Technical Insight Series

Co-Managed Aquifer Recharge (Co-MAR)

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International Association of Hydrogeologists
the World-wide Groundwater Organisation

Figure 1: Information board about El Carracillo MAR system (Los Arenales Aquifer, CyL, Spain), specifying the regulation framework and investment. Notice the cost is still expressed in pesetas, indicating that it has become an "adult" Managed Aquifer Recharge (MAR) system.

This series is designed both to inform professionals in other sectors of key interactions with groundwater resources and hydrogeological science, and to guide IAH members in their outreach to related sectors.

Key Messages

- Managed Aquifer Recharge (MAR) is a promising set of techniques to improve integrated water resources management (IWRM), and cope with a variety of water management-related issues.
- International multi-level governance is evolving, from a top-down to a mixed top-down and bottom-up approach.
- The participation of "irrigation communities" or groundwater user's associations can help improve IWRM planning and organisation, reinforcing aspects of modern governance through co-design and co-management, i.e. a social inclusion approach.
- The obligation in some countries to formally involve irrigation communities is increasing, offering a valuable representative to discuss and negotiate with water authorities, and helping to create "spaces of trust". These modify the classical decision-making organisation, leading to more socially inclusive water management, which can help change social perceptions on roles and responsibilities.
- The participation of stakeholders in decision-making can improve governance, rural development, water security, and therefore IWRM, opening the possibility of a new management approach: the co-managed aquifer recharge (Co-MAR) concept.
- Co-MAR is based on the co-management of end-users in the management of the resources that they use and benefit from, within a multilevel structure and a teamwork approach.

What is Co-MAR?

The term co-managed aquifer recharge (Co-MAR) is an innovative procedure that includes stakeholders in decision making on aquifer recharge, thus helping to implement IWRM. Co-MAR is related to multi-level governance, with a bottom-up approach and scaling up. It is also useful for other related aspects like optimising design, finding additional ways to finance MAR systems, and by enhancing applied research and capacity building of all involved.

Co-MAR key concepts

- **Collaborative Governance.** Governing arrangement where one or more public agencies directly engage non-government stakeholders in a collective decision-making process that is formal, consensus-oriented, that aims to make or implement public policy or manage public programs or assets' (Ansell and Gash, 2008).
- **Irrigation Communities or Groundwater users' associations.** A community of groundwater users either set up voluntarily or imposed by the administration, especially when an aquifer is declared to be overexploited. Legally it has a public-private nature.
- **Integrated Water Resources Management (IWRM).** "A process which promotes the coordinated development and management of water, land and related resources, in order to maximise the resultant economic and social welfare in an equitable manner without compromising the sustainability of vital ecosystems" (GWP, 2000).
- **Managed Aquifer Recharge (MAR).** "MAR is a water management method that allows water to be introduced into underground aquifers. Once stored in these, it can be extracted for different uses (urban supply, irrigation, combat saline water intrusion, reduce pollution, regenerate ecosystems, etc.)" (DINA-MAR, 2011).
- **Space for collaboration or space of trust.** Environment created based on trust, and on the fair use of (ground)water resources. It is also based on strong functional organisational structures, which help decision making and direct positive outcomes on improved groundwater quality and quantity. These spaces become the basis for new governance arrangements that are better suited, and are more responsive, to the collective interest.
- **Public-Private Partnership (PPP).** Public–private partnership (PPP, 3P, or P3) is a "cooperative arrangement between two or more public and private sectors, typically of a long-term nature" (Hodge and Greve, 2007).
- **Public-Private-People Partnership (PPPP).** New term based on PPP, including people in the equation, to increase the scope of governance and water security. The authors propose a variation, People Public-Private Partnership (PPPP') considering people to be the most important component, and therefore, the first.
- **Stakeholder (corporate)**. Group, corporate, organisation, member, or system that affects, or can be affected, by organisation's actions.
- **Water security.** "Capacity of a population to safeguard sustainable access to adequate quantities of acceptable quality water for sustaining livelihoods, human well-being, and socio-economic development, for ensuring protection against water-borne pollution and water-related disasters, and for preserving ecosystems in a climate of peace and political stability" (UN Water, 2013).

