OCS Study
BOEM 2023-011

Supporting National Environmental Policy Act Documentation for Offshore Wind Energy Development Related to Offshore Aquifers

U.S. Department of the Interior
Bureau of Ocean Energy Management
Office of Renewable Energy Programs

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List of Abbreviations and Acronyms

BOEM	Bureau of Ocean Energy Management
km	Kilometer
L	Liter
MA	Massachusetts
mg	Milligram
OCS	Outer Continental Shelf
U.S.	United States
USGS	U.S. Geological Survey

Executive Summary

Fresh water sources submerged beneath the ocean floor have been recognized for decades; however, recent news coverage has raised the awareness of a specific aquifer offshore of the northeast Atlantic coastline. In the last 20 to 30 years, this aquifer has been studied to gain understanding of its geologic and hydrologic composition, how it developed, how it functions in present day, and the possible use as a water source. The dissolved salt content of the aquifer has varied in reporting, but most studies describe the aquifer as having more salt than potable fresh water based on direct water sampling, requiring desalination if the source were to be used in the future. Although a great deal has been learned about this aquifer, much more is still to be understood and quantified.

As with so many aspects of offshore wind, new questions about how turbines and related infrastructure interact with human and natural surroundings are ongoing. This paper seeks to provide a high-level overview of aquifers, a description of the aquifer off the Atlantic coastline, the viability of the aquifer as a water source, and how offshore wind development may interact with the aquifer.

1 Introduction

Water sources submerged beneath the ocean floor have been recognized for decades; however, recent news coverage has raised the awareness of a specific aquifer offshore of the northeast Atlantic coastline. In the last 20 to 30 years, this aquifer has been studied to gain understanding of its geologic and hydrologic composition, how it developed, how it functions in present day, and the possible use as a water source. Although a great deal has been learned about this aquifer, much more is still to be understood. As offshore wind energy is expanding across the Atlantic Outer Continental Shelf (OCS), questions are arising regarding how the installation of wind turbines might affect the offshore aquifer, such as if construction activities could penetrate the aquifer or affect the availability or quality of the water source.

This paper seeks to provide a high-level overview of aquifers, the specific aquifer off the Atlantic coastline, the viability of the aquifer as a water source, and how offshore wind may interact with the aquifer. Links to more in-depth resources with detailed descriptions of the aquifer development, composition, and salinity can be accessed in the References Section at the end of the document.

2 Background

For centuries, onshore fresh and saline water sources have been found underground in ranging depths and soil types across the country. More recently, underground water sources were identified offshore along the OCS. Water from rain, streams, lakes, or snowmelt flows downward, pulled by gravity, through the soil and permeable mineral layers where it collects underground. The saturated area belowground within porous or permeable rock or within voids underground that hold water is known as an aquifer (USGS, 2019a). Aquifers can be recharged through rainfall or snowmelt that is generated through the hydrologic cycle of evaporation and precipitation. Water within an aquifer usually is in motion, flowing with gravity from a high point to a low point where the water is held in place belowground geologically or exits aboveground in a spring, a body of surface water, or in many cases, is pumped through a well for use in agriculture, industry, or for drinking water (USGS, 2019a).

A confined aquifer is one that holds water between two impermeable geologic layers, above and below the contained water. Because the water is held between two confining layers, water within confined aquifers is often under pressure when tapped for use as a well. An unconfined aquifer contains water within soil or rock particles, often described as the water table, and is more prone to influence from drought conditions. Unconfined aquifers will rise and fall based on rainfall and are generally closer to the land surface than confined aquifers (USGS, NDa). Figure 1 displays a cross-section of a confined and an unconfined aquifer.

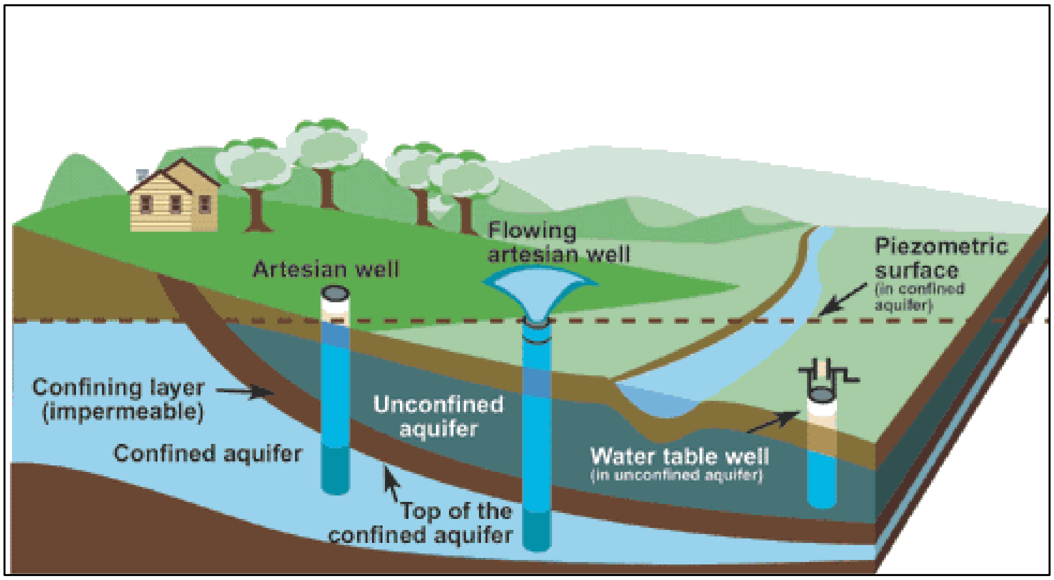


Figure 1. Confined and Unconfined Aquifers

(USGS, 2019a)

