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Water Rock Interaction [WRI 14]

Groundwater salinization in France

W. Kloppmann^{a*}, A. Bourhane^{a,b}, S. Schomburgk^a

^aBRGM, 3 Av. C. Guillemin, F-45060 Orléans, France

^bUniversité de la Réunion, Laboratoire Géosciences Réunion – IPGP, 15 Avenue René Cassin, BP 7151, F-97715 Saint-Denis, CEDEX 9, La Réunion, France

Abstract

The state, sources, and vectors of salinity in French aquifers are assessed through a GIS-based approach and a literature review of geochemical studies. Seawater intrusion is dominant in the insular context, but the most impacted water bodies are inland aquifers affected by WRI with Permian to Tertiary evaporites, mixing with primary and secondary sedimentary brines, partly derived from human activities (salt mining). The complexity of the superposition of natural and anthropogenic sources is illustrated for the alluvial Rhine aquifer.

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Keywords: salinization, evaporites, brines, seawater intrusion, groundwater bodies, salt mining, geochemical fingerprinting, France.

1. Introduction

Salinization of groundwater bodies is one of the principal causes of degradation of water resources worldwide. This phenomenon is a major drawback for water use for irrigation and drinking water supply in arid and semi-arid regions where water quality problems superpose to a general quantitative limitation of freshwater availability. The mechanisms of salinization are diverse and complex situations with multiple sources of salinity are frequently encountered, notably in coastal aquifers. The principal natural vectors of salinity in groundwater bodies (fig. 1) are seawater intrusion, mixing with paleo-seawater and brines, WRI with direct dissolution of evaporites by fresh groundwater, infiltration of saline surface water, but also a large variety of human sources of saline solutions (industrial liquid or solid waste, salt mining activities, agricultural backflow). Natural mechanisms of salinization may be triggered or accentuated by human activity, e.g. over-pumping of coastal aquifers. A nation-wide synthesis of

* Corresponding author. Tel.: +33 2 3864 3915; fax: +33 2 3864 3711.
E-mail address: w.kloppmann@brgm.fr.

salinization phenomena has been undertaken in 2011 for the French National Agency for Water and Aquatic Environments (ONEMA), [1, 2].

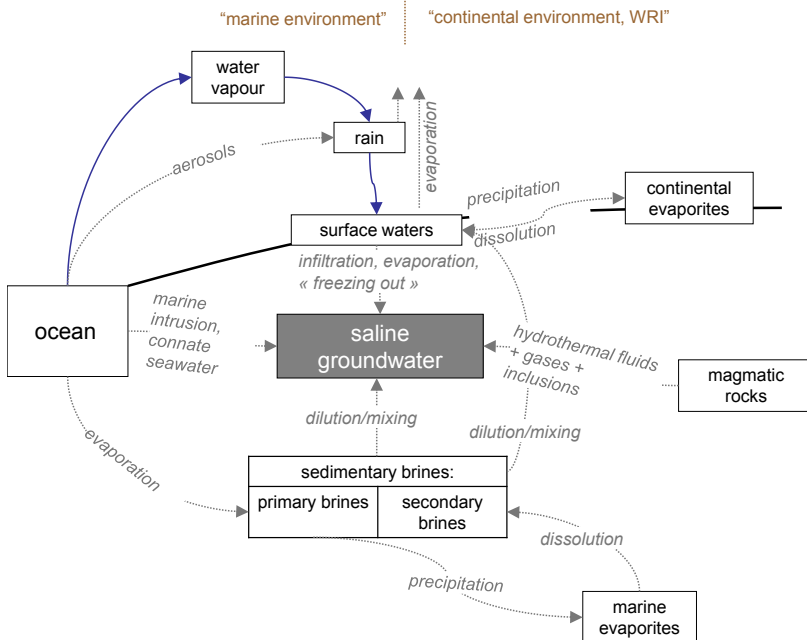


Fig. 1. Natural sources and vectors of groundwater salinization within the global water cycle [1].

