FIELD TRIP3. MADRID ASTR CYII FACILITIES.

ASR/ASTR/DEPTH INJECTION BOREHOLES IN MADRID

ASTR facility design in a deep aquifer destined to supply the Community of Madrid

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The main aquifer of the Community of Madrid and the system of supply as a whole, have ideal characteristics for the improvement of the supply guarantee through the application of recharge techniques. The recurrent droughts have given the detrital tertiary aquifer of Madrid (ATDM) a regulatory role in the hydrological variability and as a guarantor of the availability of resources in these scenarios. In these situations, the artificial recharge contributes to the improvement of the quantitative status of the aquifer, in addition to allowing the immediate availability of the water stored in the key areas of the supply system. In this work is exposed the constructive design of an experimental installation of ASTR constructed in the year 2010 by Canal de Isabel II, which is the company that manages the integral water cycle in the Community of Madrid, with more than six million inhabitants. The objectives of this installation was the realization of some tests that allowed to evaluate the suitability of the application of the technique of deep recharge in the aquifer of Madrid and to advance in its knowledge. The main conclusion obtained from this complex experimental installation is, precisely, its extreme complexity that gives it difficulty in the operation. This conclusion opens the door to assessing a design that can be generalized in the entire field of operation of the ATDM and that is more efficient in its execution and management.

Introduction

Canal de Isabel II is a public company with more than 165 years of history, dedicated to the management and operation of the supply and sanitation services in the Community of Madrid (CAM). It currently serves the water needs of more than 6 million inhabitants, taking advantage of surface and underground resources. The average annual supply is around 500 million cubic meters, in a context of high variability in the availability of the natural resource. Thus, in the last 30 years, there have been minimum annual contributions of 324 million m^3 (yH 2004- 2005) and maximum contribution values of the order of 910 million m^3 (Hy 1995-1996), requiring operations adapted to each circumstance.

Among the multiple conmitments of this company is that of maintaining, replace and planning infrastructures and services, adapting them to the expectatins of society, as well as minimising environmental impact and favouring the efficient use of available resources. Within this framework, groundwater and the infrastructures that allow its use in periods of water scarcity, when other resources are scarce, or in the event of contingencies in the supply system, are of special importance. For this reason, the application of techniques for artificial recharge of aquifers and the facilities that allow it, deserve special attention to take advantage of the structural characteristics of the supply system and the great potential of the main aquifer as a buffering element, also making it possible to take advantage of the existing hydrological variability.

Currently, Canal de Isabel II groundwater system has more than 80 facilities dedicated to these resource operations. These facilities are wells with depths greater than 400 meters, which operate groundwater as a strategic resource to cope with scenarios of scarcity and contingencies.

This article describes the design and main characteristics of a specific underground storage system with resource transfer and recovery (ASRT) designed and built by Canal de Isabel II as a pilot facility to assess the suitability of the application of managed aquifer recharge (MAR) methods by deep injection into the region's main detritic aquifer. It has been called "**ASRT FE-1 Facility**" It consists essentially of one deep recharge well, one extraction well and a set of piezometers for the control and monitoring of the operation. In this case, the water to be recharged is of superficial origin and comes from the occasional and seasonal surpluses of drinking water which final destination wasthe population supply. The system makes possible to take advantage of scenius of abundance of the resource and the additional treatment capacity.

Hydrogeological framework of the ASRT FE-1 facility

The groundwater management and operation carried out by Canal de Isabel II is structured by well fields distributed in the main aquifers of the region, following well defined exploitation criteria. 90% of the wells are in the central strip, which is the competent surface for the detritic tertiary aquifer of Madrid (ATDM). In this context, the ASRT FE-1 facility is in the Fuencarral well field, located in the center of the CAM wich constitutes one of the main well fields exploiting the ATDM (Figure 2).

Figure 1 represents the hydrogeological situation of the Canal de Isabel II wells, highlighting the Fuencarral well field and the location of the ASTR FE-1 installation.