Classifications of freshwater, seawater, and salinity can vary with author or agency. For purposes of quantifying salt water in this document, the definitions used in Barlow (2003) and the USGS (2021) are utilized. Salinity in seawater is comprised of dissolved solids, derived mostly from terrestrial rocks and minerals. The most prevalent minerals being chloride and sodium, although other minerals may be present including sulfate, magnesium, and even very small amounts of gold and silver. Saltwater is measured as having more than 1,000 milligrams (mg) of dissolved solids concentration per liter (L). Freshwater along the Atlantic coast generally has less than 20 m/L of chloride, whereas seawater has 35,000 mg/L of dissolved solids, and of those, about 19,000 mg/L are chloride. (Barlow, 2003; USGS, 2021; USGS, NDb)

Freshwater and seawater have different densities, or weights. The larger amount of dissolved minerals in seawater causes it to be denser, or heavier, than freshwater (USGS, 2018a). Temperature can also influence density; cold water is more dense than hot water (USGS, 2018b). Density of seawater allows freshwater to "float" above seawater in ocean-freshwater interfaces (Barlow, 2003). Although some mixing will occur within the seawater-freshwater boundary, unless there is some force mixing the two water bodies, most of the freshwater will naturally remain above the heavier, saline water (Barlow, 2003). In coastal areas, the boundary between the interface of the subsurface ocean water and the onshore freshwater water table can be calculated using the Ghyben-Herzberg equation. Further detail regarding this equation may be found in Barlow (2003). The area of this interface between a freshwater water table and seawater is also known as the Ghyben-Herzberg lens (Figure 3).

2.1 Offshore Aquifers

Terrestrial groundwater naturally flows toward lower elevation coastlines, creating freshwater and brackish[1] water wetlands on the surface as the water drains into the sea. Due to this water cycling process, aquifers beneath the ocean floor offshore have been suspected for decades. Direct borehole sampling of offshore sources of water has occurred near the New Jersey coast and on Nantucket (Massachusetts) (Post, et al., 2013). Further research using electromagnetic systems to measure salinity in subsurface water has shown further evidence that water with lower salinity than the ocean is present in what appear to be a large offshore aquifer system stretching at least 217 miles (350 kilometers [km]) from New Jersey to Nantucket and further northeast (Gustafson, et al., 2019; Micallef, et al., 2020). Modeling has also been used to predict the paleo-hydrologic landscape of past geology, sea level, and groundwater formation that might have occurred to allow these offshore aquifers to form (Gustafson, et al., 2019). Seismic surveys have been conducted near Massachusetts to describe the geology of the coastline and how it formed through glaciation and sedimentation (Siegel, et al., 2012).

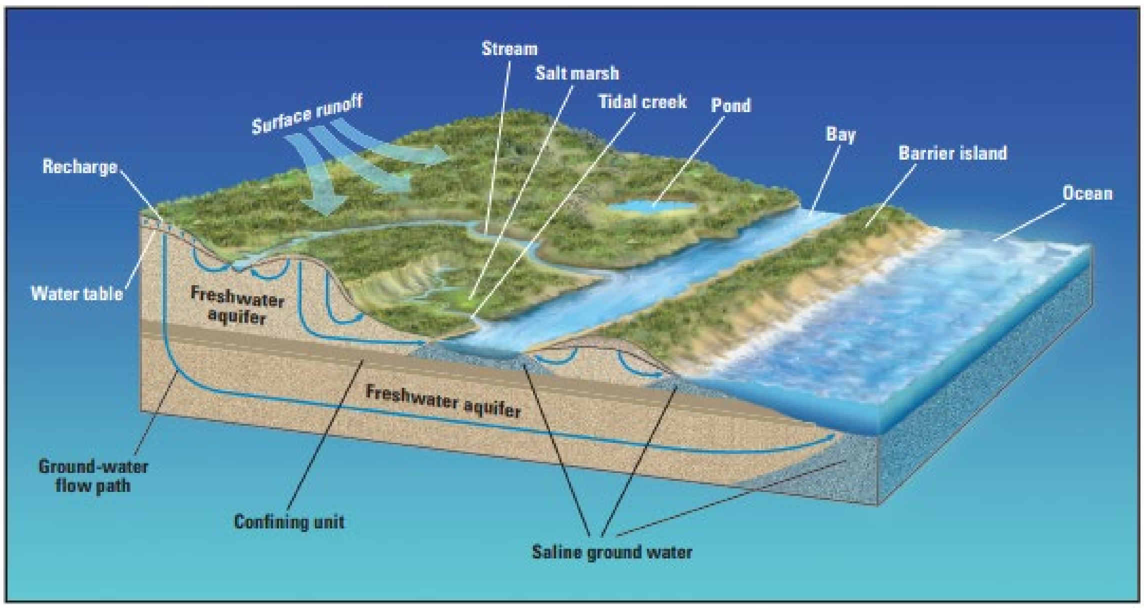


Figure 2. Idealized Depiction of Water Paths in a Coastal Aquifer System

(Barlow, 2003)