Introduction

Some water laws and regulations require that, for every intensely exploited aquifer, the responsible water authorities must coordinate actions with appointed groundwater (GW) users' communities, for example in Spain and Peru. Hence, these associations have become a unique and legitimate counterpart to negotiate and reach agreements on water planning and management with traditional decision-makers. This modifies the traditional top-down approach.

Now, groundwater users can collaborate with each other, and members of the public have the possibility to provide inputs into policymaking and administrative issues. This new and more socially inclusive approach relies on the creation of "spaces of collaboration and trust building". These can generate collective benefits for those involved; for example, closer observation and more detailed first-hand knowledge and information on water use practices, energy efficiency aspects, and, specifically, on how to ensure water security for long term agricultural development planning. The concept has two important key aspects, first, to guarantee water supply in the future, and second, to help safeguard water quality.

Shared data, information and knowledge by all stakeholders, and in particular between key participants, such as the river basin agency, rural associations, and the population at large, can help design more robust decision support systems (DSS), and thus, identify appropriate and negotiated management responses and measures to address intensive groundwater use.

Methodology

MAR and stakeholders are basic components of the Co-MAR concept, and entry points to understand the whole system. The methodological approach for Co-MAR involves and combines a 4-stage method (Fig. 2), consisting of: i) literature reviews, ii) case-study analyses, iii) primary data treatment from interviews and surveys (over 50 in the examples), and iv) capacity building activities in rural areas. In the first example, we ran seven workshops.

