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FRESH GROUNDWATER BENEATH OUR OCEANS

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YOUNG REVIEWERS:

ALYSSA
AGE: 12

ANNA
AGE: 12

AURORA
AGE: 11

BRANDON
AGE: 13

LUIZA
AGE: 13

Have you ever tried to dig a deep hole at the beach? At the bottom of the hole, it probably got very wet, making it difficult to dig any deeper. That is when you reached the groundwater. In many places, groundwater is the main source of fresh water for drinking and farming. In your hole on the beach, the water was probably salty and not drinkable right? That is because you are so close to the salty ocean. However, in some locations, you can find freshwater coming out of the ground right on the beach. In other locations, if you swim out into the ocean and dive down, you can find holes in the seafloor where fresh groundwater comes out. These groundwater springs in the ocean are important for the surrounding ecosystems and coastal communities. Fresh groundwater can be found up to 90 km off the coast and could be a potential future source of drinking water in dry regions.

WHAT IS GROUNDWATER?

Groundwater is all the water that exists beneath Earth's surface. On land, groundwater is used by billions of people as a source of fresh drinking water. We also use groundwater to water our plants and grow our food. Groundwater generally forms and renews when it rains or snows, as the water slowly trickles down into the soil. We call this process of water trickling into the ground "recharge" of the groundwater. Actually, 99% of the liquid freshwater on our planet (everything not stored in ice caps and glaciers) is found underground, in the tiny spaces between grains of sand and other sediments [1]. This means that all the freshwater you can see on the surface, for example in rivers or lakes, makes up only 1% of the Earth's liquid freshwater!

Geological formations called **aquifers** store and transport groundwater underneath Earth's surface (Figure 1). Within these aquifers, groundwater slowly flows downwards, generally from the mountains toward the oceans, just like rivers. By drilling wells into aquifers, we can pump groundwater back to the surface and use it for drinking, irrigation, or other purposes. Often, aquifers are blocked at the top and bottom by geological layers that are very dense, like rock or clay, and where the groundwater cannot move through easily. These flow-blocking layers are called **aquitards** (Figure 1).

AQUIFER

An underground layer of porous rock or soil that collects and transports water that people can pump out and use.

AQUITARD

An underground layer of rock or sediment that slows down or permits the flow of groundwater between aquifers above and below it.

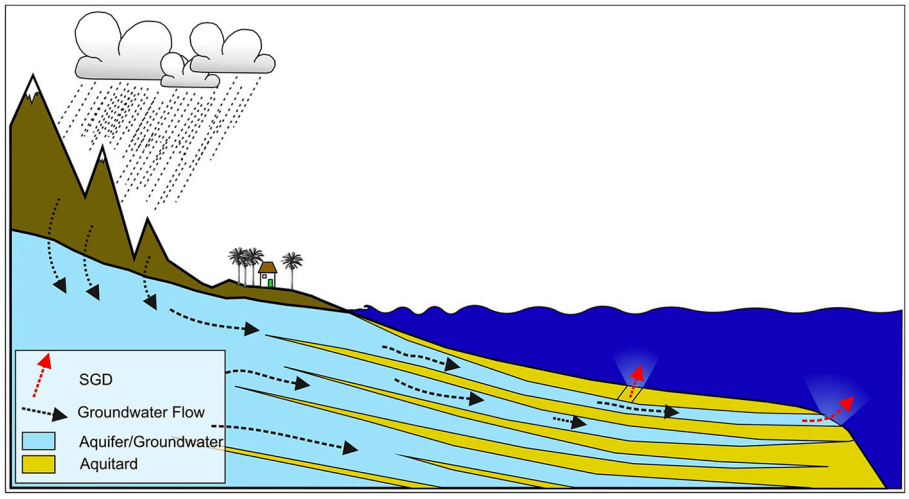

Figure 1

Groundwater forms through rain and snow falling on land and seeping into aquifers. Aquifers then flow "downhill" underground, from the land to the sea. The groundwater is contained in the aquifers by aquitards—layers of rock or other dense material that do not allow water to seep through. Aquifers can continue to carry water beneath the ocean. Red arrows indicate places where fresh groundwater can be released into the ocean by a process called submarine groundwater discharge (SGD).

WHAT IS OFFSHORE FRESHENED GROUNDWATER?