The water found in aquifers offshore is generally defined in two main categories. The first is a relict aquifer, which developed thousands of years ago and became trapped without groundwater recharge flows. The second is an active aquifer that may have developed thousands of years ago during the Pleistocene Epoch (about 2 million to 10,000 years ago) but is actively fed by aquifer hydrology flowing from onshore to offshore (Post, et al., 2013; Barlow, 2003). The flow of water from onshore aquifers toward the sea where it is discharged is "submarine groundwater discharge" (Weymer, et al., 2020). The

[1] Brackish water is more salty or saline than freshwater but not as salty as ocean water. It often occurs at the interface of a freshwater body and a saltwater body. According to the United States Geological Survey (USGS) brackish is described as "water that has a greater dissolved-solids content than occurs in freshwater, but not as much as seawater (35,000 milligrams per liter) (USGS, 2021).

mechanism that forms most offshore aquifers is described as “meteoric recharge” that may have been established in prehistoric times of glaciation caused lower sea levels (Micallef, et al., 2020). In general, the basic geology of the aquifers on the Atlantic coastline appear to be rivers and deltas that flowed during periods of lower sea level (Post, et al., 2013). As sea levels moved inland, the rivers and deltas became submerged and filled with sediment over time (Post, et al., 2013). The areas where the submarine groundwater discharge continued following sea level rise exhibit the least seawater intrusion. Figure 3 depicts a connected or meteoric recharged aquifer system in the top image; the lower image depicts two disconnected relict aquifers below a connected aquifer (Weymer, et al., 2020).

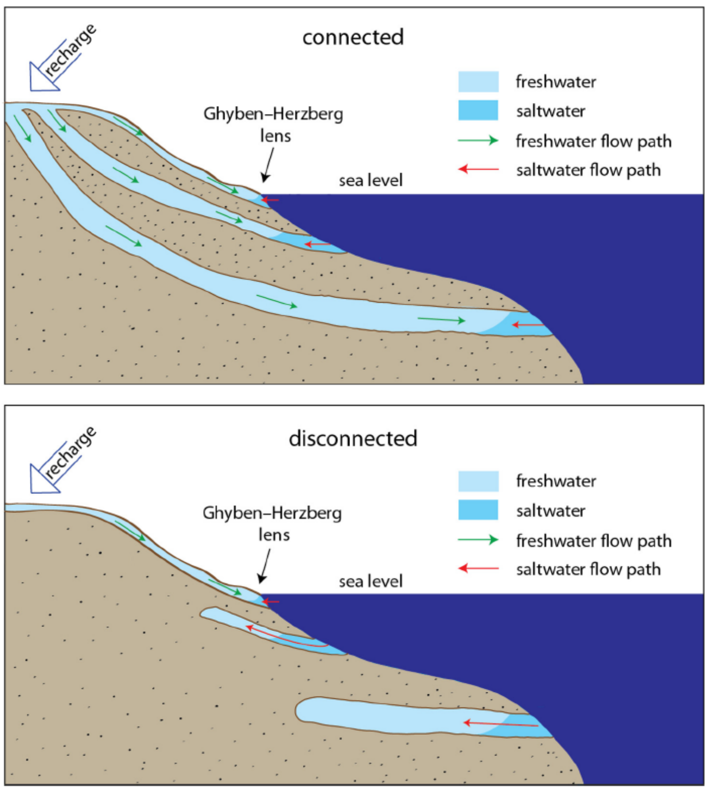


Figure 3. Depiction of a Connected (Meteoric), Offshore Aquifer System, above, and Disconnected (Relict), Offshore Aquifer System, below

(Weymer, et al., 2020)

The level of salinity within the offshore aquifers depends on several factors: whether the aquifer is confined; if the aquifer discharges as a spring or outflows into the sea in some way; and, if the water exits the aquifer, how strong the flow is into the ocean environment. The more interface the aquifer has with the ocean water, the higher the salinity will be (Post, et al., 2013; Gustafson, et al., 2019). An unwelcome occurrence in island or coastal communities is saltwater intrusion into freshwater wells if water is pumped too quickly or a large amount of water is used at one time. The void left by the freshwater may be filled by brackish water located below the freshwater, an occurrence known as upconing (Weymer, et al., 2020). The chances of upconing increase with the depth of a well, or proximity to the ocean, salt marsh, or brackish surface water (Delaney, 1980). Figure 4 displays an example of upconing during pumping in an aquifer on Cape Cod and where saltwater intrusion could occur if pumping were to continue.

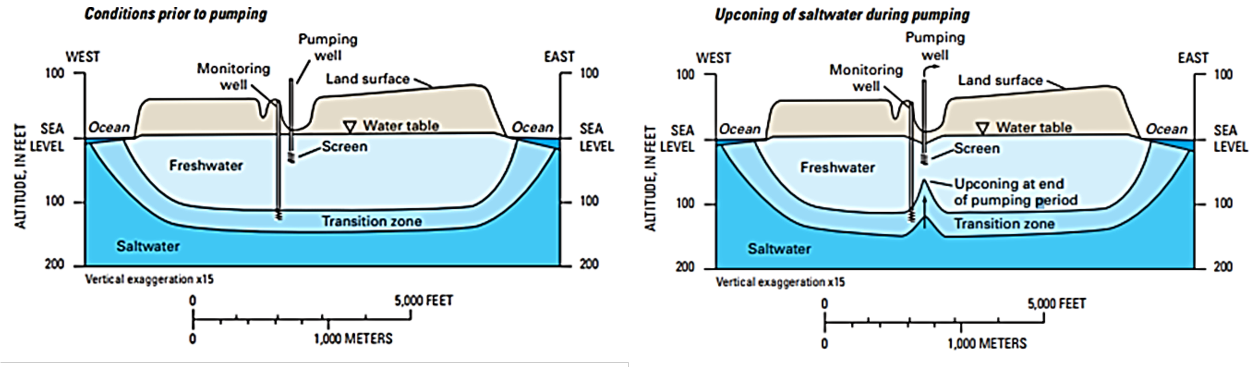


Figure 4. Depiction of Well Upconing and Saltwater Intrusion in an Aquifer on Cape Cod, Massachusetts