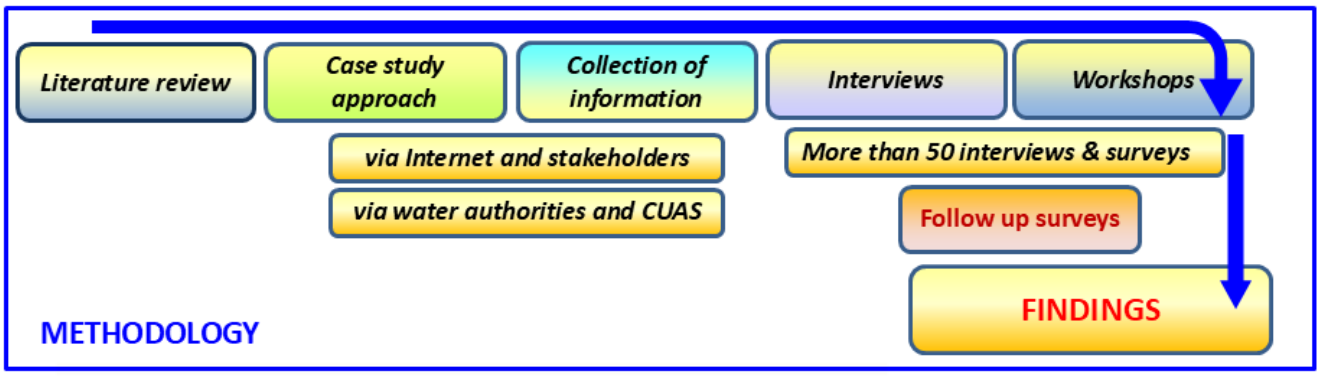
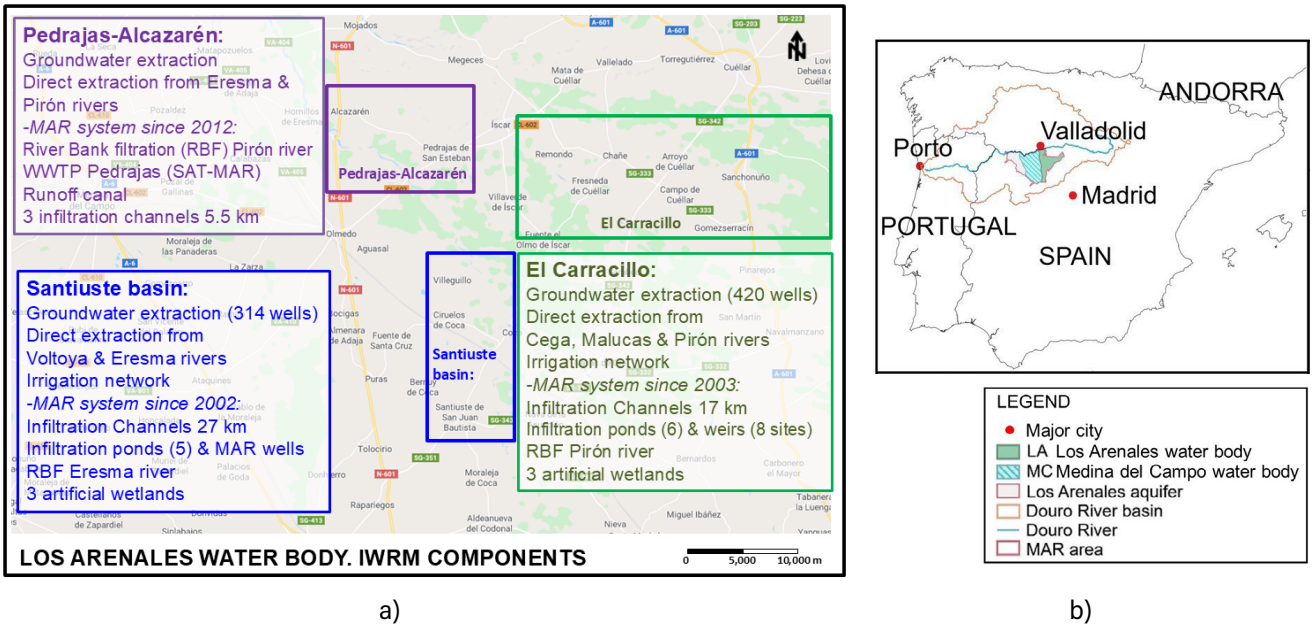


Figure 2: Co-MAR methodological approach.

Case 1. Los Arenales Aquifer, Castile and Leon region, Spain.

The Los Arenales aquifer is in Castile and Leon region, Central Spain. Here intensive groundwater exploitation started in the 1970s, with the groundwater table declining by about 25 m due to irrigation. The Water Exploitation Index (WEI), or relation between exploitation and recharge, was 1.30, thus the aquifer became "provisionally overexploited" by law.

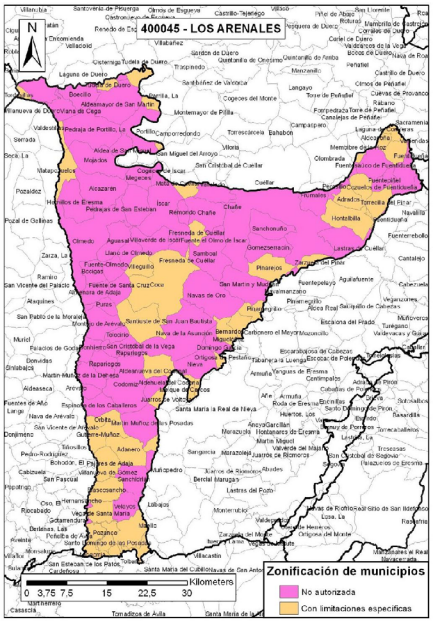


a) b)

Figure 3: Case 1. IWRM main components at the Los Arenales Aquifer, Spain (a) and general geographical location (b, modified from Henao et al., 2022).