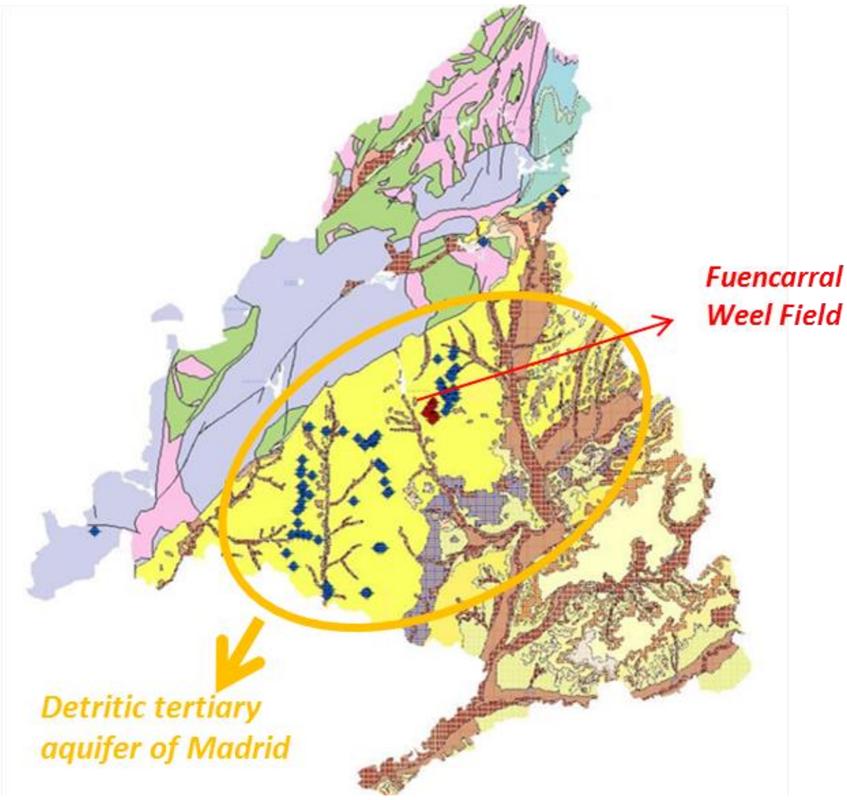


Figure 1. Locations of Canal de Isabel II wells

ATDM is a multi-layer aquifer that constitutes an important strategic reserve, as it has adequate structural, hydrogeological and hydrochemical characteristics. Its great extension and thickness make it a great potential as a warehouse and as an element of hydraulic buffer, due to its large storage capacity, slow flow speeds, low vulnerability to variations in rainfall and pollution is more reliable than surface aquifers.

However, its hydrogeological parameters may be low (for example: average total porosity of around 50%, typical of clayey materials, and average vertical permeability between 0.03 and 0.15 m/day). It is an aquitard and not an aquifer itself, so the sustainability of its exploitation is a fundamental factor (Sánchez, E. 2018).

Its characteristics may vary greatly depending on the area and depth. Thus, in a very general way, according to CyPS-UCM-Group of Catalysis and Separation Processes (UCM) (2007), can showt:

- Transmissivity (T): 1 - 852 (m^2/day)
- Vertical conductivity (KV): 0,089 - 0,31 (m/day)
- Horizontal conductivity (KH): 10-5 - 0,9 (m/day)
- Storage Coficient (S): 10^{-5} - 10^{-1}
- Porosity (m): 1 - 20%

The following are some **technical challenges** that hinder the efficient application of recharge in this aquifer:

- It is a very deep aquifer. The wells that are part of the extraction system have depths greater than 400 meters.

- Its hydrogeological parameters give these depths the condition of confined or semi-confined aquitard, making it difficult for water to enter the formation. However, this feature may help to keep the recharged water within a radius of less than 1000 meters from the injection point, being this aspect very interesting for later use.

- It is its configuration as a deep aquitard that influences, among other more operational considerations, the design of the artificial recharge facilities, forcing the injection to be carried out at high depths and preventing air from entering the system, in such a way that could be occluded, hindering the process of water admission into the aquifer and opening up possibilities of generating significant problems in the installation.

- These characteristics require to provoke narrow cones of pumping and with important descents, obtaining specific flows normally lower than to 0,5 l/s.m, wich do not facilitate the application of MAR techniques.