Offshore groundwater describes all the water that is stored in the ground beneath the seafloor. Since the oceans are very salty, the groundwater within the seafloor is generally also salty and cannot be used for drinking or cooking. In some regions though, very large volumes of freshwater can be found beneath the ocean. In fact, these

regions can extend up to 90 km off the coast and contain more freshwater than all the water that has ever been removed from aquifers on land [2]. Because the water in these offshore aquifers is sometimes fresh but might be mixed with some saltwater, we call these water bodies offshore freshened groundwater.

WHERE DOES OFFSHORE FRESHENED GROUNDWATER COME FROM?

Groundwater forms when rain and melting snow slowly soaks into the soil and trickles down through the rocks. But no rain or snow falls on the seafloor, right? Rain and snow fall *on top* of the ocean—so how can there be freshwater beneath our salty oceans? Two main processes are responsible for groundwater beneath the seafloor [3].

First, aquifers that are recharged on land can extend beneath the oceans. Often, aquifers are capped at the top and the bottom by aquitards and the water cannot escape. So, when it rains on land and the aquifer fills with water, it will run "downhill" within the aquifer and continue past the coastline, so that the freshwater ends up under the ocean (Figure 1). When a lot of rain falls on land, the pressure in the aquifer builds up. Then the groundwater starts to seep out from the seafloor, like fountains of freshwater under the ocean. We call this submarine groundwater discharge (SGD) (Figure 1). SGD happens in many regions, most of the time relatively close to land, where it often results in holes in the seafloor [4].

A second reason that freshwater can be found beneath the seafloor is that it has been there for thousands of years. During past ice ages, a lot of water was frozen at the North and South Poles. This caused sea levels to drop about 120 m lower than they are today. When the sea level dropped, large areas that are currently covered by the ocean were dry land. During this time, rain was trickling into the ground, building up large volumes of groundwater. By the end of the ice ages, the sea level rose again and these areas became covered with water, as they are today. However, in many places, the groundwater is still there, under the ocean (Figure 2). Since these areas are now covered by seawater, which is slightly heavier than freshwater, the seawater slowly sinks down into the ground, forming salty groundwater beneath the ocean. Eventually, the offshore freshened groundwater will be replaced by seawater.

WHY IS OFFSHORE FRESHENED GROUNDWATER IMPORTANT?

Humans can pollute the groundwater in coastal areas due to farming or release of industrial wastes and sewage. When this groundwater seeps out from aquifers beneath the ocean, it often carries large