2. State of salinization of French aquifers

The approach is based on recent data (2005-2010) on the mineralization of the French groundwater bodies as defined by the European Water Framework Directive, extracted from the ADES data base (<http://www.ades.eaufrance.fr>) and integrated in a GIS. A classification of water bodies was undertaken based on the number of observation points impacted by average chloride concentrations above a threshold (100 mg/L) to identify those with salinities significantly above the mean geochemical background values in the French context without taking into account specific water uses. Based on literature, hypotheses on the origin and vectors of salinization are formulated for most of the concerned water bodies and a general typology of French continental and overseas groundwater bodies is established.

Even if seawater intrusion appears as the principal vector of salinization in the insular context (Corsica, Guadeloupe, Martinique, La Réunion), this is not the case for the French mainland. Water bodies with the highest numbers of impacted points are found inland (fig. 2). Main salinization mechanisms encountered in the French continental aquifers are:

- Natural dissolution of evaporites of Permian to Tertiary age in the principal sedimentary basins (East of the Paris basin, Rhine Graben, Aquitaine Basin, Provence basins)
- Conservation of paleo-seawater or brines derived from seawater evaporation in confined parts of the multi-aquifer systems of the sedimentary basins. Those saline fluids are either syn-sedimentary (connate) or post-sedimentary. In the latter case, basin-wide migrations of sedimentary brines have been evidenced but also residual saline fluids from Tertiary and Quaternary marine transgressions in coastal water bodies (Camargue, Poitevin marshlands, Jurassic limestone of the Caen plain, Landenian

sands of Flanders...). In certain cases such paleofluids are found in the same aquifers concerned by recent seawater intrusion (Camargue)

- Divers industrial point sources contribute to salinity often in addition to natural sources and are principally linked to exploitation and use of salt-bearing formations. Sylvite extraction in the Mulhouse potash basin led to most spectacular salinization plumes over 60 km in the alluvial aquifer of the Rhine River; halite extraction for soda production was identified as salinity source in the Lorraine and the Jura. Such point sources contaminate both rivers (Rhine, Moselle) and the accompanying alluvial groundwater (e.g. alluvium of Durance and tributaries).
- Diffuse input from human activities creates a “background noise” of salinization, normally without exceeding alert thresholds. Some chloride rather systematically accompanies agricultural nitrate and pesticide contamination, and road salts contribute to the salinity balance mainly in the N and E of France.

3. Geochemical fingerprinting of salinity in French aquifers

Untangling multiple salinity sources in a groundwater body is a complex task that needs a combination of tools from geophysics, flow and transport modeling and geochemistry, including isotopes and radioisotopes. Stable isotopes of the water molecule are used to assess mixing with seawater, evaporative concentration of surface water and aquifer hydrodynamics in general. They are frequently combined with isotopes of solutes accompanying salinization phenomena, e.g. B, Sr, Li, S, O... and with indicators of residence time of saline and fresh waters, both radio-elements (^{14}C , ^3H) and chemical tracers (CFCs, SF_6). The latter allow for discrimination of anthropogenic (i.e. recent) and natural triggers of salinization. The example of the most impacted French water body, the Rhine alluvial aquifer, monitored since the 1970^{ies} illustrates the complexity of multiple salt sources and of multi-tracer studies in French aquifers. Solid and liquid waste disposal from potash mining contaminated large parts of the groundwater over one century, a contamination that slowly resorbs due to stringent remediation measures. Natural brines up to 120g/L with highly variable facies are found in the sedimentary and crystalline bedrock below the alluvial aquifer up to depths of 5 km [3,4]. These brines are partly syndimentary, partly secondary due to WRI with Triassic and Oligocene evaporites and they may mix with alluvial freshwaters in zones through faults and through direct contact with diapirs. Discrimination of natural and man-induced salinity is a major challenge in this context as rain water leaching of solid waste from potash mining creates brines similar to those derived from underground leaching of the same evaporite formations which host the potash salts. A large variety of environmental isotope tracers ($^{87}\text{Sr}/^{86}\text{Sr}$, $\delta^{11}\text{B}$, $\delta^{34}\text{S}$ and $\delta^{18}\text{O}$ of sulfates, $^{234}\text{U}/^{238}\text{U}$, $\delta^2\text{H}$ and $\delta^{18}\text{O}$ of the water molecule), and dating tools (^{14}C , ^3H , SF_6 , CFCs) were applied in numerous studies (synthesis in [5]). Boron isotopes revealed promising for the identification of brines disposed in surface reservoirs, due to strong enrichment of ^{11}B ($\delta^{11}\text{B}$ close to +60 ‰) in certain contamination plumes, sulphur and oxygen signatures of evaporites are specific for potash layers [6, 7] and are found in the corresponding mining-related brines. Groundwater dating identified mixing of old geogenic brines with younger components related to the mining activity. This has practical implications for the monitoring and efficiency assessment of the current remediation measures.

