Unlocking Offshore Freshened Groundwater

OFF-SOURCE Utilization Working Group
Technical Report

Introduction

Coastal aquifers have been described as the nexus of the world's oceanic and hydrologic ecosystems, as they provide water for over one billion people (Small and Nicholls 2003). Freshwater resources in coastal areas have been exploited beyond sustainable limits (Werner et al. 2013; Ferguson and Gleeson 2012), and these systems are under increasing pressure due to rapid population growth, urbanization and climate change (Bates 2008; Hofste et al. 2019). Offshore freshened groundwater (OFG) is water stored in pores of sediments and fractures of rocks in the sub-seafloor and with a total dissolved solid (TDS) concentration below that of seawater (Micallef et al. 2021). In recent years, there has been mounting attention toward OFG systems due to their classification as a potential unconventional water source for coastal regions grappling with heightened water scarcity (UN-Water 2020; Bakken et al. 2012, Post et al. 2013). The utility of freshwater stored in aquifers that extend offshore beneath the seafloor has been known to coastal communities for centuries, and documented as far back as 1000 BC (Person and Micallef 2022). Moosdorf and Oehler (2017) provide an extensive historical review of the variety of ways that fresh submarine groundwater discharge has been valued as a water resource for drinking, hygiene, agriculture, fishing, tourism, culture, or ship navigation. A multidisciplinary review by Micallef et al. (2021) provides a global overview of offshore freshened groundwater (OFG) occurrences, highlighting its potential as a valuable resource. The study, which analyzed over 300 records, shows that OFG is widely distributed across continents worldwide (Figure 1).

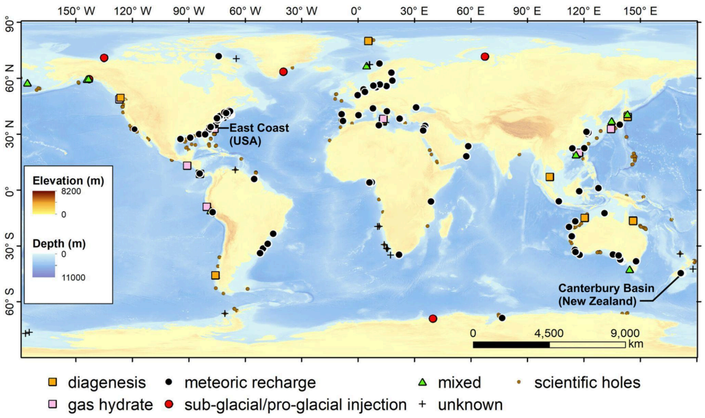

Figure 1 Map of OFG records and emplacement mechanisms. "Mixed" refers to two or more reported emplacement mechanisms. Scientific holes refer to sites drilled by the International Ocean Discovery Program (IODP), Ocean Drilling Program (ODP), and Deep Sea Drilling Project (DSDP) in continental margins with no record of OFG. Source: [(Micallef et al. 2021)](#)

OFG can be emplaced by meteoric recharge (either at present or during sea-level lowstands (Meisler et al., 1984; Michael et al., 2016)), sub-glacial and pro-glacial injection (Person et al., 2007), diagenesis (Kastner et al., 1991) or gas hydrate dissociation (Hesse and Harrison, 1981). The large majority of OFG records are meteoric in origin and located in siliciclastic, passive, non-glaciated margins, within 55 km of the coast in water depths of less than 100 m. There are some key challenges that need to be addressed in order to properly assess the feasibility of OFG as a resource. These include:

1. **Lack of appropriate data**: Incidental discoveries during scientific and industry drilling, in conjunction with analyses of total dissolved solids and chloride anomalies in pore waters, have provided most fundamental information on OFG thus far.
2. **Limited availability of approaches to constrain OFG systems**: We have a poor understanding of the distribution, extent and dimensions of OFG bodies. Recent improvements in marine electromagnetic systems have provided the geoscience community with a non-invasive technique that can resolve electrically resistive sub-seafloor freshwater
3. **Technological and economic feasibility of OFG utilisation is unknown**: OFG exploitation requires drilling, extraction and transportation of the groundwater from offshore aquifers to onshore and, in most cases, treatment at water processing plants.
4. **The environmental impact of OFG utilisation is poorly understood:** It is not clear how an OFG body responds to extraction and climate-related changes.
5. **Legal implications of OFG use are unclear:** Most OFG that has been discovered to date lies within the legal continental shelf of numerous states, although higher salinity OFG has been detected in marine areas beyond national jurisdiction. While OFG bodies will almost certainly be found straddling maritime boundaries, the United Nations (UN) Convention on the Law of the Sea provides no guidance on transboundary resources.