According to the Spanish Water Act, Art. 40, each water body with a WEI exceeding 0.80 requires intervention by the Water Authorities. As a result, Managed Aquifer Recharge started in the Los Arenales aquifer (Fig. 3); in 2002 in Santiuste basin; one year later it also started in El Carracillo, the main MAR systems of Los Arenales water body. The importance of MAR can be seen in Fig. 4 where it can be appreciated how, despite the intensive groundwater exploitation from 2002 to 2024, there has been a significant recovery thanks to MAR and Co-MAR, reducing the GW decline by about 11 m. It is worth noting that MAR provides about 24% of the total water used for irrigation in the area and supplies a well-developed agro-industry that is an important part of the local economy.

Changes in regulation facilitated a deeper participation of stakeholders in water management decision-making, helping to develop the Co-MAR concept in the area, while at the local level with day-to-day management, demonstrating to the farmers the use and benefits derived from MAR. Groundwater users must be organised and cooperate in the wise use of water, to increase water and food security for current and future generations.



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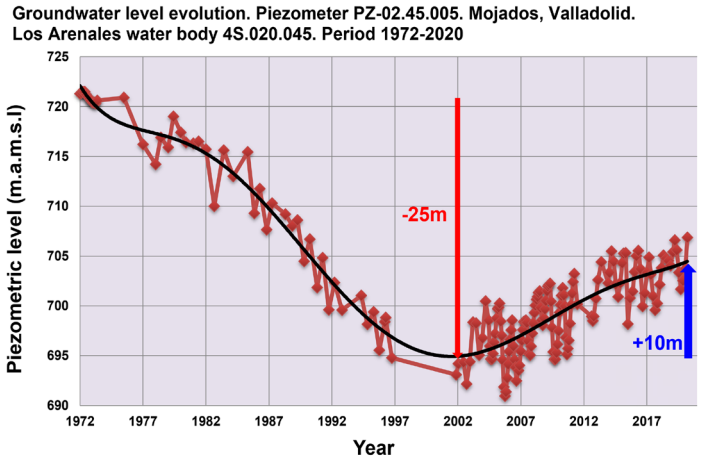


b)

Figure 4: Los Arenales water body (a) (general context in Figure 3b). Groundwater level evolution between 1972 and 2020 according to a representative piezometer. Between 1972 and 2002, a 25 m groundwater decline was registered in the aquifer. Since 2002, the groundwater level has raised more than 11 m thanks to MAR (b).

Figure 5: Los Arenales MAR system and agroindustry example. Author: Enrique F. Escalante.

Case 2. Co-MAR in the Ica aquifer, Ica region (Peru)

The Ica aquifer is located in the southern region of Peru, with a high level of agro-industrial development, dependant on groundwater irrigation. Thus, it is the main driving force in the region and supports the livelihood of hundreds of families.

The number of hectares permanently irrigated with groundwater is close to 33,000 out of a total of 68,000 (Navarro and Fernández, 2017). Alternative sources of water, like canals and surface reservoirs, are also used (Fig. 5).

In 2012, groundwater artificial recharge began, which required progressively building up knowledge of the physical environment and forecasting the aquifer's response for reducing the impacts of clogging, planning O+M work, and working to improve the coordination and communication with all those involved.

The system, initially developed through trial and error, has become increasingly technical, thanks to geophysical prospecting, the installation and real-time monitoring of a piezometric control network, the development of a mathematical model, and the expansion of the MAR area. However, probably, the most important has been the raising of public awareness on the care and importance of the recharge areas of the aquifer, in order to maintain its sustainability. All these activities have been promoted, mainly, by