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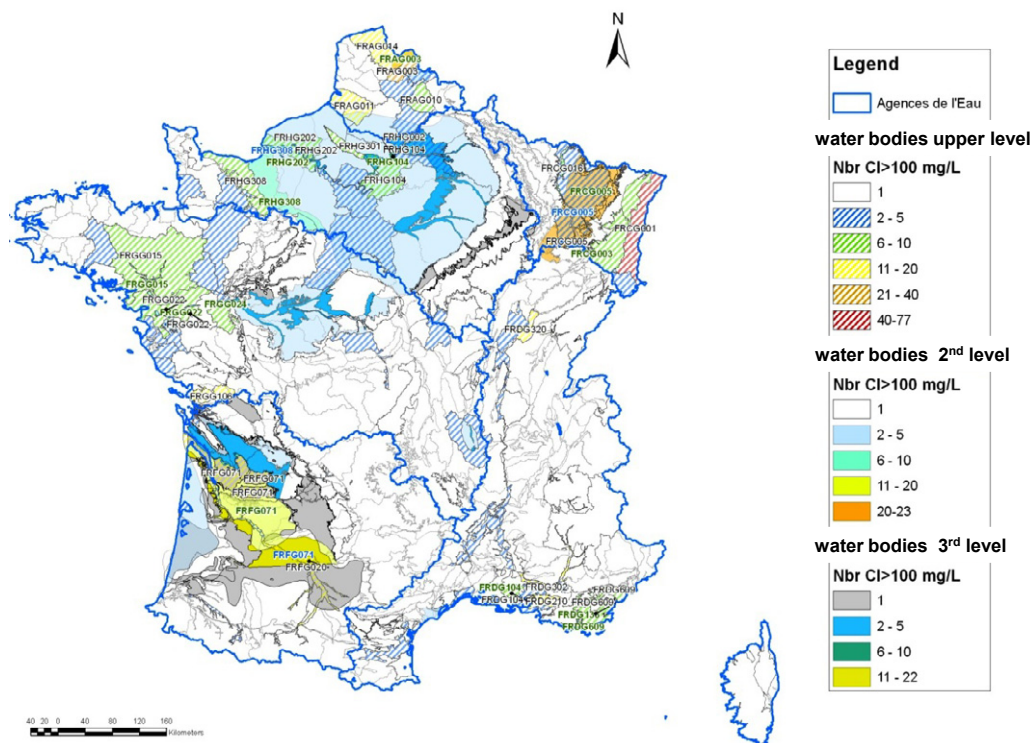


Fig. 2. State of salinization of French groundwater bodies as defined by the Water Framework Directive based on the number of points exceeding a threshold of 100mg/L of mean (2005-10) Cl⁻ concentrations. For multi-layer aquifer systems the uppermost three levels are considered.

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