(Barlow, 2003)

The aquifer system identified off the coast of New Jersey, that is presumed to stretch about 217 miles (350 km) north toward Massachusetts and beyond, is described as a flowing aquifer, or a meteoric aquifer, due to the meteorologic influence of rainfall and runoff that recharges the system with freshwater (Gustafson, et al., 2019; Micallef, et al., 2020). These aquifers are generally porous, similar to an unconfined aquifer onshore, rather than enclosed like a confined aquifer. Although some layers of water within the aquifer may be confined, in general, the aquifers are surrounded by sedimentary deposits of fine- to coarse-grained sand, silt, and clay (Delaney, 1980; Bertoni, et al., 2020). These deposits allow the outflow of freshwater within the aquifer to submarine groundwater discharge. This flow reduces the permeation of saline water through the surrounding porous materials; however, as the pressure of the discharge reduces further offshore, more saltwater infiltration occurs (Bertoni, et al., 2020). The water found offshore from New Jersey to Massachusetts is described as low-salinity groundwater, but ranges in salinity from very low to moderately saline, expressed in most research as less than 15 practical salinity units (psu), roughly translated to less than 15,000 mg/L for very low saline to greater than 15 psu, roughly translated to greater than 15,000 mg/L dissolved minerals (Post, et al., 2013; Gustafson, et al., 2019).

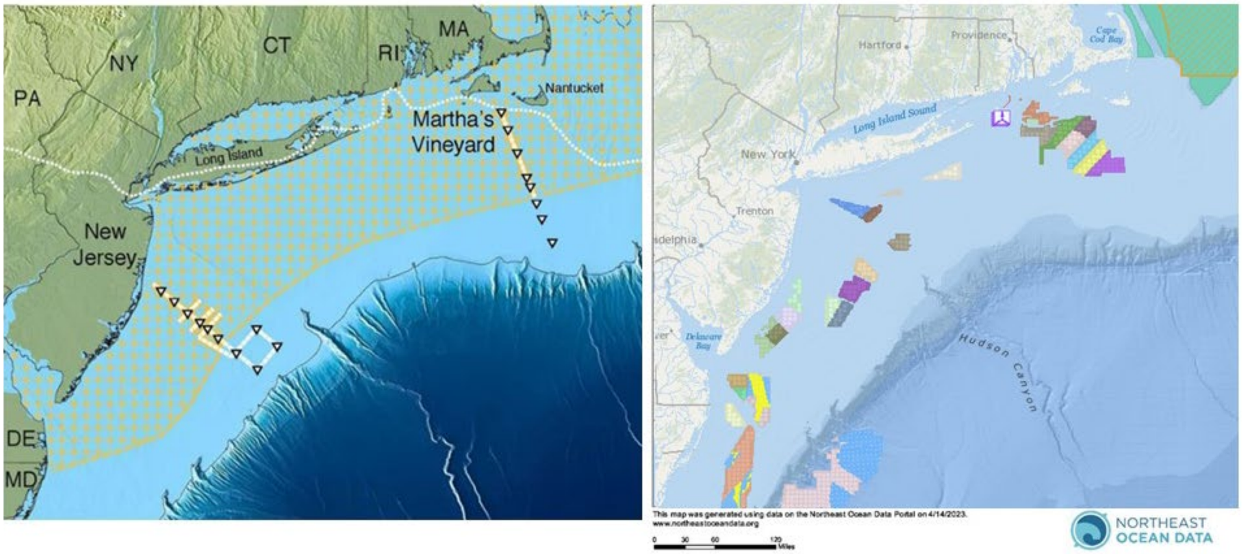
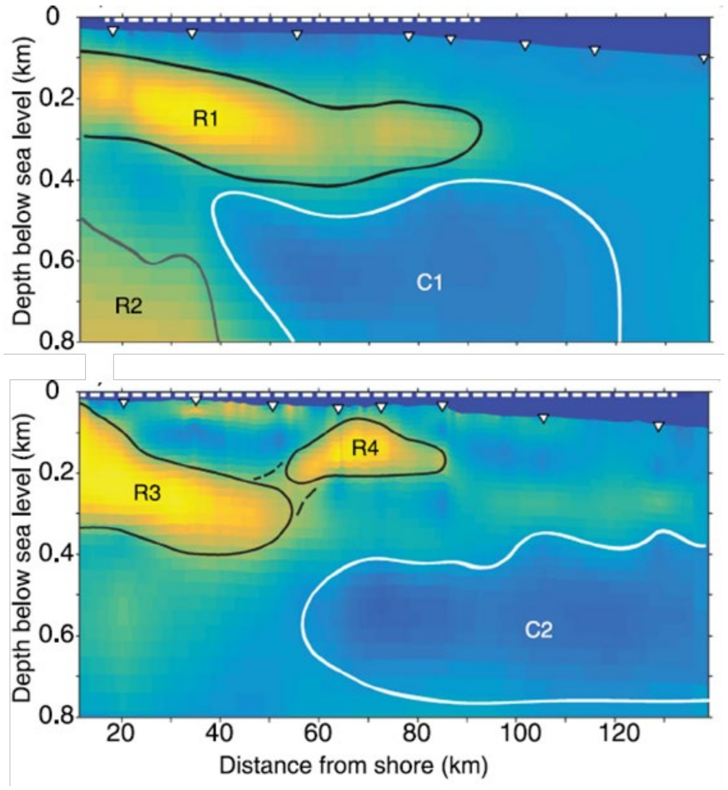


