Managed Aquifer Recharge in Los Arenales (Segovia, Spain)

Year of issue

2025

Summary

Managed Aquifer Recharge (MAR) in Los Arenales, Spain, aims to address severe groundwater overexploitation through the seasonal diversion of surplus flows from the Cega and Voltoya rivers into infiltration basins and channels. Since the early 2000s, three MAR systems (El Carracillo, Santiuste, Pedrajas–Alcazarén) have helped reverse declining groundwater trends - replacing average losses of −1.4 m/year with rises of +0.3 m/year - while also improving water quality through soil filtration, notably reducing nitrates.

The systems are low-energy and gravity-fed, co-managed by the Duero River Basin Authority (CHD) and local irrigation communities. Monitoring shows benefits for aquifer recovery, flood buffering, wetland restoration (e.g. La Iglesia Lake), and energy savings (~22% reduction in pumping), with positive socio-economic outcomes including improved irrigation security and reduced rural depopulation.

Recent adjustments have been made to optimise recharge periods and flow thresholds from the Cega River, ensuring ecological flows are maintained. During droughts, stored water from wet years allows irrigation to continue, even if aquifer levels temporarily decline. These are recovered in subsequent wetter periods. The recharge system is well accepted by users, and flood events are managed by redirecting excess water back to the Pirón River, minimising basin transfer effects.

Photo Gallery



Location

41.1445, -4.572

Project

NWRM

National ID

Spain_03

Sector

Hydromorphology

Installation Date

2002

Implementation status

Ongoing

Contact

Estefanía Ibáñez (IMDEA Water) in close cooperation with Enrique Fernández Escalante (TRAGSA-SEPI) whose valuable contribution is acknowledged and very much appreciated.

Overview

Location of the project

The Los Arenales Managed Aquifer Recharge (MAR) project is located in the southern part of Castile and León, in central Spain, within the Duero River Basin. The project spans several municipalities across Segovia and Valladolid provinces, and targets the Los Arenales Groundwater Body (LAGB).

Country

Spain

NUTS2 Code

Castilla y León

Sponge measures implemented in the case study

Restoration of natural infiltration to groundwater

Objectives

Reverse groundwater overexploitation in the Los Arenales aquifer

Secure water supply for irrigated agriculture in the region

Recharge the aquifer using surface water surpluses

Improve water quality through natural soil filtration

Test and validate MAR as a long-term water management tool

Promote participatory water governance

Involved partners

Authority type	Authority name	Authority role	Comments	Authority responsibility
—	Ministry of Agriculture, Food and Enviromental Affairs, Spain	Initiation of the measure	The ministry responsible for environmental affairs.	Responsible
Regional / sub-national water authority	Castilla y León Regional Government (Agriculture and Livestock Office)	Initiation of the measure	Is the regional authority for agricultural affairs.	Responsible
Other	Tragsa	Determination of design details of the measure	Type: Public Company Role: Tragsa has been involved since the begining is most of the stages: Initiation of the measure; Determination of design details of the measure, Implementation, Financing (from 2007 to 2010) and Monitoring.	Responsible
Local water authority	Duero River Basin Authority	Other	Supporting tragsa withdata collection and providing information.	Supporting
Research institute / University	Universidad Complutense de Madrid	Monitoring	Type: education and research institution Role: monitoring and field research	Supporting

Authority type	Authority name	Authority role	Comments	Authority responsibility
Farmers	Irrigators Community	Monitoring	Framers were actually involved in all the process. They were responsible for opening and closing the recharge devices following Tragsa instructions.	Supporting

Site Information

Climate Zone

Cool temperate moist

Precipitation

461.00 mm

Temperature (°C)

11.20 °C

Evapotranspiration

379.00 mm

Elevation range

828

Slope range

0-1%

Vegetation class

The region is a rural agricultural zone dominated by irrigated crops, especially in the El Carracillo and Santiuste systems.

WFD Ecological status

Good

WFD Chemical status

Good

Water quality status

The main pressure is diffuse agricultural pollution, particularly nitrate contamination of groundwater.

