[00:00:07] Carolyn: Hello, and thanks for joining this World Water Day Groundwater Chat with the Jameel Water and Food Systems Lab, or J-WAFS. We are a program that funds water- and food-related research at MIT.

My name is Carolyn Blais, and I am the Communications and Program Manager at J-WAFS.

March 22nd marks World Water Day, an annual United Nations Observance that celebrates water and raises awareness of the billions of people living without access to safe water.

This year's theme is groundwater. Out of sight, under our feet, groundwater is a hidden treasure that enriches our lives. But what is groundwater? And how exactly is it used to enrich our lives? Is all groundwater safe? And where on Earth is it found?

We'll explore these questions and more in a discussion with J-WAFS Director, John H. Lienhard and J-WAFS Research Manager for Climate and Food Systems, Greg Sixt.

Welcome, John and Greg. Would you like to take a moment to introduce yourselves?

[00:01:12] John: Sure. I'm John Lienhard. I'm a professor at MIT. I'm in the Department of Mechanical Engineering, where I work on water, water supply, desalination, and heat and fluid flow.

I'm also the Director of J-WAFS, the Abdul Latif Jameel Water and Food Systems Lab, which is an MIT-wide initiative in water and food research. We cover all departments; we've funded essentially all units at MIT.

[00:01:43] Greg: And I'm Greg Sixt. I'm the Director for the Food and Climate Systems Transformation Alliance, a J-WAFS-led global initiative, and I'm also the Research Manager for Food and Climate Systems at J-WAFS.

My area of expertise is in groundwater governance and agricultural knowledge and innovation systems.

[00:02:03] Carolyn: Okay, great. Well, thank you both for joining us, and let's just jump right into it.

So, Greg, I'm guessing groundwater is exactly what it says it is: water found in the ground. Is the definition as simple as that?

[00:02:21] Greg: It’s kind of as simple as that.

So, groundwater and aquifers are synonymous. You might have heard the term "aquifer."
I think some people might visualize groundwater as an underground lake, you know, just under there, like surface water, but it's not.

Groundwater—or aquifers—are porous rock, soil, or sand in which the water is kind of embedded in between the particles, and it's accessible by drilling down to it. It could be anywhere from right at the surface, all the way down to 100s, or over 1,000 feet.

[00:02:57] Carolyn: Okay, and John—maybe you can tell us. Why is groundwater important?

[00:03:03] John: Groundwater is important, in part, because it's one of the major water supplies of the world. Freshwater from rainfall lands on the surface as precipitation. But where the ground, as Greg mentioned, is porous or where there are fissures of one sort or another, precipitation finds its way underground.

And it travels through porous layers in the ground, it collects in them and forms aquifers, and humans have figured out how to extract that water, either by digging a well or drilling a well, and pumping water up where they can.

In some cases, we're lucky, and groundwater just comes naturally to the surface as an artesian spring. But quite often, it takes a little more effort to get down there and get it out of the ground.

But it's used for household supplies, for municipal supplies, for irrigation and farming, and it's used worldwide.

[00:04:04] Carolyn: Okay, and that brings me to my next question: Is most of this water that's under the ground—is it drinkable or is it brackish? How does that compare to, say seawater?

[00:04:18] John: The water in the ground, in some cases, is fresh, and it will be pumped up and used.

In some cases, it has a certain amount of what's called hardness, the stuff that scales up your pipes and may require some softening. And in some cases, the water contains significant levels of salt, dissolved salts, which are not just sodium chloride (table salts), but they might be calcium and carbonate and magnesium and sulfate, and various other things that come from the rocks in the ground.

As it turns out, if you look at sort of annual water consumption in the U.S., the amount of brackish groundwater in the U.S. is maybe 35 times larger by some estimates, so there are significant amounts of groundwater that are brackish.

The United States Geological Survey has recently updated its atlas of groundwater; it has samples from more than 100,000 wells, and from our analysis, on the order of 20 or 30 thousand of those wells are quite brackish, and those are just the things that have been sampled to give you some idea.

[00:05:34] Greg: To build off what John was saying, another issue with groundwater is this pollution from the surface, right?

So, especially under agricultural areas, you've got an increasing problem worldwide with nitrate concentrations. The consequences of nitrate can have an impact, especially on children and babies, if the water is drunk. You know, much of the land underlying major agricultural production areas are polluted at some level with nitrate.

But another key point here is that about 2 billion people in the world rely on aquifers as their primary water source, so it is a fundamentally important source of water, and it's one that, we're only starting to recently understand better. The technology to really start to monitor it and model it is relatively new when you look at it compared to things like surface water or other sorts of natural resources that we use.