Figure 5. Modeled Area of the Atlantic Offshore Aquifer (left) and Locations of Offshore Wind Call and Lease Areas (right)

(Gustafson, et al., 2019; Northeast Ocean Data Portal, 2023)

A combination of electromagnetic and seismic mapping, plus modeling and direct water sampling, have provided an estimated depth and distance from shore for a New Jersey location of the aquifer. It is estimated that the upper portion of low saline water extends up to 80 miles (130 km) off the coast of New Jersey and about 37 to 50 miles (60 to 80 km) off the coast of Nantucket (MA) with an average distance of 56 miles (90 km) for the entire offshore aquifer system (Post, et al., 2013; Bertoni, et al., 2020; Gustafson, et al., 2019). For the most part, the aquifer depths are closer to the seafloor surface near shore and become deeper with distance away from the shore; although in New Jersey, a portion of the aquifer rises closer to the seafloor approximately 40 to 45 miles (65-70 km) offshore (Gustafson, et al., 2019). The offshore aquifer system is, on average, found within water of less than 328 feet (<100 m) deep (Post, et al., 2013). Figure 5 is a map created by Gustafson, et al., (2019) using the combination of mapping, modeling, and other methods described above. The inferred area of low-salinity aquifer is depicted by yellow dash lines and yellow crosses (Gustafson, et al., 2019). The white squares and triangles near New Jersey and Martha's Vineyard are where controlled source electromagnetic system combined with a magnetotelluric method was used to identify salinity levels in groundwater offshore, depicted in Figure 6 (Gustafson, et al., 2019). The smaller white dots denote where the ancient ice sheet was located during the last glacial period, about 15,000 years ago (Gustafson, et al., 2019).



Imagery taken from the shoreline to the edge of the OCS using a controlled source electromagnetic system combined with a magnetotelluric method to identify salinity levels in groundwater offshore.

Martha's Vineyard (upper) showing very low salinity water in yellow and very high salinity brine in dark blue.

New Jersey (lower) displays a shallow portion of aquifer further offshore in this location (R4).

Figure 6. Imagery of Cross-sections of Martha's Vineyard and New Jersey Offshore Aquifers

(Gustafson, et al., 2019)

3 Viability of Offshore Aquifers as a Water Resource

Direct sampling of water through drilling boreholes off the coast of New Jersey in the 1970s and more recently in 2010 showed that low-salinity water was present in continuous samples below the sea floor to about 75 miles (120 km) offshore (Gustafson, et al., 2019). Samples taken on Martha's Vineyard and Nantucket have also contained low salinity water, although presently no samples have been taken offshore (Gustafson, et al., 2019). Electromagnetic imaging conducted off the coastlines of New Jersey and Martha's Vineyard supports the initial borehole data and shows a more detailed extent of the subsurface groundwater offshore (Gustafson, et al., 2019). Based on the sampling, imaging, and studies conducted on this aquifer system, most researchers have concluded that the water within this offshore aquifer continues to be recharged by meteoric water onshore (Weymer, et al., 2020). Although some researchers suspect that part of the aquifer could be a non-renewable source of relict water trapped underground for thousands, or even millions, of years (Bertoni, et al., 2020). Overall, the consensus is that the onshore water source is actively supplying the offshore aquifer with freshwater, and salinity within the aquifer is due to the mixing of seawater and deeper subsurface brines through the porous seafloor materials surrounding the freshwater column.

Many countries with limited freshwater resources, including 11 locations in the U.S., have turned to desalinating ocean water or saline groundwater for use in homes and businesses (USGS, 2019b). Desalinating may be conducted in a few different ways, the most straightforward is using distillation - boiling water into steam which is captured and cooled back into liquid water (USGS, 2019b). The minerals and salts are collected separately in a concentrated brine and disposed of, often discharged back into the ocean or containment wells (USGS, 2019b). Reverse osmosis is a more complex system for removing salts from water, which uses pressure to push the water through a specialized filter membrane that allows smaller water particles to pass through but catches larger particles such as salts, other minerals, and contaminants (USGS, 2019b; International Desalination Association, 2011). Distillation and reverse osmosis have evolved over time to become more effective, with other desalination processes now in use or in development (International Desalination Association, 2011). Energy needs for large-scale desalination is a present concern, with much of the energy produced by fossil fuels (United Nations, 2021). Advances in technology are helping to reduce energy consumption, making more efficient systems, and incorporating renewable energy sources into the systems (International Desalination Association, 2011). The other concern is the waste salts, or toxic brine, that are produced from the desalination process (USGS, 2019b). Disposal of the desalination byproducts is an environmental concern, whether they are discharged into the ocean or other storage facilities (United Nations, 2021).