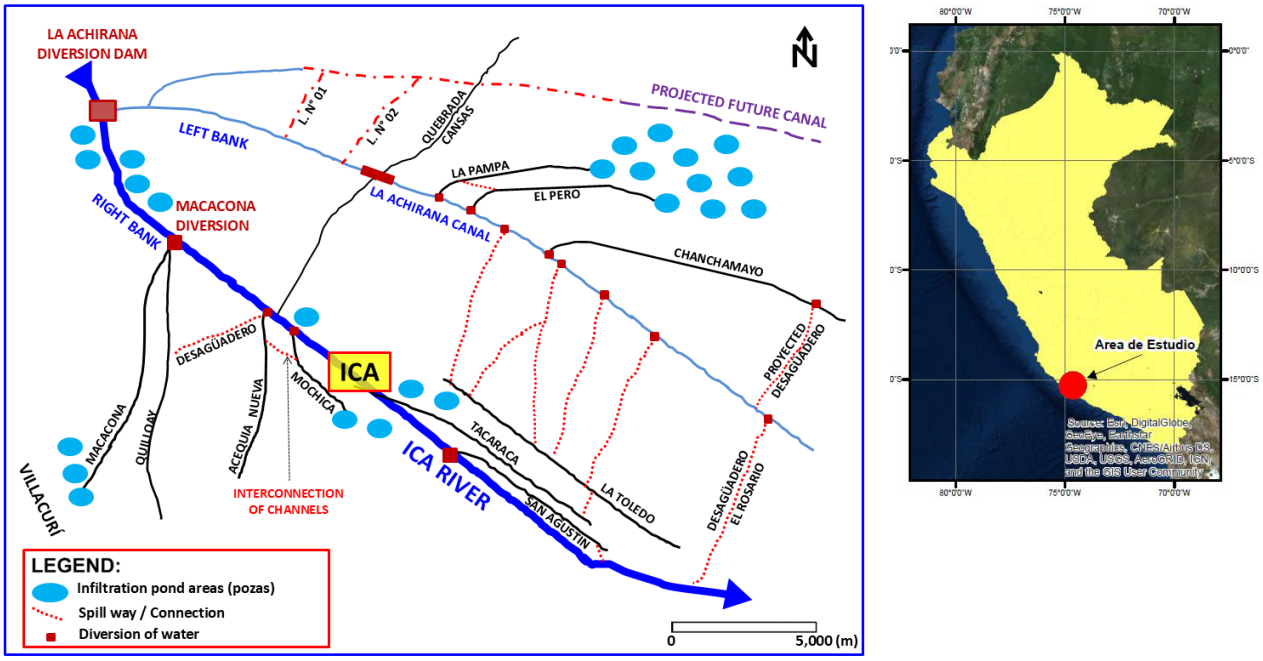


Figure 6: Case 2. IWRM main components in Ica aquifer, Peru (Fernández et al., 2020).

groundwater users (JUASVI) and the Peruvian government's National Water Authority (ANA) (Navarro and Fernández, 2017).

The maximum exploitable rate of the aquifer is calculated to be around eight m3 /s (252.3 million m3/ year) (Navarro and Fernández, 2017). The legally granted allowances have already reached 225.44 million m3 /year, which leaves little margin for future legal water allocation. The forecasts for water allowances or licensing have already exceeded the situation which was considered sustainable in 2014 by 26.86 million m3 /year.

The volume intentionally infiltrated is increasing as the infiltration area expands, helped by the increased awareness by stakeholders of the importance of aquifer recharge, to the extent that farmers themselves become active participants (co-mar) by lending private plots for temporary MAR for the good of their community. There are few publicly owned plots in suitable locations that are already temporarily used for artificial recharge. The shared benefits of this approach are shown because the plots are hired for the remaining months to the economically disadvantaged population to grow crops, usually free of charge or at very low cost.

In the rainy season of 2017, 16.96 million m3 were derived from the Ica River, and after deducting evapotranspiration, the estimated volume infiltrated into the aquifer was 16.7 million m3. This quantity is insufficient compared to the overexploited volume, and very far from the "safe yield" concept (recharge intentionally the same volume that is extracted) in the short term. It is therefore a palliative technique for the impact of 'over-exploitation of groundwater', but it is not yet a cure.

