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Water & the People: A Relationship in Flux

INTERVIEW WITH DR. DAVID SEDLAK

David L. Sedlak, PhD, *is the Plato Malozemoff Chair Professor in UC Berkeley's Civil & Environmental Engineering Department. He is currently the Co-Director of the Berkeley Water Center, the Deputy Director of the NSF Engineering Research Center for Reinventing the Nation's Urban Water Infrastructure (ReNUWIt), and Chair of the Research Advisory Council in the National Alliance for Water Innovation (NAWI). In addition to his research and advisory policy work, Dr. Sedlak frequently engages the public through interviews, TED talks, books, and more. He is a leading expert on water reuse management and the author of* Water 4.0: The Past, Present, and Future of the World's Most Vital Resource. *In this interview, Dr. Sedlak discusses potential water reuse systems and point-of-use devices along with their respective limitations.*

BY: ALEXANDRA DU, ALLISUN WILTSHIRE, ANANYA KRISHNAPURA

BSJ: What led you to study urban water infrastructure?

DS: I did not set out to study urban water infrastructure; I did not even know what it was when I was a college student. My undergraduate major was environmental science, and after graduating I was trained as an environmental chemist in the University of Wisconsin, where I was interested in the transport of chemicals and their effects on the environment. It was not until I arrived here in Berkeley that I became interested in water infrastructure, particularly urban water infrastructure, and started studying it more seriously. In part, that was because California and the rest of the West are quite different from the East and the Midwest. Whereas water is widely available in the East and Midwest, that is not the case for the West; here, we are more focused on where our water comes from and more tightly control where it goes after use. This means there are a lot of opportunities for us to use treatments to remove contaminants and directly minimize their impact on surface waters.

BSJ: What is the current "water revolution," and why is it important?

DS: The water systems that we have today have essentially remained unchanged for the past 70 years or so, at least in most places within the wealthy parts of the world. They are what people refer to as "linear systems," where water comes in one side from a reservoir or a series of groundwater wells, and we then treat it to make it safe for people to drink. People use it, we treat it again in sewage treatment plants, and then we release it into the environment. That system has worked pretty well for those 70 years, but now a lot of places are dealing with water scarcity. As water becomes more scarce, there is a benefit in using it multiple times. The revolution that is going on concerns this idea of recycling water. In other words, using it multiple times.

There are other revolutions going on simultaneously—for example, transitioning away from a reliance on water that is imported over great distances and replacing it with locally-sourced water. That would mean capturing the rainwater that falls within a city and making it part of the water supply. We could also use shallow groundwater in cities, which oftentimes in the past had been considered too contaminated for use. Finally, there is another revolution that is taking place in many parts of the world, which is the use of desalination to make seawater and salty groundwater drinkable. All of these things are upending the current way that we provide water to cities.

BSJ: Which cities have been indicated as possible potable water reuse adopters? Why those in particular?

DS: There are two parts of the world that are leading the drive toward potable water reuse. One is Southern California, and the other is Singapore. Southern California has

been at it the longest, starting in the early 1960s as water stress and water shortage drove the need to find new water supplies. Utilities in Los Angeles and Orange County have adopted potable water reuse as a way of increasing their supply. They have pioneered transformative technologies, using advanced treatment combined with groundwater storage to make water reuse possible. The model developed in Orange County was picked up in the 1990s by Singapore. As a city state without its own water supply, it had historically been reliant upon Malaysia for water imports. Singapore considered their water supply a vulnerability, so gaining water independence became an issue of national security. When they saw what was happening in Orange County, they realized that this was a way to reduce their vulnerability to having their supply cut off. Southern California and Singapore are two main places that everyone looks to, but if you look a little closer, there are many other cities that have been quietly pursuing potable water reuse. For example, Atlanta, Georgia, has two sizable potable water reuse facilities that have been in operation for over 20 years. Northern Virginia, outside of Washington, D.C., has a large potable water reuse facility. Phoenix, Denver, and Perth, Australia, are all moving in the same direction as well.

BSJ: What is reverse osmosis?

DS: In the 1960s the US government funded a program with the goal of making it possible to desalinate seawater. Up until then, the way in which seawater was desalinated was essentially distillation. You just boiled the water and captured the steam to turn it into freshwater, leaving the salts behind. However, that was a very energy intensive and expensive process, so the federal government funded a program to try to drop the cost. A team of scientists at UCLA then discovered a new way of taking salt out of water that involved thin plastic polymeric membrane. This was a polymer made out of cellulose acetate, the material that they used to use to make movie films. If you apply pressure to it, you can drive water molecules through the plastic membrane and leave the salts behind. This is called "reverse osmosis" because you are working against the osmotic pressure and the salt gradient to push the water through, but it just lets the water molecules go through. The basis for most modern seawater desalination and potable water recycling is now the reverse osmosis membrane, a University of California product designed at UCLA and improved upon gradually by the rest of the world.