The viability of mining the offshore aquifer for use of the low salinity water is possible, but at present it is not necessarily economically cost-effective. Although the Atlantic offshore aquifer has been studied and mapped in two locations, the overall structure and understanding of where recharge from onshore occurs is still being researched. In addition, possible locations of any paleo-meteoric (relict) disconnected aquifers are yet to be identified offshore along the Atlantic coast (Micallef, et al., 2020). The aquifer still requires further study before considering extraction. If active meteoric recharged offshore aquifers were tapped for use, the multi-step process of submarine well installation, extraction, transport to shore, and desalination would be costly, estimated at exceeding $5 million in 2020 (Micallef, et al., 2020). The onshore freshwater aquifer feeding the offshore system is a more economical source of water and would not require the extra step of desalination. If a relict paleo groundwater source was located, extraction costs would be similar to a recharged aquifer; however, the water would be a finite resource (Post, et al., 2013). In either case, unless the aquifer were confined and not subject to permeation of surrounding saline water, the risk of upconing or permeation of seawater or adjacent concentrated brines is highly likely, making the further desalinization of the water more costly (Micallef, et al., 2020; Post, et al., 2013). Until extraction costs decrease, and the entire geologic and hydrologic composition of the offshore aquifer is better understood, use of the low-saline water from offshore may not be realistic.

4 Offshore Wind Farms

Offshore wind development on the Atlantic OCS has evolved quickly in the past decade, and concerns have been raised that the installation of wind turbines might affect the offshore aquifer, such as if construction activities could penetrate the aquifer or affect the availability or quality of the water source. Size of turbines, distance of windfarms from shore, and depth of water where turbines can be placed have all grown larger with technological advances. Data from 2019 show that offshore wind projects were located approximately 29 miles from shore (National Renewable Energy Laboratory, 2020a). Based on project plans, the distance from shore is expected to increase to 43 miles from shore in 2025 (National Renewable Energy Laboratory, 2020a). Water depth for offshore wind projects has grown as well. In 2019, the average depth was about 100 feet, projections for 2025 have grown to approximately 141 feet (National Renewable Energy Laboratory, 2020a). The reality of floating wind turbines has progressed and cost for installation is decreasing, which will allow wind farms to move even further offshore into depths ranging from approximately 196 to 3,280 feet (National Renewable Energy Laboratory, 2020b).

Monopile foundations have increased in use as windfarm development has expanded to deeper water and consist of a single, large-diameter steel pole or pile (Figure 7). Monopile foundation penetration depths range between 80 and 200 feet in the ocean floor, while piled jackets – another common foundation type – range between 200 and 300 feet (Figure 7). Floating wind uses several different types of mooring and anchoring systems, such as suction caissons, suction buckets, monopiles, or even weighted anchors (Figure 8) (ICF, 2020). Much of the U.S. floating wind design is still in preliminary development and ideal depths for the various anchoring systems are being researched as part of a larger floating offshore wind design program (National Renewable Energy Laboratory, 2022).

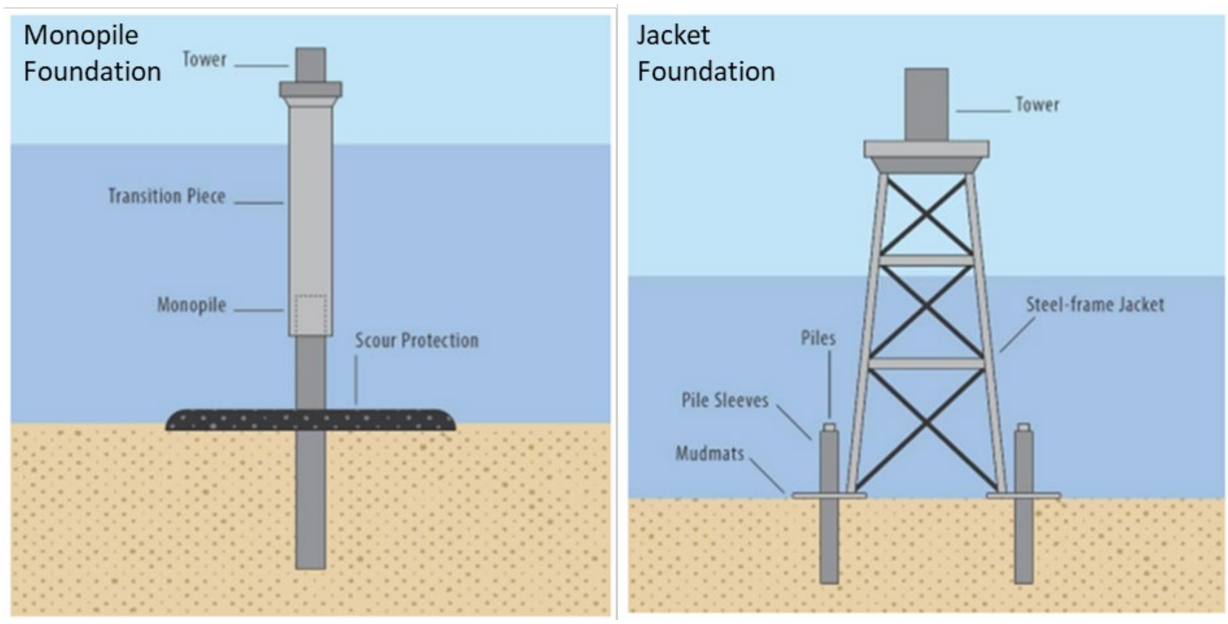


Figure 7. Examples of Monopile and Jacket Foundations

(ICF, 2020)