Figure 2 shows a lithological correlation profile of the Fuencarral well field, which includes the wells of the ASRT FE-1 facility. There is a predominance of fine particle size materials and, consequently, reduced permeability of the whole. The drilling depths are represented, as well as the position of the electro-pump units installed in the wells. The exploitation zone of the wells is defined between the two discontinuous lines that mark the maximum static level of the aquifer and the maximum dynamic level reached with the exploitations that occurred to date.

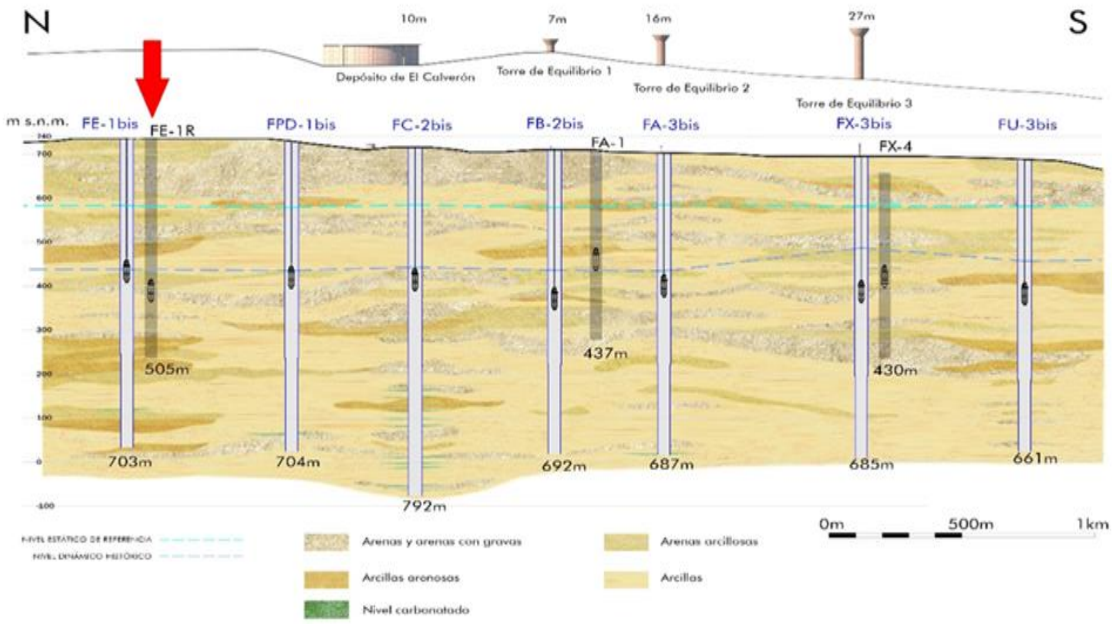
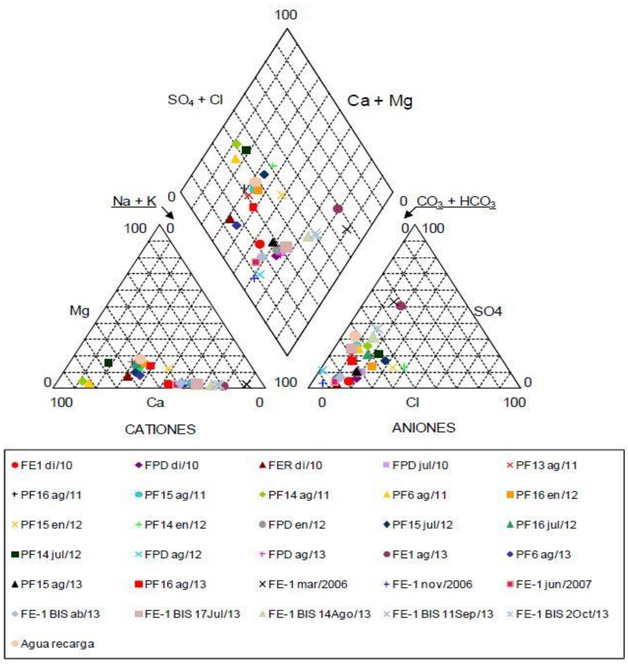


Figure 2. Lithological columns correlation in the Well Field.