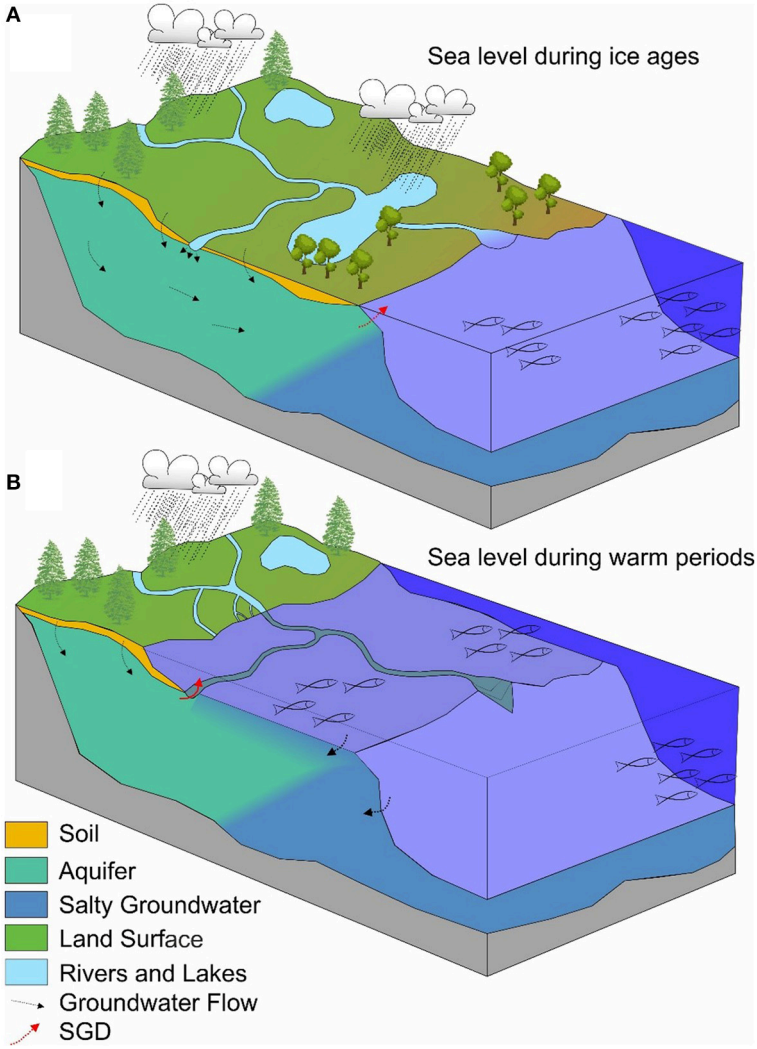

Figure 2

(A) During the ice ages, in the last 100,000 years, sea level was ~120 m lower than it is today, so more land was exposed where rain and snow could seem in to help build up groundwater. **(B)** As the weather warmed and ice melted at the poles, sea levels rose again but the groundwater remained in its place. Red arrows indicate places where fresh groundwater is released into the ocean.

amounts of **nutrients** into the ocean water. These nutrients can cause harmful overgrowth of tiny plants called algae. Such **algal blooms** can damage the marine ecosystem. In other areas where groundwater seeps out under the ocean, certain ecosystems thrive because the water is not as salty as the surrounding ocean. Some fish, corals, and plants grow better when the water is less salty and carries more nutrients [5]. So, to protect these environments in the future, it is important to understand where this groundwater discharge occurs, the quality of the groundwater, and how the groundwater affects the surrounding ecosystems.

Freshwater is a valuable resource. In many regions worldwide, people do not have access to fresh, clean drinking water. With the advance of climate change and an increase in droughts, the groundwater in some regions is being increasingly depleted. When the normal water reserves are no longer enough for the coastal population, offshore groundwater might be a unique resource to help with freshwater

NUTRIENTS

A substance that provides nourishment. Nutrients are contained in food and are essential for life and for the growth of biology.

ALGAL BLOOMS

Dense layers of tiny green plants (algae) that occur on the surface of the ocean when there is an overabundance of nutrients.

shortages in some regions [2]. In the future, we could be pumping groundwater from offshore aquifers back onto land, to provide people in coastal areas with enough water to drink and water their plants.

WHERE AND HOW DO WE FIND OFFSHORE GROUNDWATER?

Offshore freshened groundwater has been found along many coastlines around the world (Figure 3). On land, it is relatively easy to drill a groundwater well and to explore aquifers, but it is a lot more complicated and expensive in the ocean. We cannot just use a snorkel and some goggles to dive down to the seafloor and start digging! The freshwater is far too deep under the ground, and the water is much deeper than in swimming pools. Because it is so expensive to drill a well in the ocean, it is very important for us to know exactly where offshore groundwater and SGDs are *before* we try digging. When the groundwater seeps out into the ocean, the freshwater mixes with the saltwater very quickly. That makes it quite difficult to find the regions where SGDs occur.