[00:06:33] John: You had asked me about the difference between brackish groundwater and seawater. That's an important difference in the sense that seawater is much, much saltier than most brackish groundwater and saltier in the sense that it may contain 10 times the number of dissolved ions, or even 30 times the number of dissolved ions.

And so, when you think about treating or desalinating seawater, you're looking at a process that takes considerably more effort or specifically more energy than desalinating brackish groundwater because we don't have as much content to take out of the water. So that's an essential thing that makes brackish groundwater—in some sense—a more attractive resource than seawater.

[00:07:31] Carolyn: Okay, and that does bring me to another question, John, for you, about the technology that you use—if you can touch on that a little bit. I know you said it takes a lot less energy to treat the brackish water as opposed to the seawater.

Can you tell us a little bit about the method you have found for treating that kind of brackish groundwater?

[00:07:59] John: Sure, happy to. The world standard, the most common technology for desalinating seawater, is a process called reverse osmosis, and reverse osmosis is essentially a semi-permeable membrane where you pressurize seawater on one side of this membrane. The membrane only lets water through—it won't let salt ions through. So, the water passes through to the lower pressure side as essentially pure water.

Now, the thing is, with seawater, because you have so many ions, the pressure has to be much higher. About 70 atmospheres is typical working pressure for a seawater RO system. For brackish groundwater, you can use RO, and depending on the amount of salt present, you may only need a few atmospheres… maybe only 10 atmospheres, maybe 5 atmospheres of hydraulic pressure to desalinate the groundwater. But there are other ways to do it because the concentrations of ions are lower.

Another common technique is something called electrodialysis, which uses electric fields and again, semi-permeable membranes, to allow some ions to move through the membrane and others to stay behind. And so, you can purify water by blocking all the ions from going through, or you can select which ions you'd like to let through—if you choose to—by using other kinds of membranes. And so, electrodialysis is typical for groundwater treatment as well.

I should add salts, per se, are not the only thing that we worry about in groundwater, and depending on what kind of rock structures are beneath the community in question, you might have uranium in water, you might have arsenic in water, and the treatments for those ions may often go in another direction—ion-exchange resonance or some other technology. I should emphasize that arsenic in groundwater is a major health issue in some parts of the world, including in some parts of the U.S.

[00:10:21] Greg: And to build off that as well, John mentioned uranium in groundwater.

To the point I made about fertilizer nitrates and infiltrating groundwater, they've actually found places, in parts of Nebraska, for instance, in a certain city of about 40,000 people called Hastings, Nebraska, they've actually found that the nitrates that mobilized uranium that was natural to the soil geology had mobilized that and actually brought it out.

They were first treating one problem, the nitrates, and then they found out that over time, the nitrates were increasing the uranium challenges in the water. So, human activity has a real role to play in the quality of our groundwater, as well as natural systems.

[00:11:10] Carolyn: Greg, can you tell us: is groundwater found all over the earth?

And I know you have done some research around groundwater governance. Are there parts of the world where people are perhaps fighting over the groundwater or, maybe there's not enough to go around?

[00:11:28] Greg: Yeah. So, groundwater is found in all the continents in the world, and it varies considerably by location, right? So, in some areas, you may have groundwater where the geology is more sand-like. The groundwater—it's called recharge. So basically, as long as you are withdrawing or abstracting less than is infiltrating on a yearly basis, you're either increasing your groundwater levels or you're maintaining it. So, in some places, the soil's sandy, and it recharges quite fast.

In other areas, they have the opposite extreme: what's called fossil groundwater, which is from thousands of years ago, tens of thousands of years ago. And it may be trapped below a rock layer or a clay layer and doesn't really recharge, and when you use that fossil water, you're actually mining the groundwater. Once it's gone, it's gone.

And other areas, we are withdrawing it so fast that the ground's actually sinking, and once the aquifers collapse, there's not an opportunity for those to recharge.

On other areas, if it's coastal aquifers with sea-level rise or with over-pumping of groundwater, you start to get sea-level infiltration into the groundwater.

In terms of governance, there are two key terms that are really important: one is common-pool resources. And so, virtually all types of water resources, or conflict resources, are CPRs—and groundwater is one of those. And what a common-pool resource is; it means that the resource base is sufficiently large to make it difficult to exclude users, and each individual's use reduces benefits to users who share the resource.

So, other examples of common-pool resources are the forests, fisheries…these are things that are really difficult to govern because the logical move for an individual is to use as much as they need, and sometimes even to use more than they need. But collectively, that depletes the resource.

And the other is social-ecological system. And so, a social-ecological system is one that is connected and impacted by one or more social systems. So, an economic system is drinking water systems, for example. And it’s a subset… it’s that interplay between human relationships that are deeply involved with biological units, the non-human biological units, and biophysical conditions.

So, as to my point earlier, human behavior has a dramatic impact on the water, the groundwater they rely on.