Design and Implementation

Project scale

Meso

Project scale specifications

The project covers a regional portion of the Duero River Basin, targeting the Los Arenales Groundwater Body, which spans around 2,400 km² across multiple municipalities in Segovia and Valladolid provinces. It involves three MAR systems (El Carracillo, Santiuste, and Pedrajas–Alcazarén), coordinated under basin-level planning by the Confederación Hidrográfica del Duero (CHD). While not national in scope, it operates at the sub-basin and multi-municipal scale, addressing regional water resource challenges related to agriculture, groundwater overexploitation, and climate adaptation.

Project area

4800

Area subject to Land use change or Management/Practice change (ha)

7.56 ha

Size

27960.00

Size unit

m2

Basis of design

Peak flow (for a standard return period of 5 years) = 100 m3/s
Peak flow (for a return period of 500 years) = 560 m3/s

Constraints

In winter, water freezing reduce infiltration to the aquifer. This might be relevant considering that the concesion of water for this propose goes from November to April.
Some years have not been successful due to silting up in soakways and pond.
The water transfer from Voltoya River to the recharge channel needed to be stopped during heavy rain days in order to avoid flooding.
Additionally, the Lisse effect (excess of air trapped in to the aquifer reduces the infiltration capacity) has been a problem during the implementation, having to modify the design and structure of the devices.
Erotion of soakways/channels banksides, jeopardising stability.
The transfer of water to the recharge system was only allowed is the flow in Voltoya river was be above 600 l/s (in order to guarantee the ecological flow.

Favourable preconditions

The channel was designed to take advantage of the former route of the Ermita strem to enhance infiltration.

Essays and monitoring in the site of study showed that in areas were the aquifer was more than 3m deep, infiltration was more effective.

Literature lists favourable conditions for aquifer recharge: scant vegetation, permeable or fractured soil, high water table level, and aboundant rainfal (De Vries and Simmers, 2002).

Financing

Total cost

4608946.00 €

Total cost information

Initial investment until 2006:
Water intake: 409657 €
Transfer conveyance: 2641615 €
Recharge channel 1: 289940 €
Recharge channel 2: 606867 €
Investment in the second period: 660867€ (The amount was devoted to maintenance, studies and projects)

Costs operation maintenance

3000.00 €

Costs operation maintenance information

Each recharge cycle had maintenance works of the channel and basins depending on the results of the previous year. However, there is not a specific budget with details on these specific costs.

Information on Economic costs - income loss

In very wet years, agricultural fields (generally with potato crops) have been occasionally flooded after the groundwater level reached the limit that should not be exceeded in aquifer managment and recharge practices (defined in 1.5m by Fernández Escalante, 2005).

Financing authorities

Authority name	Type of funding	Comments
The Ministry of Agriculture, Food and Environmental Affairs.	National funds	—
Castilla y León Regional Government (Agriculture and Livestock Office)	Sub-national funds	—
European Union	EU-funds: Rural development funds	European Agricultural Guarantee Fund
Trasgsa	Other	Trasgsa (public company) financed an RTD programme (2007-2010) to continue the research activity regarding aquifer management activities. SEPI Group (Spanish Society of Industrial Participations) was the main shareholder

Compensations

Non

Compensations annual information

There is no specific records of compensation payments to landowners or irrigators affected by the measure. In fact, the implementation of the measure was originated from a social claim to recover a damage aquifer, and irrigators and landowners were involved in the petition.

Policy and Governance

Policy description

The exploitation of the superficial aquifer, mainly for irrigated agriculture, has led to a 10 m fall of the water table, which has led to related salinization and pollution processes. [WFD pressure: 3.1 Abstraction, Agriculture]

Land ownership

Mostly publicly owned or managed under easement agreements with local irrigation communities (ICs).

Policy targets

Groundwater Recharge

Increase Water Storage

Part of a wider plan

Non

Public consultation

Non

Has contractual arrangements

Oui

Contractual arrangements

Arrangement type	Responsibility	Name	Role	Comments
Contractual agreement	Use the diverted surface water legally and transparently. Operate and maintain MAR infrastructure locally.	Public–User Agreements with Irrigation Communities	The Irrigation Community (IC) of El Carracillo signed agreements with the Confederación Hidrográfica del Duero (CHD).	These agreements are formalised under Spanish water rights legislation, where ICs receive water concessions for shared use and commit to maintaining infrastructure and adhering to operating rules.