The water quality of the ATDM progresses with depth, from bicarbonated calcium facies to bicarbonated sodium facies (Figure 3 shows the Piper diagram of the wells and piezometers controlling the recharge zone). The extraction of water, increasingly deep as the extractive activity occurs, increases its sodium concentration and reduces the calcium concentration (there is an exchange of calcium from the water retained in the clays for sodium from the aquifer matrix) (IGME-CYII, 1997). Regardins conductivity, the average value of aquifer water is normally greater than 300 µS/cm, while the conductivity of the recharged water is 90-100 µS/cm.

Figure 3. Piper diagram of the set of water samples from wells and piezometers around the ASRT FE-1 facility.



The quality of the water extracted must meet the requirements established in the Spanish standard of drinking water RD 140/2003, of February 7, *which will establish the sanitary criteria of the quality of water for human consumption*. Special attention is given to the arsenic parameter since the Fuencarral well field tends to give incidents related to this parameter. In the study area, this parameter remains close to 9 µg / l (in the recharge well, which is less deep, the concentration of As is lower than 3.8 µg /l). During exploitation, arsenic levels may increase and therefore dilution is required. A disinfection is also carried out before the water is incorporated into the supply system.

Further data related to the chemical quality of the aquifer water in the area are (table 1):

Conductivity	659 µS
pH	8,06
Temperature	28,3 ºC

Table 1. Chemical physical parameters of the water extracted by the FE-1 Bis well (1996)

The Basin Agency required that the water destined for recharge also comply with the Spanish standard of quality of water for human consumption (RD 140/2003). For this reason, the water used in the recharging activity comes treated and is suitable recide to suplly of distribution network of Canal de Isabel I.

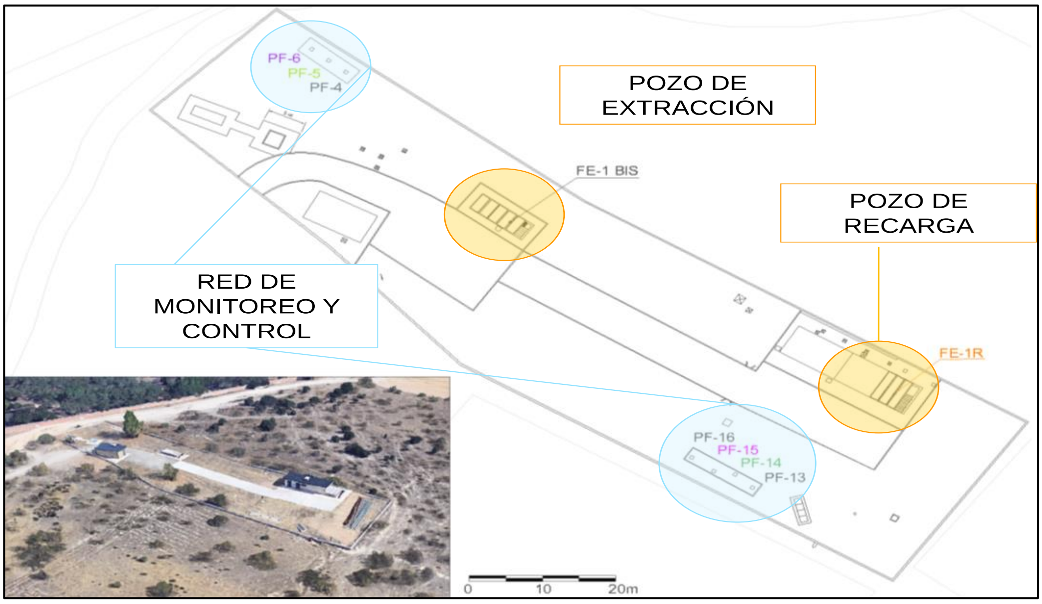


Figure 4. ASRT outdoor and floor ASRT facilities.

