the Júcar River Basin Agency (CHJ)</p>	<ul style="list-style-type: none"> - Any use of water requires authorization as much as any discharge does - Up to now, there is no legislation to regulate the artificial recharge of groundwater. - In the Júcar's district, there are only two experiences of artificial recharge, which are the one of Belcaire pond and the other one of the Algar reservoir. - It is necessary to reinforce the legislation in terms of artificial recharge of the groundwater. <p>One of the decisions that the CHJ is about to make now is to take out wells and try to use other water sources.</p>
<p>Manuel Torán The technical director of the Júcar River Basin Agency (CHJ)</p>	<p>Mainly he talked about the Algar reservoir (6hm³)</p> <ul style="list-style-type: none"> - The main objectives of the Algar reservoir are the increase of surface resources, recharge of aquifers, reduction of groundwater withdrawals, and flood control - The high rates of infiltration have turned the real purpose of the Algar reservoir into recharge of the Algar-Quart aquifer, but one of the main problems faced in groundwater recharge was the lack of data about the aquifers. - According to the hydrological report on aquifer recharge induced by the Algar dam and proposal for a monitoring plan for this recharge (July 2019), the main conclusions were as follows: <ul style="list-style-type: none"> • Infiltration in the Algar reservoir cannot be accurately determined, since for that all the input data and the corresponding output data would have to be accurate, which are highly uncertain, especially in the calculation of lateral transfers between aquifers. • The increase in infiltration into the aquifer is manifested in three fundamental aspects. The guarantee of water resources for users by correcting the temporary overexploitation, the improvement of the energy cost in the exploitation of groundwater by having higher piezometries in the aquifer for some time



and the increase in the availability of water in the Quart Spring.

- For the observation period from 1/04/2012 to 1/07/2019 the average infiltration flow in the reservoir basin was estimated at a value close to $0.57 \text{ m}^3/\text{s}$, although peak values have been reached that have produced periods of filling in the reservoir. This means an average supply to the aquifer by infiltration into the reservoir of 17.94 hm^3 .

- Due to the structural arrangement of the aquifer (does not have areas in which to store the hyper-annual water surpluses), the extraordinary infiltration contributions from the reservoir will correct the effects of overexploitation that may have occurred and will be drained off through the source of Quart after remaining in the aquifer for a certain period of time.

- The proposed measures for monitoring the recharge induced by the Algar reservoir are the following:

- Build a gauging station in the Regajo-Algar region to measure the inflows from the Palancia river to Algar reservoir outside the area of influence of the reservoir.

- Establish two gauging stations on the Palancia river, downstream of the dam. One immediately downstream and the other at Estivella. The differential measurements will make it possible to determine precisely in which sectors of this section of the riverbed infiltration occurs.

- It is recommended that infiltration tests be carried out periodically, with a duration of 48 hours, for different levels of the water level in the reservoir.

- The third component of the discharge is constituted by the subway transfers to nearby aquifers, which represents a total annual average value of 5.3% of the discharge, and has been estimated for the average year at $1.25 \text{ hm}^3/\text{year}$.



	<ul style="list-style-type: none"> - The technical direction of the CHJ is trying to follow a strategy of not using groundwater.
<p>•Arancha Fidalgo The head of the hydrological planning office of the CHJ</p>	<p>She mainly talked about the different experiences of groundwater recharge in Spain in general and the one of Belcaire pond and Algar reservoir in particular. She also presented the groundwater action plan (objective, guidelines, considerations..).</p> <ul style="list-style-type: none"> - In the DHJ, there is an implementation of recharge in the Medio Palancia mass through the replacement of the Sagunto irrigation channel. - The main actions that need to be considered in the groundwater plan are improving the knowledge about groundwater recharge, implementation of assessment programs, groundwater protection, governance, and legislation. <p>* Artificial recharge of the La Rambleta aquifer, Belcaire Pond:</p> <ul style="list-style-type: none"> - This aquifer is located in the southern zone of the groundwater body Plana de Castellón and is subject to very intense groundwater exploitation for urban uses (municipalities of Nules, Moncofar and Vall d'Uixó) and for irrigation (agricultural areas of Vall d'Uixó and Moncófar). - The major problem facing this area is the lowering of piezometric levels and reduction in the volume of groundwater discharges to the sea as well as anthropogenic seawater intrusion pressure. There is also an increase in the level of chlorides, especially in the parts that experience more marine intrusion. <p>* Artificial recharge by means of the Algar dam:</p> <ul style="list-style-type: none"> - The Algar dam is located on the Palancia river. Its objectives are the induced recharge of the Mesozoic aquifers that feed the coastal plain of Sagunto, and the improvement of river regulation for irrigation and flood control.