The OFF-SOURCE COST Action seeks to establish a new scientific network to evaluate the potential of Offshore Freshened Groundwater (OFG) as an unconventional source of potable water in coastal regions. To advance this objective, a workshop was held on September 25th, 2023, at the Valletta Campus of the University of Malta. This pioneering event brought together 27 experts from 17 countries, including professionals from the oil and gas industry, groundwater researchers, hydrogeologists, and water treatment engineers. The workshop focused on the feasibility of utilizing OFG as a sustainable freshwater resource. This report presents a comprehensive summary of the workshop's key discussions and includes a preliminary economic analysis to evaluate cost-effective infrastructure solutions for OFG utilization, addressing both scientific and economic considerations involved in harnessing this resource. Finally, we highlight regions that are most likely to be able to benefit from OFG, either because of availability and/or water stress.

What is the potential?

Water scarcity affects nearly 4 billion people globally (Knorr & Augustin, 2023). Regions where annual water withdrawal exceeds 20% of availability or where per capita availability falls below 1,700 m3/year are considered water-stressed (Hanasaki et al., 2018). Offshore freshened groundwater (OFG) represents a significant potential water resource in coastal areas worldwide. Recent studies have identified and modeled large OFG reserves in various locations, including the New Jersey Shelf, USA (Gustafson et al., 2019), Canterbury Bight, New Zealand (Micallef et al., 2020; Morgan & Mountjoy, 2022), Pearl River Estuary (Sheng et al., 2023), and East China Sea (Thomas et al., 2023). Bakken et al. (2012) suggested the resource potential of OFG systems, proposing their use as potentially a more cost-effective source of raw water for desalination. In recent years, a number of attempts have been made to estimate the volume of fresh - brackish water stored offshore using different approaches.Some studies estimate freshwater using a Total Dissolved Solids (TDS) cutoff value of 1 g/L, while others include brackish water, using a TDS cutoff of less than 10 g/L. These are briefly summarized in Table 1.

Table 1 Summary of recent global estimates of OFG volumes

Estimate OFG volume (km^3)	TDS (g/L)	Methodology	Reference
$1.06 \pm 0.2 \times 10^6$	< 1	Estimated from numerical groundwater models on geologically representative shelf transects	Zamrsky et al. (2021)
1.09×10^6	< 10	Mean OFG volume per km of shoreline was calculated from known occurrences then scaled globally by the total length of passive and active margins	Micallef et al. (2021)
5×10^5	< 10	Estimated by analysing seven shore-normal cross sections each of which had a relatively high observation data density	Post et al. (2013)
3×10^5	< 1	Calculated based on 3.8 km^3 per kilometer of shelf, derived from salinity profiles in the U.S. and Suriname, and a global shelf length of 80,000 km.	Cohen et al. (2010)

To place these figures in Table 1 into perspective, the global groundwater volume in the upper 2 km of the continental crust is estimated at 21.8×10^6 km^3 (Ferguson et al 2021). Based on current estimates, OFG represents an additional 5% of this volume, highlighting its significance as a potential supplementary source.

Key Criteria for Offshore Freshwater Feasibility

To assess the viability and value of extracting Offshore Freshened Groundwater (OFG) as a freshwater resource, it is essential to compare it to existing water supply options, such as desalination and traditional freshwater sources. This comparison requires analyzing several key parameters, including the quality of the water, extraction and transport costs, environmental impacts, and treatment requirements. While some factors, such as transport logistics and local infrastructure, will be geographically specific, others, like basic resource availability and treatment technologies, will have broader applicability across various regions. A comprehensive evaluation of these parameters is crucial for determining the economic and technical feasibility of OFG in comparison to other water sources. The following list outlines some of the primary considerations.

Water Quality and Treatment Requirements

- End Use of Water: The intended purpose of the water (e.g., agricultural use vs. potable water) will determine the quality standards and, subsequently, the treatment costs (Plappally & Lienhard, 2013). For agricultural irrigation, water quality must meet public health and agronomic requirements (Bahri, 1999), with standards varying between developed and developing countries (Bouwer, 1992).

- Water Quality at Source: The initial quality of the extracted water, including contamination by salt or chemicals, directly impacts the cost of treatment. Geologically older and fossil waters, as is the case for some OFG systems, may require extensive purification to meet drinking water standards. Conversely, it is equally important to consider what the existing quality of the water allows it to be used for with minimal additional treatment.

Sustainability and Resource Longevity

- Duration of Use: The viability of OFG as a resource may depend on whether it is considered a long-term supply or a temporary/emergency backup for situations like natural disasters.