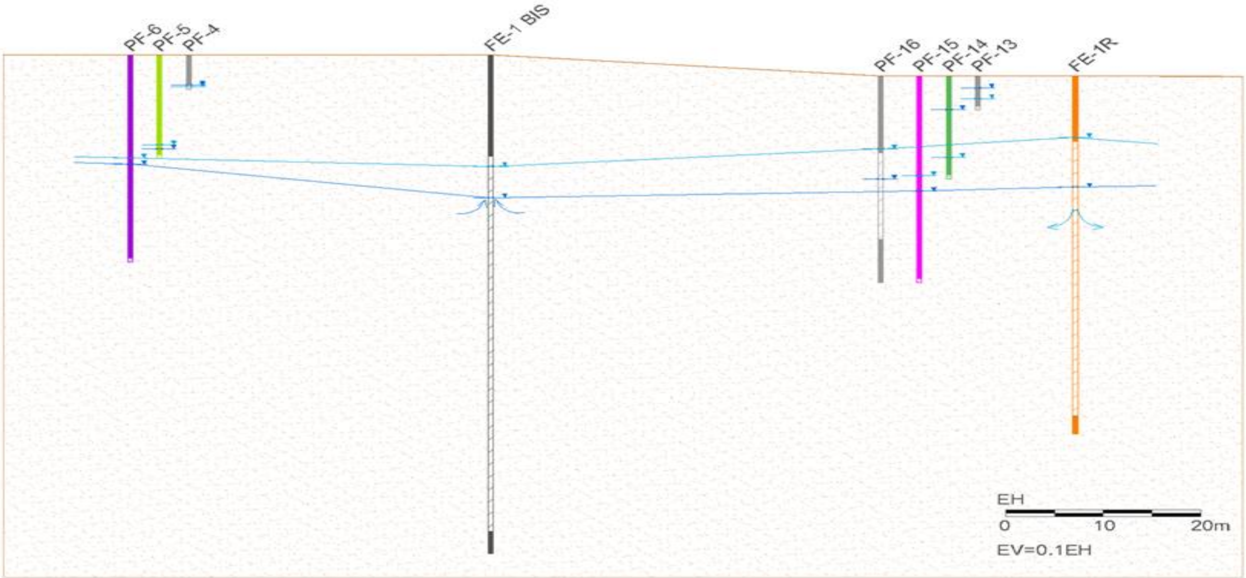


Figure 5. Recharge operation scheme.

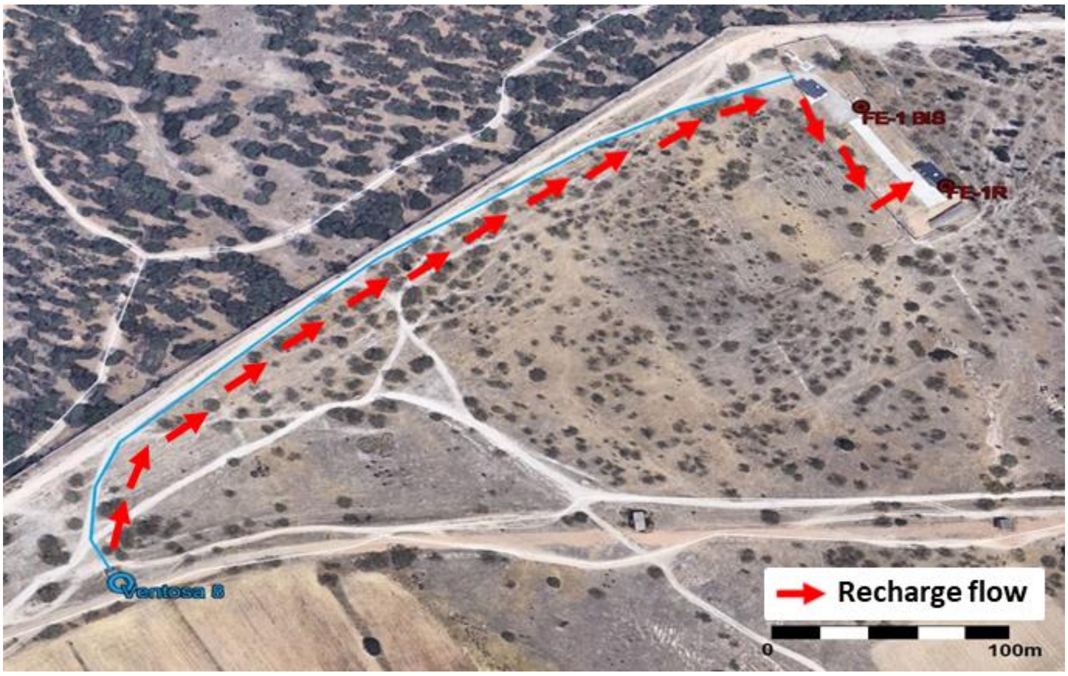


Figure 6 Recharged water source location.