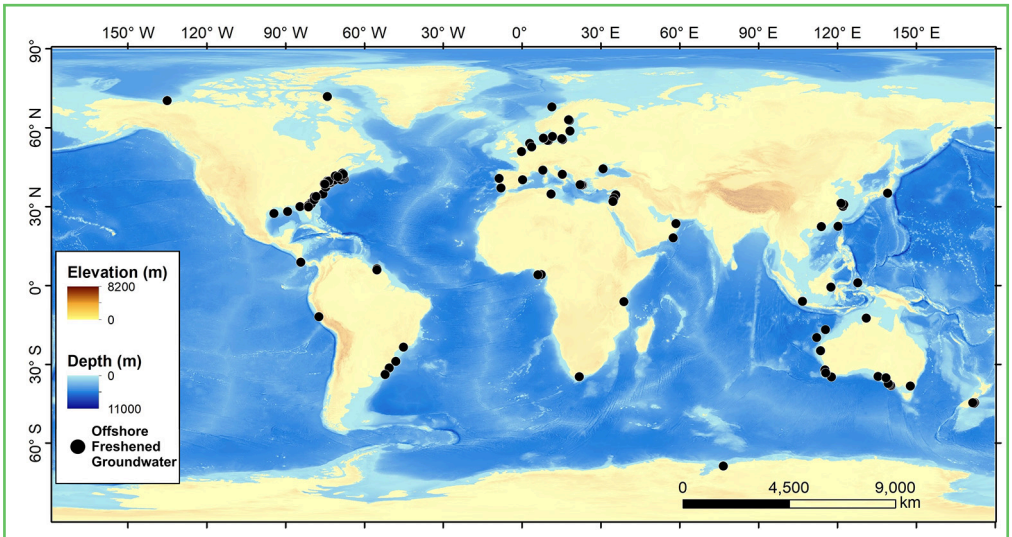

Figure 3

Figure 3

Locations where large quantities of offshore freshened groundwater have been found [figure adapted from [2]].

To find offshore groundwater, we use our research vessels to take special kinds of measurements. One of these methods measures the **electrical conductivity** of the seafloor. We use a battery and a long cable to send electricity into the ground, to see how well the seafloor conducts the electric current. Saltwater is a very good electrical conductor, so the electric current can easily pass through it. Freshwater, on the other hand, cannot conduct electricity very well. Therefore, we look for regions where the seafloor and the ground below show low electrical conductivity. This gives us clues about where we might find offshore freshened groundwater.

ELECTRICAL CONDUCTIVITY

The ability of a material to allow electric currents to pass through it.

We can also look at the properties of water samples that we collect from the ocean. Groundwater can not only carry large amounts of nutrients but can also sometimes have very small amounts of radioactive elements like radon that normally do not occur in the ocean. So, when we find elevated concentrations of radon in our water samples from the ocean, it is likely that groundwater is coming out of the seafloor in these regions.

CONCLUSIONS

It is difficult to find freshwater beneath the ocean, but better techniques are being invented and more and more scientists are searching for these water sources. Several normal Earth processes can generate freshwater beneath the oceans, and a better understanding of these processes could help us to more accurately predict where offshore freshwater might occur and where we should search. The use of offshore freshened groundwater can potentially help us meet our increasing need for freshwater in the future.

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CONFLICT OF INTEREST: The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

YOUNG REVIEWERS

ALYSSA, AGE: 12

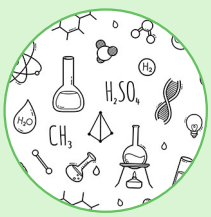
I am Alyssa, in my free time I enjoy going to my local library and checking out books. It is exciting picking what will be my next reading adventure; whether it is fiction, science, or about history. I love reading books about science theories the most because they talk about the many possibilities in the universe.

ANNA, AGE: 12

I am Anna and I am a Swimmer who likes to engage in any fun physical activities. I love art specifically painting. I am a girl scout and boy scout. I love to go camping with my troop and go on hikes. I also love to engage in sciences. I love chemistry because I love to watch how the reactions happen and learn why it happens. Although I love to do activities, I love to sit on the computer and make videos and watch.

AURORA, AGE: 11

I am Aurora, I really love science. We have biology classes at school, but I really want to explore and learn more about chemistry.



BRANDON, AGE: 13

I am Brandon, I am in 8th grade and the types of science I am interested in are biological science, physical science, and social science.

LUIZA, AGE: 13

I am 13 years old, I really like to write. I am passionate about adventures, suspense and magic. I like to go out with my friends and family. I am very interested in biology, as I am the daughter of biologists. Since I was a little girl, I have had contact with many animals and I love catching cockroaches and other arthropods in my hand. When I grow up I will be a comic artist, I love to draw.

AUTHORS

JASPER J. L. HOFFMANN

I am a marine geophysicist, which means I investigate the seafloor and everything that lies underneath it. I completed my Ph.D. at the University of Otago in New Zealand and my research now focuses on groundwater occurrences and discharge under the ocean. In my free time, I enjoy swimming in the ocean, windsurfing, hiking, and playing football with my friends. *jasper.hoffmann@um.edu.mt

AARON MICALLEF

I am a marine geologist with an interest in exploring the seafloor to better understand the hazards and resources that it hosts. I received my Ph.D. from the University of Southampton in the UK. My pastimes include hiking, running, and reading.