Figure 7: MAR and IWRM actions at Ica Aquifer (Peru). Author: Roberto Navarro.

End-users participation has driven the creation of the Hidr-ICA working group, which includes groundwater users, agro-exporters, water authorities representatives, consultants, etc., which then can help organisationally to implement and enhance the Co-MAR concept in the aquifer. The Hidr-ICA team participates in the highest level of decision-making, because the coordinator is a civil servant of ANA, involved in granting permissions and allowances, and dialogues with stakeholders, agroindustry CEOs, etc. The results have not been slow in coming.

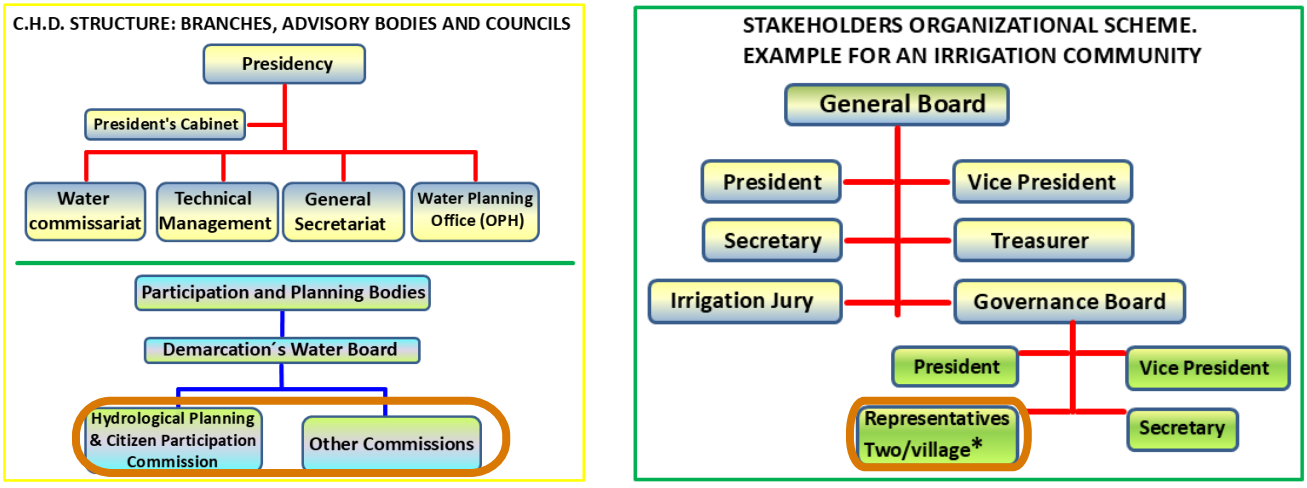
Results

Changes in the stakeholders' structure

Both systems have developed a pragmatic "management model", based on the consideration of water as a public good, with an intimate relationship between the water cycle and ecosystems. They also pay special attention to water quality, promoting water policy tools, such as planning and user/citizen participation.

The next figures show the structure of the governing units which formally link water authorities and groundwater user associations for the Spanish case, where the Co-MAR term was first coined. Notice the presence of the stakeholders (inside the red rectangle) at the base of both organisational charts.

The structure of the water authorities (Duero River Basin Authorities or CHD), and the competences assigned for each branch, as well as the advisory bodies and councils are indicated in figure 8 (a). The Groundwater user's association organisational tree is shown in figure 8 (b). Both include the representation of "end-users".



a) b)

Figure 8: CHD structure, advisory bodies, and councils. Modified from Duero River Basin Plan, or PHD (CHD, 2016) (a). Irrigation communities' structure (b). Orange ovals: formal end users' participation in decision-making.