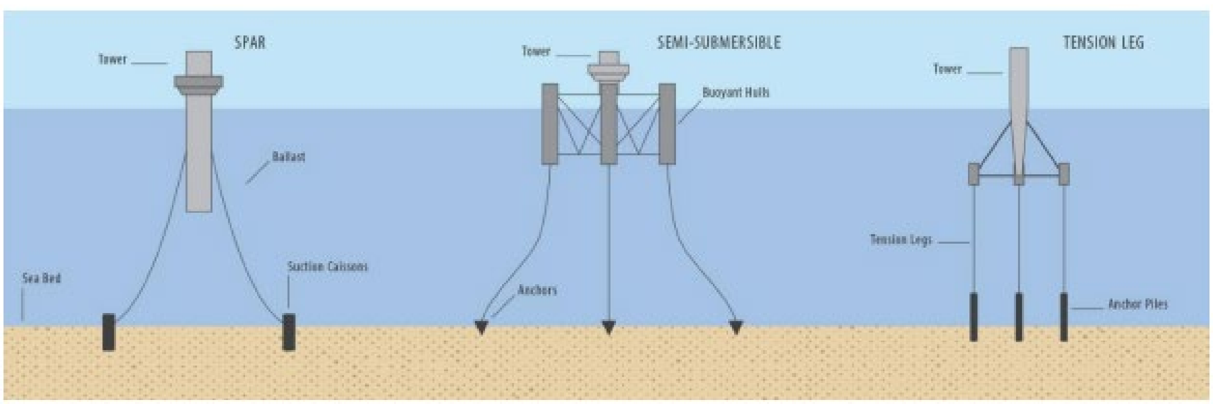


Figure 8. Examples of Floating Turbine Anchor Foundations

(ICF, 2020)

Monopiles and other pilings are simply a very large pipe that is hollow in the middle (Figure 9). The piling is hammered or vibrated into the seabed and the center of the piling fills with the sediment it has been driven through. The driving of piles does not involve use of drilling fluids or other potential contaminants. Once installed, the piles resist their structural loads (turbines) partly by friction between the pile walls and the adjacent sediment so a pathway for vertical water transmission is very unlikely. Physical drilling or excavation may be used when installing piling foundations in offshore wind farms where substrates are rocky or contain shallow bedrock; however, these conditions are often avoided or another type of foundation will be used (ICF, 2020).

If an offshore wind farm were to be constructed over the aquifer system, the pilings used generally do not require excavation or drilling for installation, reducing effects to the hydrology below the ocean floor. This is because the pilings are settling into the surrounding sediments without creating a void, unlike a drill, which creates a deep void into the substrate. The identified aquifers have shown to be surrounded by permeable sediments rather than confining layers, which means that if a piling were to be inserted into the sediments surrounding an aquifer, no holes or punctures would occur, and the aquifer would not be drained (Bertoni, et al., 2020).

Seafloor surveys are conducted prior to offshore wind construction to avoid large rocks, shallow bedrock, and problematic substrates such as glauconitic sands. The surveys could also help avoid any unknown confined aquifers beneath a large rock layer, although the installation of a turbine in an area of bedrock is most often avoided.

Figure 9. Monopiles on an Installation Vessel, Laying Horizontal on Deck

(Bureau of Ocean Energy Management, 2021)

Any nearshore to onshore installations, such as cable routes, are not buried deep enough to interact with a confined aquifer, nor will installation affect an unconfined aquifer. Most cable landfalls are buried within 3.3 to 50 feet deep (Exponent, 2021; Gradient, 2021). In addition, most onshore aquifers are well mapped, and projects avoid interaction with aquifers, wetlands, and other sensitive hydrologic resources whenever possible.

5 Conclusion

The low-saline aquifer off the northeastern coast of the U.S. is an intriguing natural feature. The present studies of the aquifer provide insights into how it formed and how it currently functions. Only certain locations near New Jersey, Nantucket, and Martha's Vineyard have been the focus of in-depth study, surveys, and modeling. Much of the remaining extent of the northeast aquifer has yet to be studied and specifically mapped. Variation of aquifer depth below the seabed is not yet quantified, and prediction of where monopiles could intersect areas of the aquifer is currently unknown. The aquifer has been identified up to 80 miles (130 km) off the coast of New Jersey and about 37 to 50 miles (60 to 80 km) off the coast of Nantucket with an average distance from shore of approximately 56 miles (90 km) for the entire offshore aquifer system (Post, et al., 2013; Bertoni, et al., 2020; Gustafson, et al., 2019). Presently, offshore wind farms are being sited within these distances from shore along with the water depths predicted in the studies (328 feet or less). Planned offshore wind farms are likely located over parts of the aquifer. Although overlap could occur, the use of monopile foundations is the best-known technology for use within an area that may have a portion of an aquifer beneath the submarine surface. Installation of pilings into these permeable sediments is not anticipated to cause any noticeable draw-down, draining, or increased salinity of the aquifer from dislodging sediments during pile driving.

Although the estimated size of the offshore aquifer is very large, extraction and desalinization are not currently an economically viable option for consumption of the resource. Presently, the freshwater source onshore is the most economical and reliable source of water. Responsible use and conservation of this onshore source is the upmost way to protect the onshore and offshore aquifers in the coastal northeast.