	<p>- The Impressions of several agricultural users on the filling of the Algar reservoir indicate that the reservoir fulfills the main purpose for which it was built: the artificial recharge of the aquifers of the region.</p> <p>-The CHJ currently monitors the water level in 23 control points downstream of the Algar reservoir. Most of these points are wells for agricultural supply:</p> <ul style="list-style-type: none"> • At control points located downstream of the reservoir and near the Palancia river bed, there is a very fast aquifer response to reservoir filling as well as piezometric level variations of over 60m. • For the monitoring points farthest from the reservoir and the river. There is a less marked but apparently existing relationship with less rapid aquifer response to reservoir filling in the absence of rainfall. With rainfall, there is faster response. • At the control points around the Quart Spring, there is a time lag comparing the level of water in the reservoir and in the control point. There is a water level variation of no more than 10 meters. • At the Control points far away from the reservoir, it exists relationship with aquifer response lagged in the absence of rainfall and lagged with respect to reservoir filling. There is also a shallow piezometric level variation.
<p>Bruno Ballesteros Head of the Valencia Territorial Unit of the Spanish Geological and Mining Institute (IGME).</p>	<p>He talked about water resources that can be used for artificial recharge of aquifers.</p> <ul style="list-style-type: none"> - There is two types of aquifer recharge: <ul style="list-style-type: none"> • Managed aquifer recharge (MAR): It's an intentional recharge of water to aquifers for subsequent recovery or environmental benefit. • Supervened (surplus) aquifer recharge (SAR): It is an artificial introduction of water into an aquifer caused by actions that are not intended to contribute to its recharge.



	<ul style="list-style-type: none"> - The most important elements in terms of aquifer recharge are water resources/recharge technique and types of aquifers. - The conditions and requirements for efficient recharge are surplus resources and compatible quality. * Aquifer recharge with flood waters: → Belcaire pond: Recharge of 300000m³ during 6 months → Algar reservoir: The aquifer drains into the Font de Quart * Aquifer recharge with purified urban wastewater, ALBACETE: → Experience of canal María Cristina (10km): Estimated recharge: 14 hm³/year → Experience of Benitachell, Alicante * Rainwater recharge: → Manises experience: several 40 m deep recharge wells (4.4 ha surface area) * Natural infiltration: → Chiva experience → Barranco del Coscó. Jijona and barraanco de Fontilles. Orba <p>- Artificial recharge in Spain is the 5th hydrological revolution.</p>
<p>Fernando Juan Project Manager at ACUAMED</p>	<p>He addressed his talk to describe the experience of Belcaire pond.</p> <ul style="list-style-type: none"> - The Belcaire River drains a watershed of 96km². Its inputs are the Barranco de San José and the Rambla Cerverola. It has a base flow that can last up to 15 days. - Among the problems faced, are the irrigation areas of Castellon that present a high demand for water, advancement of the marine intrusion in the aquifer of the Rambleta, increase of the number of saline wells in the aquifer. - A diversion weir supplies the Belcaire pond. - The different phases of the Belcaire pond project:



- In 1998, the CHJ drafted the regulation works project for the recharge of the winter surplus of the Belcaire River and the Environmental Impact Assessment (EIA).
- In 2000, the Project and EIA are made public.
- In 2004, it is included in the PHN as a regulation for the recharge of the winter surplus of the Belcaire River and is declared priority and urgent. The direct management agreement was signed between ACUAMED and the Ministry.
- In 2005, the ministry classified the Belcaire pond in category A according to the potential risk derived from its possible breakdown.
- In **2006**, the Ministry approved the mandatory feasibility report with several conditions. ACUAMED and CHJ signed a collaboration agreement for financing and operation of works (recovery of costs, collection of the regulation fee, and operation of the works).
- Between **2007** and **2008**, ACUAMED executed the project (Total investment : 29.3 M€ with 8M€ of European Funds). In 2007, the ministry authorized the partial filling of the reservoir up to 58 m.a.s.l. until the implementation of the Emergency Plan.
- In 2010, the ministry approved the Emergency Plan.
- Between **2013** and **2014**, a pilot aquifer recharge test was carried out , (Geological and Mining Institute (IGME) and Jaume I university) with a recharge of 314,613m³, with an average flow of 21.46 l/s (a maximum of 34.30 l/s and a minimum of 18.04 l/s).
- In **2014**, Given the drought situation, the CGR of Vall d'Uixó requested provisional use of the pond volume for irrigation, which was authorized with a maximum volume of 420,000 m³.
- In **2015**, the implementation of the Emergency Plan was completed through the execution of a rupture drill,



and started the Commissioning Program after its approval by the ministry.

- In **2020**, the ministry approved the Belcaire pond Exploitation Rules. The emptying stage began up to 58 m.a.s.l. (Emptying in a balanced way in order to control the recharge and supply water to the irrigators.)

- **Volume to be emptied:** 1,526,766.68 m³
- **Maximum emptying speed in the commissioning program:** 1 m decrease in pond level every 2 days.
- **Minimum speed:** no limits.
- **Estimated rate of emptying of the pond with recharge:** 2 centimeters every two days.
- **Estimated emptying time with recharge:** 28 months.

➔ The CGR of Vall d'Uixó requested provisional authorization for the water supply of the pond during its emptying stage according to the Loading Program.

➔ ACUAMED requested authorization from the CHJ for the emptying of the reservoir by means of artificial recharge to the aquifer and simultaneous supply to the CGR. The joint supply is requested due to efficiency criteria, in order to minimize the time necessary for the completion of the Commissioning Program and commissioning of the works under normal operating conditions. It was estimated that the emptying time would be reduced by more than 50%.

➔ CHJ issued a resolution authorizing the provisional use requested by CGR for up to 12 months or exhaustion of the available volume, pending authorization for artificial recharge.

- Between **2020** and **2022**, the volume supplied to CGR Vall d'Uixó was 941,698.88 m³. The recharge volume through wells to aquifer was 0 m³, pending authorization.



	<ul style="list-style-type: none">• In the current situation, they are finalizing the emptying phase of the commissioning program:<ul style="list-style-type: none">- Level in the pond: 59.56 m.a.s.l.- Volume impounded: 674,996 m³- Volume available above 58 m.a.s.l. : 247 961,07 m³- CHJ's provisional authorization for the CGR has expired.
<p>Vicente Ambou, General Community of Irrigators of Vall d'Uixó</p>	<p>The subject discussed was the historical recharge of the Rambleta aquifer by irrigators and evaluations for the future.</p> <ul style="list-style-type: none">- The Rambleta aquifer has been significantly degraded relative to the rest of the water body due to salinization caused by seawater intrusion.- The process of seawater intrusion began in the 1950s and progressed inland, initially following the course of the Belcaire River, although it later spread to the entire aquifer. The main reason was the exploitation of groundwater for irrigation, due to their disconnection from the rivers Mijares and Palancia, although it has also been influenced by the draining of wetlands, the channeling of the last stretch of the Belcaire and extractions for the supply of the municipalities of Vall d'Uixó, Nules and Moncofar.- Historically, irrigation had taken advantage of the springs of the San José to supply the market gardening area and later it was diverted for storage in regulating ponds.- The salinity was reduced by the contributions of the recharge induced with the water of the source. The aquifer recharge also occurs naturally when there is heavy rainfall, although it does not recharge as much as it could due to the limited runoff from the Randero ravine.- The Department of Agriculture built two ponds for the use of treated water from the Vall d'Uixó



wastewater treatment plant. These ponds would also be used to store water from the source, of much better quality, and at the same time, the water was kept at a higher level.