Arrangement type	Responsibility	Name	Role	Comments
Contractual agreement	Land use rights were formalised via easement agreements or permits, enabling CHD and ICs to build and manage infrastructure.	Land Use and Access Agreements	Infiltration basins and canals were sometimes built on public land or land ceded temporarily or permanently by municipalities or landowners.	—

Impacts and Monitoring

Monitoring System

Monitoring requirements

Monitoring is conducted by CHD and research partners (e.g. Tragsa, UPM), focusing on groundwater levels, water quality, recharge volumes, and system efficiency, with data used to support adaptive management and climate resilience.

Monitoring parameters

A range of hydrological, hydrochemical, and operational parameters are systematically monitored at the Los Arenales MAR sites. Groundwater levels are measured in a network of at least 8 piezometers, with data collected over decades to assess storage trends and recharge effectiveness. Water quality parameters, especially nitrate concentrations, are tracked to evaluate the natural filtration benefits of the infiltration process. Recharge volumes are recorded to quantify water diverted and infiltrated from rivers (mainly the Cega and Voltoya). Additionally, the system’s energy performance is assessed by comparing energy used for groundwater pumping before and after recharge implementation. There is also occasional use of satellite imagery and digital tools to monitor surface area changes in infiltration ponds and nearby wetlands. Monitoring supports compliance with environmental standards and guides potential future adjustments, including the integration of reclaimed wastewater as an alternative source.

Upstream station

Dina-Mar ZNS-1 (Sig-Pac plot 40:221:0:0:1:6244; Coord 369694:4557512)

Downstream station

Dina-Mar ZNS-2 (Sig-Pac plot 40:65:265:0:7:5372:2; Coord 369246:4561559)

Maintenance

Maintenance requirements

Maintenance operations include regular cleaning of infiltration basins and channels, vegetation control, and infrastructure repair, carried out mainly by local irrigation communities in coordination with the Confederación Hidrográfica del Duero (CHD).

Impact Assessment Methodology

Performance impact assessment method

Laboratory

Performance impact estimation information

Changes in water table have been studied with the Water Table Fluctiation Method (Healy and Cook, 2002). Studies of the non-saturated zone were carried out with control stations, which measured humidity, temperature and pressure (or tension). The latest monitoring technique is the use of a thermal camera to study the evolution of silting

Socio-economic Impacts

Direct benefits

Secured water supply for irrigation, improved yields and reduced production risks.
Lower energy demand for groundwater pumping.
Rural development & demographic stability : In areas benefiting from MAR (e.g. El Carracillo), population decline has slowed or stabilised, in contrast to surrounding rural zones. This is interpreted as a positive impact on local economies and livelihoods, helping to retain youth and agricultural employment.
Reduced illegal groundwater abstraction : With legal, MAR-supported water supply, unauthorised pumping has decreased, improving compliance with water laws.

Information on ecosystem impact, reduced energy use

Thanks to shallower groundwater levels, energy required for pumping was reduced by ~22%, equating to :
Energy savings: ~10.4 GWh/year
CO_2 emissions avoided: ~9,300 tonnes over the lifetime of MAR operations to 2021

Biophysical impacts: Hydrology

Retained water

2555000.00

Retained water unit

m3/year

Information on retained water

Average value per recharge cycle calculated on the basis of the data obtained after 8 effective recharge cycles. Of the total volume derived to the infiltration devices, that is the volume that was actually infiltrated into the aquifer in each of the cycles in which the measure was working. Values obtained per cycle: 1300000 m3 (cycle 1; 2002/03); 1800000 m3 (cycle 2; 2003/04); 970000 m3 (cycle 3; 2004/05); 3560000 m3 (cycle 4; 2005/06); 12190000 m3 (cycle 5; 2007/08); 460000 m3 (cycle 6); 2500000 m3 (cycle 7; 2008/09); 640000 m3 (cycle 8; 2009/10); 2130000 m3 (cycle 9; 2010/11); 0 m3 (cycle 10; 2011/12).