- Recharge Rate and Aquifer Properties: In cases where an OFG is proven to be hydraulically connected to an onshore aquifer, the natural recharge rate of the OFG aquifer influences its sustainability and the cost of continuous extraction. A study by Zamrsky et al. (2021) noted that OFG should be considered a non-renewable resource.

Infrastructure and Logistics

- Existing Infrastructure: It may be possible to utilize existing infrastructure (e.g., oil rigs) in order to extract OFG. The presence of existing infrastructure, or the need to build new facilities, will have a significant impact on cost.

- Distance and Transport Costs: The proximity of the OFG source to the point of use is crucial in determining overall costs. Additionally, unique offshore factors like metocean conditions and seawater depth significantly impact engineering challenges and expenses, unlike onshore scenarios (Bailey and Freedman, 2024).

Alternative Water Sources

- Availability of Alternatives: The cost-effectiveness of OFG extraction is intricately linked to the availability, feasibility, and costs of alternative water sources in the region, such as desalination and surface water. Desalination, while offering a reliable supply, often entails high energy costs and environmental impacts, which can be mitigated by incorporating renewable energy but may increase overall investment. Evaluating these factors through case studies and regional examples will provide a comprehensive understanding of the most viable and sustainable water resource strategies.

Site-Specific Conditions

- Site-Specific Variability: Due to the complex interplay of factors such as geography, geopolitical framework, geology, and climate, the cost-effectiveness of OFG extraction cannot be generalized and must be assessed on a case-by-case basis. This is similar to offshore wind energy projects, where the feasibility and economic viability of wind farms can vary significantly depending on factors like wind patterns, water depth, and proximity to the grid. Just as each offshore wind project requires a detailed site assessment to determine its cost-effectiveness and potential benefits, OFG extraction must also be evaluated on a case-by-case basis considering local conditions and constraints

Case Study in Wellington, New Zealand

To illustrate the practical considerations of offshore groundwater (OFG) extraction, we examine a case study from 2018 involving Wellington, New Zealand. This initiative aimed to enhance the resilience of Wellington's water supply against natural hazards, such as potential ruptures of the Wellington Fault and associated damage to water pipelines (Rowan and Pipe, 2019). The project explored the feasibility of using offshore groundwater as an emergency source for potable water, particularly in the event of disruptions to land-based supplies.

In this case, two offshore wells were drilled into an extension of an onshore aquifer that extends beneath the ocean for several kilometers (Gyopari et al., 2018). This aquifer system, which is actively recharged from land, is known to create fresh submarine groundwater discharge, forming pockmarks on the seafloor where freshwater seeps from muddy sediments (Hoffmann et al., 2023). The onshore portion of this aquifer is a critical groundwater source for Wellington.

The exploratory drilling, conducted from a jack-up barge, reached depths of 79.3 m and 71.15 m below the seafloor. The pumping tests produced flows between 5 and 13 l/s, indicating significant transmissivities of up to 5000 m²/d. Modelling suggested that up to 20 megaliters per day could be abstracted without significant risk of saline intrusion if land-based wells are operating at lower rates (Rowan and Pipe, 2019). Despite promising physical parameters, the project faced challenges. Age dating of the groundwater revealed it to be between 175 and 200 years old (Rowan and Pipe, 2019), and chemical analyses showed that the water did not meet New Zealand Drinking Water standards without treatment. Elevated concentrations of manganese, iron, ammonia, and arsenic were present, and the necessary treatment would increase project costs by approximately 50%, rendering it economically unfeasible (Rowan and Pipe, 2019).

This case study underscores the complexities of implementing OFG extraction projects, including technical feasibility, cost considerations, and water quality challenges. It provides valuable insights into the practical aspects of using offshore groundwater as a potable water source and highlights the need for comprehensive assessments in similar projects.

Preliminary Cost-Effectiveness Analysis

Seawater desalination is an obvious choice for a baseline to serve in an evaluation of the cost effectiveness of OFG. It is a readily available and increasingly used technology for supply augmentation in coastal communities that may potentially be served by OFG. Both desalination and potential OFG sources are also similar in that they require large upfront capital costs (CAPEX), as well as operational and maintenance costs (OPEX), once up and running.

A range of desalination technologies exist and are used in commercial operations. Of these reverse osmosis (RO) is currently the most popular such technology in new desalination facilities. It is also the most cost effective of the commercially available technologies. For this reason, it will be used as the reference cost. The cost of RO depends on the cost of energy, materials and labor in the market in question, as well as the cost of capital, and the production capacity of the facility, as there are economies of scale. Costs also may be influenced by the salinity of the intake, for instance, if it is sourced from a gulf or bay with higher than average salinity.