6 References

Barlow, P., 2003. *Ground Water in Fresh Water-Salt Water Environments of the Atlantic Coast,* Denver: USGS.

Bertoni, C., Lofi, J., Micallef, A. & Moe, H., 2020. Seismic Reflection Methods in Offshore Groundwater Research. *Geosciences,* 299(10), p. 34.

Bureau of Ocean Energy Management, 2021. *Kitty Hawk Offshore Wind Project Scoping Board - Project Construction.* [Online]
Available at: https://www.boem.gov/sites/default/files/documents/renewable-energy/state-activities/KH-Construction-Activities.pdf
[Accessed 24 March 2023].

Delaney, D., 1980. Plate 2. Ground-Water Quality. In: USGS, ed. *Ground-Water Hydrology of Martha's Vineyard, Massachusetts.* s.l.:USGS, p. 6.

Exponent, 2021. *Revolution Wind Farm Offshore Electric- and Magnetic- Field Assessment,* Bowie: Revolution Wind, LLC.

Gradient, 2021. *Electric and Magnetic Field (EMF) Assessment for the Proposed Mayflower Wind Project,* Boston: Mayflower Wind Energy.

Gustafson, C., Key, K. & Evans, R., 2019. Aquifer Systems Extending Far Offshore on the U.S. Atlantic Margin. *Scientific Reports*, 18 June.

ICF, 2020. *Comparison of Environmental Effects from Different Offshore Wind Turbine Foundations,* Sterling, VA: U.S. Department of the Interior, Bureau of Ocean Energy Management Headquarters.

International Desalination Association, 2011. *Desalination at a Glance,* Topsfield: s.n.

Micallef, A. et al., 2020. Offshore Freshened Groundwater in Continental Margins. *Reviews of Geophysics*, 20 November, pp. 1-54.

National Renewable Energy Laboratory, 2020a. *NREL: News - Data Show Big Gains for Offshore Wind.* [Online]
Available at: https://www.nrel.gov/news/program/2020/2019-offshore-wind-data.html
[Accessed 23 March 2023].

National Renewable Energy Laboratory, 2020b. *Floating Offshore Wind 101 Webinar Q & A,* Washington: NREL.

National Renewable Energy Laboratory, 2022. *Wind Research - Floating Offshore Wind Array Design.* [Online]
Available at: https://www.nrel.gov/wind/floating-offshore-array-design.html
[Accessed 23 March 2023].

Northeast Ocean Data Portal, 2023. *Northeast Ocean Data.* [Online]
Available at: https://www.northeastoceandata.org/data-explorer/?{%22point%22:{%22type%22:%22point%22,%22x%22:-8032111.642646324,%22y%22:4925247.648818291,%22spatialReference%22:{%22wkid%22:102100,%22latestWkid%22:3857}},%22zoom%22:7,%22basemap%22:%22oceans%22,%22layers
[Accessed 14 April 2023].

Post, V. E. A. et al., 2013. Offshore Fresh Groundwater Reserves as a Global Phenonmenon. *Nature*, 5 December, Volume 504, pp. 71-78.

Siegel, J. et al., 2012. Geophysical Evidence of a Late Pleistocene Glaciation and Paleo-Ice Stream on the Atlantic Continental Shelf Offshore Massachusetts, USA. *Marine Geology*, 15 March, pp. 63-74.

United Nations, 2021. *UN Environment Programme - Five Things to Know About Desalination.* [Online]
Available at: https://www.unep.org/news-and-stories/story/five-things-know-about-desalination
[Accessed 24 March 2023].

USGS, 2018a. *Water Science School: Science - Saline Water and Salinity.* [Online]
Available at: https://www.usgs.gov/special-topics/water-science-school/science/saline-water-and-salinity
[Accessed 13 April 2023].

USGS, 2018b. *Water Science School: Science - Water Density.* [Online]
Available at: https://www.usgs.gov/special-topics/water-science-school/science/water-density
[Accessed 13 April 2023].

USGS, 2019a. *Water Resources.* [Online]
Available at: https://www.usgs.gov/mission-areas/water-resources/science/groundwater-basics#overview
[Accessed 10 March 2023].

USGS, 2019b. *USGS Water Science School -Desalination.* [Online]
Available at: https://www.usgs.gov/special-topics/water-science-school/science/desalination
[Accessed 24 March 2023].

USGS, 2021. *USGS Water Resources Mission Area.* [Online]
Available at: https://www.usgs.gov/mission-areas/water-resources/science/brackish-groundwater-assessment
[Accessed 24 March 2023].

USGS, NDa. *Frequently Asked Questions - Water: What is the Difference Between a Confined and an Unconfined (Water Table) Aquifer?.* [Online]
Available at: https://www.usgs.gov/faqs/what-difference-between-confined-and-unconfined-water-table-aquifer#:~:text=A%20confined%20aquifer%20is%20an,the%20top%20of%20the%20aquifer.
[Accessed 12 March 2023].

USGS, NDb. *Frequently Asked Questions: Ocean - Why is the Ocean Salty?.* [Online]
Available at: https://www.usgs.gov/faqs/why-ocean-salty
[Accessed 13 April 2023].

Weymer, B. et al., 2020. Multi-Layered High Permeability Conduits Connecting Onshore and Offshore Coastal Aquifers. *Frontiers in Marine Science*, 27 October, p. 19.