



Offshore freshened groundwater in the Northern Adriatic Basin: Insights from integrated 3D modelling and hydrochemistry

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Offshore freshened groundwater (OFG) is increasingly recognised as a potentially significant, yet still poorly constrained, freshwater resource stored on continental shelves. In the northern Adriatic Basin, OFG presence is supported by low salinity interstitial water (< 1 g/L) in a few hydrocarbon exploration-related drilling sites. Building on these observations, assessing whether OFG is widespread across the basin, and constraining its distribution, characteristics, emplacement mechanisms, water quality, and resource potential, requires a multifaceted investigation. Here, we synthesise the current state of knowledge for the Northern Adriatic Basin system, based on results obtained to date from integrated 3D modelling and regional monitoring datasets.

Onshore-offshore connectivity of high-permeability layers is supported by 3D geological geostatistical modelling. We built a 3D geological model of upper Plio-Quaternary sediments and simulated permeable facies distributions using Sequential Indicator Simulation, capturing depositional anisotropy consistent with mixed fluvial-coastal processes. The model supports laterally extensive, southward-dipping permeable units that extend offshore and remain connected across the coastline, providing a physical basis for OFG occurrence and storage. Active flow interaction is further supported by groundwater flow modelling. A transient groundwater flow model was developed and calibrated; simulated coastal exchange indicates that the Northern Adriatic Basin is hydraulically active but characterised by a very small offshore-directed freshwater flux, implying minimal present-day active recharge. Finally, regional onshore hydrochemical analysis suggests that OFG quality has not been substantially affected by anthropogenic inputs, although its potential for utilisation must be evaluated carefully. Hydrochemical results from coastal confined aquifers (multi-decadal monitoring combined with new sampling) delineate distinct groundwater families and age characteristics. Near the coast (and consistently offshore), the most chemically evolved end-member is characterised by strongly reducing conditions (elevated NH_4^+ and redox-sensitive metals) and is consistent with emplacement during the Last Glacial Maximum (LGM) sea-level lowstand. Together, these findings support the presence of

offshore permeable reservoirs saturated with freshwater that was likely emplaced during or before LGM, with minimal subsequent contribution, and currently under strongly reducing conditions, implying potential potability limitations.