Public-private cooperation can substantially help MAR implementation at various stages. For instance, private companies and landowners can give public agencies access to information and infrastructure that could be essential for MAR. Furthermore, this sort of cooperation is the core of co-management schemes, which result in substantial improvements in water governance, in terms of legitimate participation along the most sophisticated path, based e.g. on Arnstein's ladder (1969), towards partnership, delegated power and user control, much beyond consultation or token participation.

In the case of Ica (Peru), the working Group "Hidr-ICA" meets regularly, with representation of the main farmers associations, agro-exporters, and user's Commissions (called "Juntas"), a permanent representative of JUASVI and Río Seco, and eventual participation of minor institutions. The communication channel and the flow of information is ensured thanks to the coordinator. Experts in water management from the government and the public sector are involved in decision making, and share the outcomes of the meetings, publications and general inputs with the National Water Authority (ANA).

Stakeholders and performance of both MAR systems

The agents and stakeholders in the space of collaboration and trust have been differentiated; on one hand, key players, such as civil servants and authorities; and on the other hand, the members of the irrigation communities and other end-users of water resources.

Water authorities rely on Managed Aquifer Recharge (MAR) as a first-tier water management measure to address the overexploitation of both (Spain and Peru) systems, paying special attention to additional IWRM components, such as water transfers. End users' associations were created and organised to communicate with the Water Authorities, to improve aquifer management, planning, and policy development.

Figure 9: Stakeholders' capacitation at the Los Arenales aquifer, Castile and Leon, Spain. Author: E. F. Escalante

The three communities of water-users count on Managed Aquifer Recharge (MAR) facilities that provide between 22 and 25% of the total water used for irrigation in the Spanish case, whilst in the Peruvian case it barely reaches 5% of the water consumption.

The representatives of the associations of groundwater users (irrigation communities or Juntas, respectively) provide data regarding the volumes used to irrigate each crop, the evolution of the groundwater level in their piezometers, the volume diverted from rivers (while respecting essential environmental flows), volumes flowing along the MAR canals, volumes stored in their infiltration ponds, volumes of reclaimed water re-used for MAR, etc.

In addition, these associations are involved in the capture of datasets by means of different sensors installed in the soil and piezometers, guaranteeing a bilateral flow of information. This information provides solid support to science-based targets, bringing up potential issues for discussion and negotiation with water authorities to improve the current regulatory framework.

The main actions additionally performed by these institutions include information exchange meetings with the end-users, inviting individual agents (most of them from R&D projects and from the academia) to attend their assemblies, while developing ground rules to help sharing groundwater resources in homogeneous zones. They also organise formal seminars to improve the different groundwater bodies' organisation, etc.

The process ends with the signing of a binding collaboration agreement between each end-user's association and the water authorities, i.e. a public private partnership (PPP). This approach applies and enhances IWRM key elements.

Figure 10: Constitution of the Hidr-ICA working Group, to enhance communication among different IWRM agents in Ica aquifer to defend itself. 2022 March. Author: E. F. Escalante.

Social Behavioral changes in both systems

Every year, the water authorities (CHD or ANA) assess the water volume conveyed from the river source to the MAR systems, and accordingly, grant water rights to the associations (ICs or Juntas). The end-users' groups set rules to distribute these rights on water use, and report to the water authority. This process occurs via meetings between water authorities and representatives of the end-users.

Figure 11: Infiltration ponds in El Carracillo (Los Arenales Aquifer) (a); and in the Ica-Villacurí border (Ica Aquifer) (b). Authors: E. F. Escalante and Roberto Navarro, respectively.

Concerning finances, the MAR systems were initially constructed by the Spanish Ministry of Agriculture, and by the regional government for the Spanish case. The groups benefiting from MAR accepted the agreement to operate and maintain the infrastructure for 35 years. Each end-user association's member pays annual fees to meet these O+M obligations and for administrative costs. Initial investment with public money resulted in increased private funding in Peru.