Information on increased water storage

For each cycle of recharge was calculated the volumen of water devoted and the actual recharged volume. The following are the percentage of used volume vs recharged volume: 37,14% (cycle 1); 80% (cycle 2); 76,98% (cycle 3); 69,67% (cycle 4); 96,13% (cycle 5); 87,41% (cycle 6); 64,50% (cycle 7); 90,46% (cycle 8); 68,03% (cycle 9); 0% (cycle 10).

Information on peak flow reduction

In the 2013 flood event, MAR systems helped mitigate flood impacts in Viana del Cega and Mojados by capturing part of the peak flow.

Increased groundwater level

1.23 m

Information on increased groundwater level

Positive impact: Reversal of aquifer depletion. Between 1985 and 2001, groundwater levels in the Los Arenales aquifer declined at a rate of −1.37 m/year. Since the implementation of MAR (2003), groundwater levels have increased at ~+0.3 m/year, despite 20% lower rainfall in the post-MAR period

Average value per recharge cycle on the basis of the the data obtained after 10 recharge cycles (and excluding cycle 6 value -see later-). These values show the variation in the groundwater level in the monitoring network. The value of the Cycle 6 cannot be only attribuible to the recharge as there was also abundant precipitation that year, and measurement could not differ between sources. Values obtained per cycle: 2,30 m (cycle 1); 2,10 m (cycle 2); 1,17 m (cycle 3); 3,36 m (cycle 4); 0,31m (cycle 5); 3,57*m (cycle 6); 0,62 m (cycle 7); 0,41 m (cycle 8); 0,54 m (cycle 9); 0,28 m (cycle 10).

Information on increased landscape storage capacity

Total storage volume available for flood mitigation: estimated at ~350,000–500,000 m^3 per major MAR system.

Biophysical impacts: Biodiversity

Improved biodiversity

Oui

Information on improved biodiversity

The rehydration of La Iglesia Lake has begun to restore aquatic and semi-aquatic habitats, supporting biodiversity regeneration in an otherwise agricultural matrix. This wetland is considered unique due to its endorheic, alkaline nature.

Biophysical impacts: Water & Soil Quality

Water quality overall improvements

Positive impact-WQ improvement

Information on water quality overall

The hydrochemical evolution of groundwater has shown improvement in nitrate concentrations (which were very high at the beginning: 274 mg/L in the NE of the aquifer). On the other hand, some negative impacts occurred like the increased concentration of diluted iron in central-eastern areas of the aquifer, the creation of a reducing environment with calcium carbonate precipitation, and formation of imprevious crust.

Soil quality overall improvements

Not relevant for this application

Information on soil quality overall improvements

Soil is relevant for this applicationonly regarding infiltration rates. Once the recharge has began, silting is one of the major constrains in terms of infiltration reduction. This is why Soil Aquifer Tecniques are applied in the channel /soakways and in the infiltration basins.

Biophysical impacts: Others

Ecosystem impact climate regulation

Reduced energy use (farm operations)

Lessons Learned

Key lessons

- It is important to involve irrigators in the process and the implementation of measures, especially those Communities that use underground waters, since the withdrawal control is lower than for those using surface waters.
- It is important to improve economic and geopolitical indicators, apart from the hydrogeological ones, prior to the implementation of new devices.
- Monitoring is key to improve effectiveness, to improve the devices and to increase infiltration rates and the total volume infiltrated to the aquifer.
- Some key actions to ensure the proper functioning of the measure are the pre-treatment of water, the inflow regulation, reduction of suspended soils and air in water. It is advisable to avoid whipping of recharge water. Low flow speed is preferred.
- Some of the most common limitations are soil silting and increase of trapped air in the aquifer, which can be avoided with SAT techniques and the proper design of the channel.
- MAR systems can significantly reverse aquifer depletion even under reduced rainfall.
- Soil infiltration improves water quality by reducing nitrates and suspended solids.
- Simple and low-cost gravity-fed systems are highly effective in rural settings.
- Energy use and CO_2 emissions from groundwater pumping can be reduced by over 20%.
- Multi-level governance and user ownership are essential for long-term success.
- MAR can contribute to rural demographic stability by securing agricultural water supply.
- MAR systems can also provide flood retention benefits when designed with multi-purpose capacity.