In terms of governance, that common-pool resource element is the key one. There are different ways in which water is governed. I tend to have more knowledge on the U.S. on this.

But, in a sense, there are two fundamental principles to groundwater governance: one is the important distinction between a property right, and then water for the public interest or public welfare. And the other—and this has a really major impact on management options. If groundwater is considered a property right in the U.S., and if any kind of state agency tries to limit withdrawals, that's considered taking of the private property under the U.S. Constitution.

So, that makes it much more difficult to manage. So, in a place like Texas or Kansas, groundwater is a property right, which limits the ability of the state to be able to control resources. And in a place like Nebraska, the groundwater is owned by the state for the benefit of people, and that distinction has a real impact on how we can manage it.

And the other fundamental principle of groundwater governance is allocation rules. So, one is—and these are related—one is the rule of capture, which means that landowners own all the water that underlies their land. They can pump water without limitation, and that's got real implications because aquifers or groundwater doesn't abide by property boundaries, right? I mean, if I'm over-pumping on my land, it's impacting my neighbor's availability.
The other is the reasonable use doctrine, which allows a landowner to use the groundwater underlying your land, provided it's for a reasonable purpose and used on that land.

The other determines the kind of use, based on the amount of land a person owns, and the other's prior appropriation, which means that first in time, first in right principle, so if you owned your land first, you own your water rights. You have senior water rights.

You see that issue in places like California, where during drought, you might hear that junior water rights users are losing access to their water.

So, these are kind of the key principles. I might have gone down a bit of a rabbit hole here, but they're kind of important things to understand if you're talking about groundwater governance.

That property principle is really key.

[00:16:13] Carolyn: That's super interesting, and I had no idea that it varies from state to state.

[00:16:18] Greg: Yeah, groundwater governance in the US is a state-by-state issue. There isn't really federal oversight of groundwater, except for where there are interstate issues.

Also, you've got groundwater that spans international boundaries. Even in many fully developed countries, we aren't great at managing groundwater. So, what does that mean for places that don't have as strong of institutions? How do you tell a growing population to reduce, to use less, when it's a poor region that is just trying to feed itself? And these are those social-ecological systems, right?

The interconnectivity of our ecological systems and social behaviors. It's a really difficult thing we're going to have to deal with over the coming decades.

[00:17:04] John: The ownership of water and the access to water—they're certainly tied up in economics. In California, water rights are becoming more valuable. And there are actually investment funds that have been set up to purchase and hold water rights because they're perceived as becoming increasingly scarce. And so, in fact, you see some major endowments of big institutions purchasing into funds that are buying water rights in the hope that those investments will become more valuable as water becomes more scarce.

And think a little bit about what that means. It's not like we're talking about handbags or tulip bulbs becoming scarce and expensive; we're talking about something that is a human right becoming scarce and expensive, and so there will certainly be significant social tensions arising if trends like this continue in the direction they're headed.

[00:18:10.800] Carolyn: So, we've already touched on some of this, but I guess...what are some of the biggest threats facing groundwater? Is it climate change? Is it pollution?

[0:18:19] Greg: I think the answer is all the above. Climate change is drying out areas and just increasing the need to pump. Population demands are increasing demand for water, the population growth is increasing demand for water. Sea level rise, as I mentioned, is inundating coastal aquifers. I think we've got something along the lines of about a dozen of the world's aquifers, the major aquifers in the world, are depleted to the point where regional water availability is threatened.

I think one of the other challenges too is…I view groundwater as the other shoe to drop. There's a lot of focus on surface water; it's easy to see. It's easy to see when surface water is polluted. It also can be polluted relatively quickly. You know, the change is quicker.

We often forget about what's under our feet, and the changes that occur in groundwater occur over the course of decades. So, one of the challenges is: if you discover pollution, a source of pollution in your groundwater, depending on the geology, that could be, for instance, overfertilization that occurred 30, 40, 50 years ago.

And so, when you're asking farmers, or when you're asking communities to make changes to restore that groundwater, you're asking those farmers to make changes that they will not likely not see the results of in their lifetime. Right? So, if you're changing farming practices, in fact, you may actually see pollution levels increase after you implement some control measures because there could be a plume of pollution working its way down through the soil before it gets to the groundwater.

So, these are some of the challenges that make governing groundwater really difficult.

[00:20:13] John: You know, one of the biggest threats is the groundwater is simply being over-drafted all over the world. It's become more and more clear as we've developed better techniques for measuring the amounts of groundwater.

And if you think about that for a minute, the groundwater is underground, so you can't easily see where it is or how much is in the ground. But there's been some great work done with satellite sensing to actually detect where groundwater has been falling and the rates of use, and the recent work in the last five years or so has shown that most of the world's major aquifers are overexploited and the water tables are dropping.