- The water from the wastewater treatment plant was equally or more saline than the water for irrigation. Therefore, they tried to make the most of the water from the source, either to store it or to mix it with other water, so there was less surplus to be used for direct recharge.

- Some connections was executed between pipes of the irrigation entities and the ponds which resulted in the fact that all the water that could be stored not being extracted and the cost of pumping being saved.

- Limitations of the recharge include the water intake at the outlet of the spring, the small diameter of pipelines, tree roots clogging of pipelines, and even if a lot of water comes out, the flow that can be taken is reduced.

- The flow circulating in the Belcaire river do not allow direct recharge, but required the development of measures to adapt the rate of water recharge by means of temporary storage (Belcaire pond) and subsequent diversion to the recharge wells.

- The Belcaire pond has a capacity of 2 hm³, but in reality, it is not possible to take full advantage of this water because the last 10% of this water is always very turbid, explaining the fact that it cannot be used otherwise it will clog the pipes.

- The proposed future possibilities are the following:

- The improvement of joint management
- The use of a 700 mm pipe that runs along the riverbed and is no longer in use, which would allow a greater flow to be captured and at the same time used for two storage points.



	<ul style="list-style-type: none"> • Install a pumping system to give sufficient pressure to the water from the Belcaire pond and distribute it to the largest possible irrigation area, avoiding drawing from the aquifer. • Greater contributions of water from the Consortium, which would facilitate the capture of a greater volume of water from the source, as the concessionaire would not need to take it. • Water supplies from the Mijares river, establishing the appropriate Rules of Exploitation. • Improvement of the quality of the water of the municipal WWTP, to favor its use in more areas of the municipality. In case of discharge into watercourses, its filtrations will not damage the aquifer. • Conduct the discharges of the WWTP of Moncofar to the sea or to the artificial channel, so that the filtrations do not increase the salinity of the aquifer, due to its high content in salts. • Pumping to the sea from neighboring wetlands could be brought to recharge. <p style="text-align: center;">➔ It is recommended to combine aquifer recharge and water use at the same time.</p>
<p>Ignacio Morell, Jaime I university of Castellón</p>	<p>He discussed the artificial recharge (conventional water/ regenerated water) in general and the in the Júcar district in particular.</p> <ul style="list-style-type: none"> - The artificial recharge with conventional water in the Júcar district registers few experiences, good in some sectors but presents a low institutional enthusiasm - Water recovery project (WRP) was designed to face the effects of seawater intrusion. The aim was to recharge the coastal aquifers with regenerated water. - The artificial recharge system of Belcaire consists of a diversion weir, a storage pond, recharge wells, and interconnection pipes. The water used for the recharge



comes from the river Belcaire, whose excess is diverted through a weir to the storage pond. The water is then channeled to two recharge wells, called East Recharge and West Recharge.

→ The recharge was effective and triggered responses (hydrodynamic and hydrochemical) resulting in significant improvements in aquifer conditions:

- Immediate hydrodynamic effect of the recharge, very rapid piezometric rise (and fall) in 24h:

- At 80 m from the recharge wells, a maximum variation of 3 m was recorded
- Above 450m, no variation in piezometric level was observed

- The recharge experience has led to a notable improvement in groundwater quality, with significant decreases in salinity:

- At 80 m : from 3000 $\mu\text{S}/\text{cm}$ to 400-600 $\mu\text{S}/\text{cm}$
- At 450 m : from 3600 $\mu\text{S}/\text{cm}$ to 2350 $\mu\text{S}/\text{cm}$
- No change at distances above 1000 m

→ The problem of the Belcaire recharge system is that the recharge wells have been made improperly and inadequately located. So to improve the artificial recharge in this case it is necessary to dig better recharge wells in a more technical way that improves the recharge.

- Artificial recharge using regenerated water is very limited in Spain. There are some experiences like the one of Delta del Llobregat and the one of Menorca but it still remains very few.