Currently costs tend to range from US$ 0.50-1.50 per cubic meter (Cosin, 2019), though a study on water supply in California estimated these at slightly higher than this range (Cooley et al. 2019). These costs have been dropping significantly in recent years, due primarily to improvements in energy efficiency, and are roughly half of what they were in the 1990s (Zhou and Tol, 2005). Israel's Soreq B plant, has contracted for $0.41 per cubic meter, a figure which, at present, serves as the lower bound for seawater desalination costs (Ferris, 2023). The costs of desalination of seawater are roughly 2-3 times higher than that of brackish water (Ullah & Rasul, 2018; Cooley et al., 2019).

Water use scenarios

Where physical conditions of the OFG reserves dictate matters such as water quality, available volume, production potential and cost, the existing onshore water utilization and governance framework ultimately dictates how OFG could fit in and be used. Broadly speaking, the OFG utilization scenarios are:

a. Scenarios that use the OFG at its existing quality but make it suitable for use by basic water treatment such as UV disinfection and filtration. Examples are irrigation water for landscaping, domestic "gray water" applications, as a water source used for mixing (conditioning of the thermal desalination plant product stream).
b. Scenarios that require the OFG water salinity to be reduced by RO, making it suitable for any possible use of water
c. Scenarios that consider using the OFG only as a strategic back-up in cases of calamity or other unforeseen events that affect the supply and availability of existing water sources.
d. Scenarios that consider using the OFG offshore without any treatment or transport to shore, for example to support offshore energy activities.

Leveraging Hydrocarbon Technologies and expertise

The Oil & Gas industry possesses a wealth of experience and technological expertise that can be highly beneficial in exploring and developing offshore groundwater (OFG) resources. This sector's extensive involvement in offshore operations offers valuable opportunities for advancing OFG extraction and utilization, creating potential synergies that can be mutually advantageous.

1. Technological Adaptation and Innovation:

- **Drilling Technologies:** The advanced drilling technologies used in hydrocarbon extraction, such as precision drilling and enhanced safety protocols, can be adapted for OFG exploration. Techniques developed for deepwater oil and gas drilling, including the use of riser systems and subsea equipment, can facilitate the successful extraction of groundwater from offshore aquifers.
- **Seismic Surveying:** Oil & Gas companies use sophisticated seismic imaging techniques to locate hydrocarbon deposits. These methods can be adapted to map and assess offshore aquifers, improving the accuracy of resource identification and characterization.

2. Operational Expertise:

- **Project Management and Logistics:** The Oil & Gas industry has extensive experience managing complex offshore projects, including logistics, environmental management, and risk mitigation. This expertise is crucial for the successful implementation of OFG projects, particularly in remote and challenging offshore environments.
- **Maintenance and Safety:** Offshore platforms and subsea systems in the Oil & Gas sector have rigorous maintenance and safety standards. These practices can be applied to OFG extraction facilities, ensuring robust operational procedures and minimizing risks.

3. Infrastructure and Resources:

- **Existing Infrastructure:** Oil & Gas companies often have existing infrastructure such as offshore platforms, pipelines, and processing facilities that could potentially be repurposed or adapted for OFG extraction and treatment. This can reduce the initial capital investment required for developing new infrastructure.
- **Energy Utilization:** The energy requirements for desalination and groundwater treatment can be substantial. Oil & Gas companies could leverage their energy production capabilities to supply the necessary power, potentially integrating renewable energy sources to reduce the environmental impact.

4. Environmental and Social Benefits:

- **Sustainable Development:** By investing in OFG projects, Oil & Gas companies can enhance their sustainability profiles and demonstrate a commitment to local water security and social investment. This aligns with broader corporate social responsibility goals and can improve community relations.
- **Diversification of Resources:** Engaging in OFG projects allows energy companies to diversify their portfolios, mitigating risks associated with fluctuating oil and gas markets. It also opens up new business opportunities in the emerging field of offshore water resources.

5. Collaborative Opportunities:

- **Partnerships and Joint Ventures:** Collaborations between Oil & Gas companies, water resource management firms, and technology providers can foster innovation and efficiency in OFG projects. Joint ventures can leverage the strengths of each partner, combining expertise in drilling, water treatment, and project execution.

6. Research and Development:

- **Innovation in Water Treatment:** Investment in research and development can drive advancements in water treatment technologies, addressing challenges such as water quality and cost. Oil & Gas companies can play a pivotal role in supporting R&D initiatives to improve the feasibility and efficiency of OFG projects.

In summary, the Oil & Gas industry's advanced technologies, operational expertise, and existing infrastructure present significant advantages for exploring and developing offshore groundwater resources. By leveraging these assets, energy companies can contribute to sustainable water solutions while enhancing their own operational capabilities and corporate sustainability profiles.

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