You know, in some places, this has been known without the need for satellite studies. For example, if you go to the Central Valley in California, where groundwater is freely pumped typically, as Greg was explaining, by senior water rights holders. They pump as much as they want in order to grow things in what is otherwise a fairly dry area, the Central Valley, and the result has been that the surface ground level has subsided, and there are areas in the Central Valley where the land is now more than 50 feet below where it was 100 years ago because of the overexploitation of groundwater.

One of the things that's of great concern there is that as you allow those soils to compact, it's not obvious that putting water back in will allow the soil to again absorb as much moisture as it used to because it really does become compressed, and you lose the porosity between particles of soil. But more broadly, there just doesn't seem to be the prospect that that water is going to be replenished while current trends of use continue and current change in the climate system continues as it has been. So, what's really needed in those cases, in part, is to rethink the model for how groundwater is used, and to rethink, as Greg outlined, the processes through which groundwater is governed.

And, of course, very importantly, they have a more integrated water management strategy. Management across the state, management across the region, if necessary, and management that is based on current trends and conditions, not on structures and realities that were present in the late 19th century.

[00:22:59] Carolyn: We've certainly highlighted the severity of the problem. Just to wrap up, is there anything we can say on a hopeful note?

[00:23:08] John: Well, the good news is that there are many different ways to practice agriculture, and there are many technologies or approaches—perhaps not even technologies—practices available that can help to reduce the intensity of water use in farming.

A notable example is drip irrigation, where water is essentially dripped around the roots of the plants instead of being sprayed all over the place. There are practices such as growing cover crops to help keep moisture in the ground. Any number of things can be done differently to help back off the intensity of water in agriculture. There, of course, are efficiencies to be had in urban water use as well. Now, agriculture is probably 70 or 80% of the world's water consumption. It is, by far, the biggest actor. But cities can become much more water-efficient through the appliances they use, the fixtures they use, through the reuse of water, through landscaping choices, and other things. Very significant efficiencies can be obtained. Industrial use of water generally is becoming more efficient over time because water is a scarce resource, and your business is more effective if you use less of a valuable resource.

So, I think that there are a number of things that can be improved and will be improved as a matter of necessity if nothing else. There are high-tech solutions for sure. Precision agriculture or people use all sorts of remote sensing data to figure out exactly how much fertilizer to put down, so you don't wreck the groundwater. Figure out exactly how much water this part of the field needs, as opposed to this part of the field. That's very advanced stuff that's not available to smallholder farmers in particular, but it is an example of sort of the high-tech end of what people can do.

You know, in other cases, MIT, through the Poverty Action Lab, and the project that J-WAFS was involved in as well, have looked at giving farmers in India, say in Gujarat, conservation credits, essentially doing some metering and paying them for using less water, and studies they've done suggested techniques like that can be helpful.

[00:25:38] Greg: Yeah, and there are absolutely areas where you can look to for hope. One is actually…we talked about California, some of the challenges they're facing. California recently passed the sustainable groundwater management act or SGMA. If that's fully implemented and effectively implemented, that really could make a big difference in how they manage their groundwater. And also, in that SGMA law from California, you actually see a lot of elements from Nebraska's natural resource district system and how they manage their groundwater. And then, Nebraska is actually a pretty good model of how you develop empowered local governance institutions with the ability to implement control measures with more of a systems approach, and that makes it somewhat adaptable.

And the other area of hope is that now we're seeing simple, ancient technologies such as water harvesting, which go back thousands of years and can actually be reintegrated into modern production systems.

So, once you start to have the systems approach, we can start to see how the pieces relate, and so there is a move towards that, and that does give hope because, you know, the trade-offs are important to analyze, and these approaches provide some means to do that.

So, it is easy to focus on the challenges we face and how that could keep you up at night, and we are facing a pretty big uphill battle on a number of fronts, and groundwater being one of them. But there are kind of silver linings, or there are at least glimmers of hope, and there are examples we can look to on how to improve things, and so I think it's an exciting time to be in water governance and water management. And we need good people to work on this.

[00:27:27] Carolyn: Well, thank you both. That was a super informative, great discussion. I think we've learned a lot about this precious resource.

And yeah, thank you both. Happy World Water Day. Anything else to add?

[00:27:44.320] John: No, I just thank you Carolyn for the opportunity to talk about these issues, which are of critical importance to everyone. And I think it's very important for folks to think a little bit about how much they rely on water and access to water, and how they're going to ensure that for the future here on World Water Day.

[00:28:06] Greg: I think it was Benjamin Franklin who said, 'when the well's dry, we know the worth of water.' So…

[00:28:10] John: That's right.

[00:28:12] Carolyn: Thank you, that's a good one. Thanks.