The GW users improve groundwater governance and water security thanks to the greater transparency in the water allocation process, the active - and mutual -information exchange among decision makers, and the shift in farmers' mind-set from individual to collective action. These groundwater allocation schemes constitute a co-managed institutional arrangement in which the state and end-users share responsibilities.

Both systems have also created a platform for building an environment of trust, and thus, collaboration. They also ease the bidirectional exchange of information between the water authority and farmers. Under such circumstances, farmers are more likely to abide by the water rights assigned, cooperate, and perceive that the authorities have a more robust territorial control, which deters illegal groundwater abstractions (Henao et al., 2022).

a)

b)

Figure 12: Technicians, civil servants and stakeholders capacitation. Course on MAR, Ica 2022, organised by the ANA. Authors: E. F. Escalante (a) and ANA (b).

The PPPs enhance "improved governance" through the participation of farmers and the population in general in the decision-making processes (multilevel governance). So, water security, through both hard and soft management measures, is increased. The approach ultimately helps create a robust Decision Support System (DSS) for all stakeholders. It also adds people to the PPP equation, becoming public/private/people partnerships (PPPP). Now, authors have proposed a slight modification: people/public/private partnerships (PPPP'), giving to people the crucial importance that they deserve.

Conclusions & recommendations

Co-MAR at both studied sites is an example of PPPP as collaboration for the management of the water resources among public authorities and private landowners. It is key to improve the IWRM mechanisms. The bottom-up approach involves end-users, stakeholders, and the general population in the decision-making processes, resulting more in a more socially inclusive, and also, a more effective impact from actions taken.

- Co-MAR has permitted higher values for economic indicators in the studied areas where MAR activities are taking place.
- The spaces of collaboration and trust are becoming the basis for new governance schemes that aim more sensibility at the collective interest of all users.
- New aquifer recharge experiences could be implemented around both areas to bring the WEI down.
- Regulatory changes are often needed, as well as the modernization of the irrigation systems. Both measures (soft in the case of regulation and hard in the case of irrigation) help to improve water and energy efficiency backed often by an additional focus on nature-based solutions, like the ecosystem services of aquifer storage and regulatory services for resource savings and better economic results.
- New formulas for hard measures (concrete) are under permanent study, involving national, regional, local authorities, and user's associations in the investment for improvements in the system.

- Economic indicators and the degree of implementation of the MAR technique is causing "contagion effect". Nearby areas are considering seriously how to replicate the model, once they have realised it is working well, providing real benefits to users and to the local population, e.g., in Castile and Leon, new permissions and allowance have been requested from the communities of users from the neighbour Medina del Campo Water Body. In Peru, actions in Ica start being replicated in the Villacurí sector of the aquifer.
- The response to the overexploitation of the aquifer is working well, according to water level indicators and the changed rates on spatial patterns of groundwater pumping.
- The key vulnerabilities identification persists in both Co-MAR areas of study.

Priority Actions

- To ease the intervention of end-users in the Decision Support Systems (DSS) improves hard and soft management measures for IWRM.
- To facilitate the organisation of irrigation communities in areas where Managed Aquifer Recharge (MAR) technique is taking place, to introduce the Co-MAR concept, and to allow its proven benefits.
- To enable the creation of "spaces of trust", which are key in water management improvements rising from collective negotiation and teamwork.
- To make an extra effort on capacitation of end-users. We need to transfer knowledge to end-users and more hydrogeological support to wise young generations on IWRM and MAR. Therefore, they will face more successfully the new environmental context, brought by climate change.
- According to the exposed items, we may conclude MAR is safe, sound and sustainable, and Co-MAR include the social component, therefore, "Co-MAR is a must". It has become a safe opportunity that can be posed with other water management tools to ensure an integrated water management framework.
- A "shift in paradigm" is necessary in the water sector, from traditional patterns of water consumption to a circular economy approach, considering wastewater resources, and of course, MAR. It is important to define the direction to go in the coming decade.
- The knowledge to ensure water security is already available. Let's keep the hydrogeological message moving.

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