- The problem of artificial recharge with regenerated water is the insidious pollutants and clogging. This technique allows to eliminate the discharges but presents a high cost. Also, one of the most important problems is emerging contaminants.



	<p>➔ Artificial recharge is an efficient technique, little used in the Júcar basin. It is necessary to address the challenge of recharge with regenerated water.</p>
<p>José-Recto Peris, Community of irrigators of the Acequia Mayor of Sagunto</p>	<p>He directed his speech to talk about the situation of the irrigators in Sagunto region and the impact of the implementation of Algar reservoir on them.</p> <ul style="list-style-type: none"> - There is a problem of salinization of the wells in Sagunto due to seawater intrusion. - Thanks to the Algar dam, irrigators are now able to use two type of water: 50% surface water and 50% ground water. - Irrigation is done 3 days/week. - The problem for irrigators is that the water level needs more pumping, which is very expensive for them. What they are asking for is to change the current regulations in order to be able to implement solar panels, for example, to offset pumping costs. <p>➔ The Algar dam has been very beneficial for the Sagunto irrigators as well as for the recharge of the aquifers.</p>
<p>Miguel Fernández, Provincial Council of Alicante</p>	<p>He delivered some reflections MAR in the province of Alicante in Valencia.</p> <ul style="list-style-type: none"> - Alicante displays quite a few experiences of MAR as the one of the San Diego pond, the one of the dam Isbert (infiltration of 500,000-200,000 m³/year), the artificial recharge with surplus water from the Gorgos riverbed in the Jávea plain and wells of recharge of Jijona. - MAR in the Júcar district present a communication and governance issues. - There are some doubts about how groundwater balances are done because the yield of the supply network in the small mountain communities generally exceeds barely 60% and these losses return to the environment and it is not clear if they are taken into account in the groundwater balances

	<p>➔ The is a lack of a groundwater plan in Spain and MAR should be introduced in the hydrological plans.</p>
<p>José María Montes Geologist, exTragsa</p>	<p>He referred to the experience of the balsa del Campo. Chulilla.</p> <ul style="list-style-type: none"> - The system is quite simple and consists of 3 components: a pond of 85300m³ of capacity, a recharge well (1000l/s) and a control cabin. - The recharge system is a gravity system, so it has no energy costs.
<p>Vicente Canós Moncofar Irrigation Cooperative</p>	<p>He referred to the irrigators in Moncofar. The main problem of this region is that the amount of water that is collected is much higher than the amount that is recovered. There is also a water quality problem for aquifer recharge since the water is highly polluted.</p> <p>➔ His intention is not to withdraw groundwater because, in his opinion, nature will be in charge of reproducing the initial state of the aquifer.</p>
<p>Diego Iroles Head of Technical Area (CHJ)</p>	<p>His intervention was in the framework of discussion and among the important ideas he shared are the following.</p> <ul style="list-style-type: none"> - The CHJ considers that regenerated water is very expensive so they prefer to directly deliver this water to users and not use it for recharge purposes. - The CHJ is very concerned about water quality. - to carry out the MAR it is necessary to have the agreement of the mining institute of Spain; Therefore, it is important to seek to facilitate these processes because they are extremely time consuming.

At the end of this workshop the adelphi team managed to arrange 4 bilateral meetings with 4 stakeholders: José-Recto Peris of the Community of Irrigators of the Acequia Mayor de Sagunto, Arancha Fidalgo, the Head of the Hydrological Planning Office of



the CHJ, Diego Irlés, the Head of the Technical Sector (CHJ) and Fernando Juan, the Project Manager at ACUAMED. The results of these meetings can be consulted in the report elaborated by Adelphi.

In summary, the workshop fulfilled its main purpose; it was an opportunity to bring together the different stakeholders involved in this endeavor. Listening to them, learning from their different experiences, understanding their concerns, and being inspired by the ideas they proposed, has allowed to elaborate a more accurate general view of the application of MAR in the two AGREEMAR study sites in Spain and to stimulate the collaboration of stakeholders.