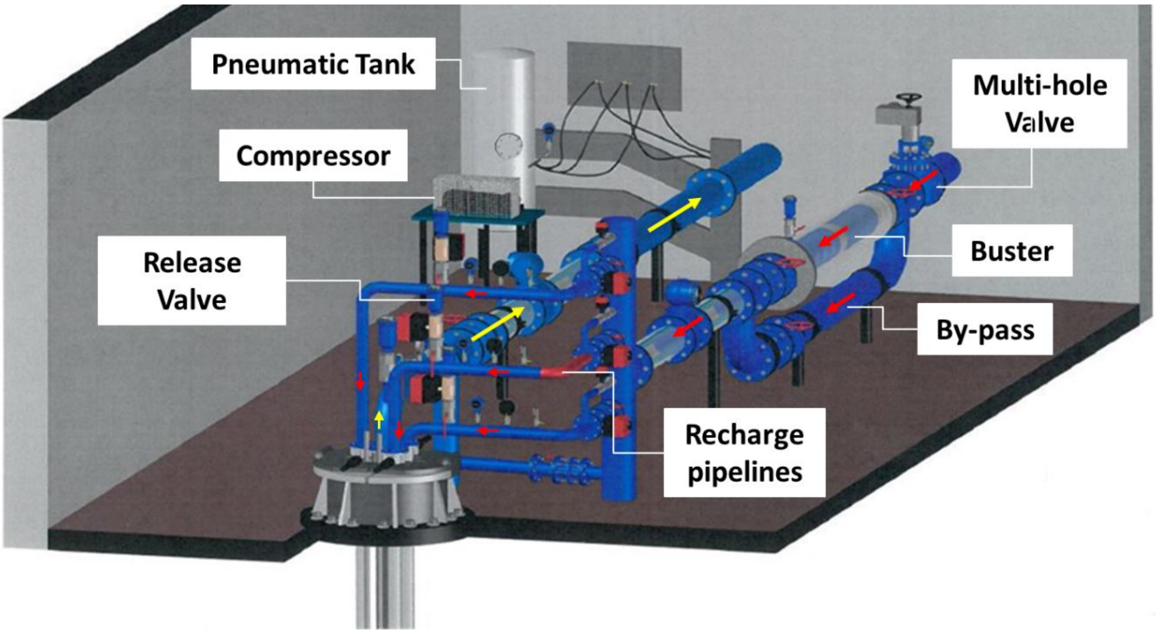


Figure 7. Devices inside recharge-pumping building.

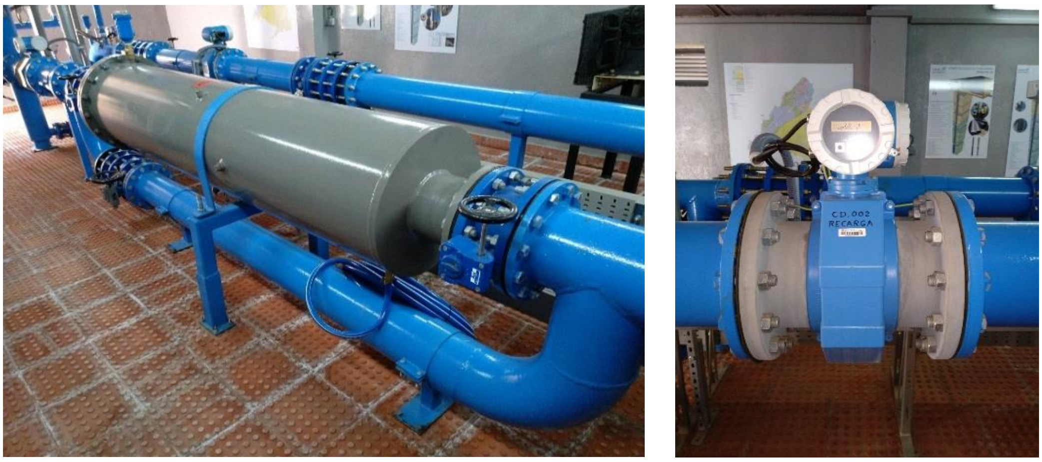


Figure 8. a) Recharge buster and bypass. b) Recharge electromagnetic flowmeter.

