Managed Aquifer Recharge in France

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In France 67% of the volume of drinking water in France is produced by groundwater. For industrial and agricultural purposes, 40% of water supply comes from groundwater. French water regulations are fixed by the European Water Framework Directive (WFD) that defines the legal framework supporting the commitment to protect and restore water quality and aquatic environments.

"Good chemical status" of an aquifer is achieved when contaminant concentrations are not higher than the standards fixed by the WFD for groundwater. "Good quantitative status" of groundwater is achieved when the volume of water withdrawn is not higher than the renewal capacity of the water body and when the connected surface ecosystem health is maintained.

In 2013, 90.4% of the 645 identified groundwater bodies in France were in a good quantitative status but only 67% of them were in good chemical status (ANSES 2016).

With the constant population growth combined with climate change, the management of groundwater resources in France is mostly focused on water conservation and enhancement of natural recharge of aquifers (*eg*. hill reservoirs). But these actions are not sufficient to face water scarcity in some localities, and Managed Aquifer Recharge (MAR) could be an interesting and efficient way to maintain and improve groundwater quality and quantity.

Centralised governance of MAR practice in France is not established. However French regulation allows MAR on a case-by-case basis by prefectural authorization most often in the context of preventing saline intrusion or to meet the need of seasonal water demand as required depending on climatic conditions.

According to the WFD, the good status of the water bodies affected by MAR must be preserved. In France, the sources of water for enhancing recharge are mainly surface water (river) that is put into infiltration ponds.

Table 1 shows the major MAR sites in France. This shows there is considerable experience since the 1950s and there have been occasional periods of quite active development in the 1960s, 1980s and 2000s. A map showing MAR sites in France is found in Casanova *et al* (2016).

Table 1. ARTIFICIAL RECHARGE OF GROUNDWATER SITES FROM SURFACE WATER IN FRANCE

SITE	Starting date of operation	Artificially recharge water volume ($Mm^3\ y^{-1}$)	Recharge system
Donzere Mondragon	1952	$8.5 m^3/s$*	Injection wells
Croissy sur Seine	1965	30.0 [a]	Infiltration ponds
Appoigny	1968	0.4 [b]	Infiltration ponds
Flins-Aubergenville	1980	8.0 [a]	Infiltration ponds/Bank filtration
Durance river	1980	5.0 [a]	Infiltration ponds
Vessy	1980	10.0 [a]	Infiltration ponds
Houlle Moulle	1983	4.4 [c]	Infiltration ponds
Flammerans	1997	6.6 [a]	Injection wells
Verneuil sur Seine-Vernouillet	2009	0.7 [b]	Infiltration ponds/Bank filtration
Hyères-les-Palmiers (France, Var)	2015	0.65 [b]	Infiltration ponds

* data in $m^3\ y^{-1}$ not available, [a] maximum capacity, [b] estimated annual value, [c] annual mean during activity period (still operating French major sites from Wuilleumier and Seguin, 2008; SIGESSN)

The Croissy-sur-Seine site can be cited as a pioneer in terms of MAR in France (Casanova et al., 2013). This site was put in operation in 1959 in order to increase the quantity of water withdrawn from the chalk aquifer for drinking water purposes (Detay, 1997). The Seine river water after pre-treatment is infiltrated into the aquifer through 9 infiltration ponds. The 12 hectares of replenishment basins help sustain 31 wells. 20 to 30 Mm^3 per year of water are infiltrated in the aquifer. Moreover, a bank filtration recharge system is coupled with infiltration ponds from Seine River under pumping wells action.

Since 2015, the active management of the main water resource of the city of Hyères-les-Palmiers (France, Var) has been developed to prevent saline water intrusion of the Bas Gapeau hydrosystem (AQUARENOVA project). This system is based on a real-time abstraction control, based on a continuous monitoring of water level and conductivity on specifically localized piezometers. The hydraulic gradients method shall optimize abstraction without risking saline intrusion (detected early 2000). In winter, aquifer recharge is operated by infiltration ponds, abstracting coastal river Roubaud water, in order to form a freshwater piezometric dome exploited in summer (Duzan *et al.,* 2016).

It is quite difficult to estimate the total amount of groundwater replenishment by MAR in France and Table 2 is based on the factual information of Table 1 and assumes that average annual recharge is approximately half the annual maximum capacity where actual volumes are unknown.

Table 2. Estimated volume of MAR in France over the last 60 years

Decade	Annual volume of MAR (10^6 m^3/y)
1951 - 1960	?
1961 - 1970	20
1971 – 1980	21
1981 – 1990	26
1991 - 2000	30
2001 - 2010	31
2011 - 2015	32

Recently, the French Agency for Food, Environmental and Occupational Health & Safety (ANSES) published opinion on the health risks related to MAR (2012-SA-0255) and put emphasis on MAR solutions using surface waters or treated wastewater to mitigate the decrease in French groundwater resources in the future. The quality of groundwater must be preserved during MAR practices and particularly to guarantee quality compatible with production of drinking water, without needing to use additional treatments funded by local authorities and consumers. ANSES recommends developing studies of MAR sites in France to ensure sustained quality of recharged groundwater and to better characterise the hazards to humans.

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