Barriers

Barrier type	Barrier role	Comments
Lacking financing sources	Main barrier	The lack of financing actually became a barrier during the recharge cycles 2010/2011 and 2011/2012, when maintenance, new infraestructures and expansions were not possible, and the little activity that remained was thanks to private efforts (of researchers and irrigators)
Existing technical standards	Secondary barrier	During the progress of the implementation silting was one of the major problems which reduded efective infiltration of water into the aquifer. Several studies were carried out in order to define best solutions and improve effectiveness of the measure.
Legal obligations / restrictions	Secondary barrier	A "spill" authorization is needed to implement this measures in Spain (despite the fact that most activities result in an increased groundwater quality)

Drivers

Driver type	Driver role	Comments
Balancing different objectives	Main driver	A group of groundwater users posed their concern about the aquifer degradation to the local authorities, which enabled a serie of interventions.
Public pressure	Main driver	—
Organisation committed to it	Secondary driver	—

Success factors

Success factor type	Success factor role	Comments
Attitude of relevant stakeholders	Main factor	Once the infiltration system started working, it was necessary the participation of the irrigator community to manage the entrance of water from Voltoya River. This procedure proved to be the most efficient to avoid excess of water and flooding in nearby areas, or to surpass the limit established by the River Basin Authority of 8,5hm3 to be used for recharge purposes. Mayors of related towns were always collaborative.
Public participation	Secondary factor	—
Attitude of decision makers	Secondary factor	Once the overexploitation problem was identified, local and national authorities reacted with a project of aquifer recharge, declaring the implementation of measures of "general interest". Mayors of related towns were always collaborative.
Successful coordination between authorities	Secondary factor	—
Communication activities	Secondary factor	The project has became a practice of interest in Spain and is often visited by students, other researcher, and even a dissemination plan has been implemented for the general public.
Existing staff and consultant knowledge	Main factor	Some of the researchers involved in the project have been very committed to the continuation of monitoring and sampling to get additional data and results even when the budget was scant.

Transferability

The Los Arenales MAR system is transferable to other semi-arid regions facing groundwater overexploitation, provided surplus surface water is available. Key success factors include strong user involvement, legal clarity, and simple, low-energy design. Attention must be given to soil characteristics, water quality (e.g. nitrates), and long-term monitoring to avoid clogging, inefficiency, or aquifer degradation.

Sources

Sources

La recarga artificial de acuíferos. Marco legal que regula sus aplicaciones.

2002-2012, una década de recarga gestionada. Acuífero de la Cubeta de Santiuste (Castilla y Leon)

DINA-MAR. La gestión de la recarga artificial de acuíferos en el marco del desarrollo sostenible. Desarrollo tecnológico.

Rechargable sustainability: the key is the storage

Recarga artificial de acuíferos en cuencas fluviales. Aspectos cualitativos y medioambientales. Criterios técnicos derivados de la experiencia en la Cubeta de Santiuste (Segovia)

Proposicion de un sistema de caracterizacion de humedales degradados susceptibles de regeneracion hídrica mediante operaciones de recarga artificial de acuíferos

Cinco anos de recarga artificial en el acuífero de la Cubeta de Santiuste (Segovia)

Contribution to the hydrogeological knowledge of an artificial recharge area based in hydrochemical investigation. Los Arenales site, Duero basin, Spain.

Hydrogeological studies previous to the artificial recharge of Los Arenales aquifer, Duero basin (Spain)

Plan Hidrológico de la Demarcación Hidrográfica del Duero 2022–2027

Three-In-One Uses of a Managed Aquifer Recharge System: The Triplets in Los Arenales

Managed Aquifer Recharge as a Low-Regret Measure for Climate Change Adaptation: Insights from Los Arenales, Spain

La recarga gestionada de acuíferos en España. Previsiones en materia de planificación y gobernanza en el corto plazo