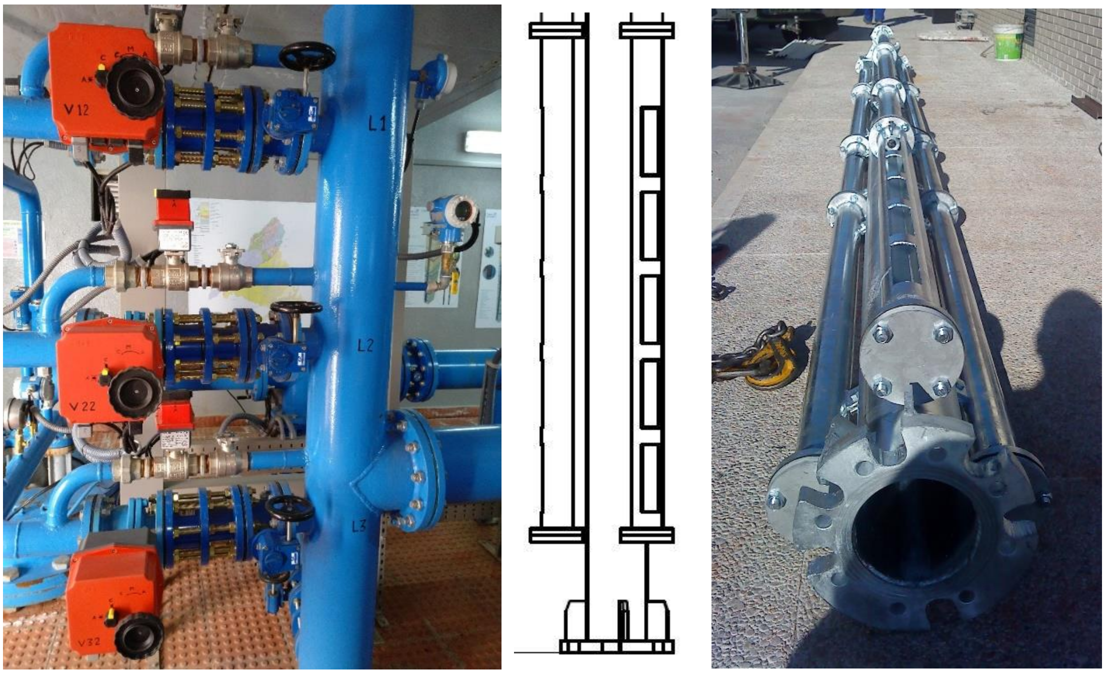


Figure 9. a) Recharge motorized valves and auxiliary lines. b) and c) Recharge pipes diagram and parts before assembling.

Figure 10. FE-1R recharge pipes and clamp.

Figure 11 a) From right to left, following extraction line flow direction, sampling valve, temperature sensor, pressure gauge, manometer and turbidimeter. b) Turbidity measurement system.

Summary

Experimental installation ASRT FE-1 confirms method feasibility despite its extreme operational and constructive complexity.

It's necessary to reduce/eliminate blockage processes that cause flow reduction.

ASRT technique is more efficient and sustainable when facilities already built are used. Canal de Isabel II has a suitable groundwater operation system for this use.

In order to prevent breaks, anomalies and clogging, ASRT technique is more appropriate than ASR for strategic supply infrastructures uses.

This pilot could be complemented in whole ATDM looking for more execution and operation cost efficiency.

Whatever, since eventual prolonged exploitation temporarily affects aquifer quantitative state, artificial recharge contributes to the recovery of the good quantitative state and ensures the recovery of the stored water in the key areas of the supply system.