BSJ: How can each water-stressed location figure out a water reuse plan and/or reverse osmosis (RO) management style that is right for their location? Who should be responsible for designing a water reuse plan for each community?

DS: The decision to adopt water reuse depends upon local geography, local economics, and local politics. It is very much tailored to the specific city and their needs. As an example, in the Western US, one of our limitations is that our water supply often starts out with high levels of salt. When water is used in someone's home, it picks up even more salt. It drives utilities toward employing reverse osmosis because this removes the salt as part of the treatment process. In the southeast places in Atlanta, Northern Virginia, and Texas, a lot of the cities that are interested in water reuse are inland. They prefer not to remove the salts from the water because their

"The basis for most modern seawater desalination and potable water recycling is now the reverse osmosis membrane, a University of California product designed at UCLA and improved upon gradually by the rest of the world."

Figure 1: Horizontal levee in Oro Loma created as part of the NSF's ReNUWIt project is an example of nature-based water treatment. *Scan the QR code for a video of the site's construction and an overview of the coastal protection offered by the levee.*

water supply is already low in salt. If they were to remove the salts from their water using reverse osmosis, they would then have to find a place to put it, so they instead use other treatment technologies. Therefore, the decision of how exactly to implement potable water reuse depends upon whether you are on the coast or inland and whether the water supply starts with high levels of salt or not. The decision on how and when to implement these technologies, though, is really a community decision. The process is normally initiated by a water utility because they are the water suppliers, but quite frequently, there are one or more politicians who take it upon themselves to then become advocates and supporters for it.

BSJ: Could you describe the benefits of a nature-based treatment of RO concentrate over the more conventional method of ozone treatment paired with biological activated carbon (O3/BAC)?

DS: When recycling wastewater effluent from a sewage treatment plant, the reverse osmosis membranes do an excellent job removing not only the salts but also the microbes, chemicals, and metals that are left behind. The material they leave behind in the membrane is called "concentrate" because it has all the stuff that was in the wastewater effluent but concentrated by a factor of five or six. The early adopters of potable water reuse were coastal cities who put this material in a great big pipe and sent it out to the ocean, where it was diluted. When you just think in terms of the mass, the amount that was flowing to the ocean was no different than what was going there before they started doing reverse osmosis.

However, over time, more and more cities have expressed interest in using reverse osmosis for recycling projects occurring inland. When that happens, we run into the problem that the concentrate might need to be treated before it is released to the environment. Traditionally engineered approaches for concentrate treatment, like ozonation followed by activated carbon, turned out to be quite expensive. We have been trying to develop a less expensive approach, and in the process we have come up with a way of doing it that provides other societal benefits. In particular, our nature-based treatment systems are a low energy way of removing those residual contaminants from the concentrate. In the process, we create a wildlife habitat called a horizontal levee, which can support a wetland ecosystem and also offer coastal communities protection from storm surges.

BSJ: Are there any limitations associated with constructed wetlands?

DS: Each time we embark on these projects is essentially like the "first time" we are building different aspects on such a large scale, so every day brings a new lesson. I can give you an example regarding the first system that we built. We used construction materials for the gravel layer underneath where the water flows; however, we think that because we used local gravel from the Bay Area that is rich in serpentine minerals, we ended up with levels of nickel that are higher than we would have liked. In the Bay Area, gravel and rock is often rich in nickel and chromium, whereas in most other parts of the world, the gravel is much more benign when it comes to those metals. Next time we build a demonstration or full-scale project, we are going to look a little more carefully to make sure we get low-nickel gravel. One of the interesting aspects of building something for the first time is you learn by making mistakes and keeping your eyes open.

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BSJ: What has the data shown from pilot-scale projects in California of RO concentrate treatment in constructed wetlands?

DS: We have built two types of constructed wetlands in California. One type treats the effluent directly from sewage treatment plants, while the other treats reverse osmosis concentrate. We built some pretty large wetlands in Southern California to treat a river where the flow is mostly wastewater effluent, and these efforts have been pretty successful. The wetlands do a good job removing not only nitrate, which is one of the key pollutants, but also some of the pharmaceuticals and other chemicals that we find in wastewater. What we are really excited about now is the second type, the horizontal levee system, which treats the reverse osmosis concentrate from potable water reuse facilities. We are finding that it does an excellent job of removing the excess nutrients and most of the chemicals. There are a few chemicals that it is still not capable of removing, but it is

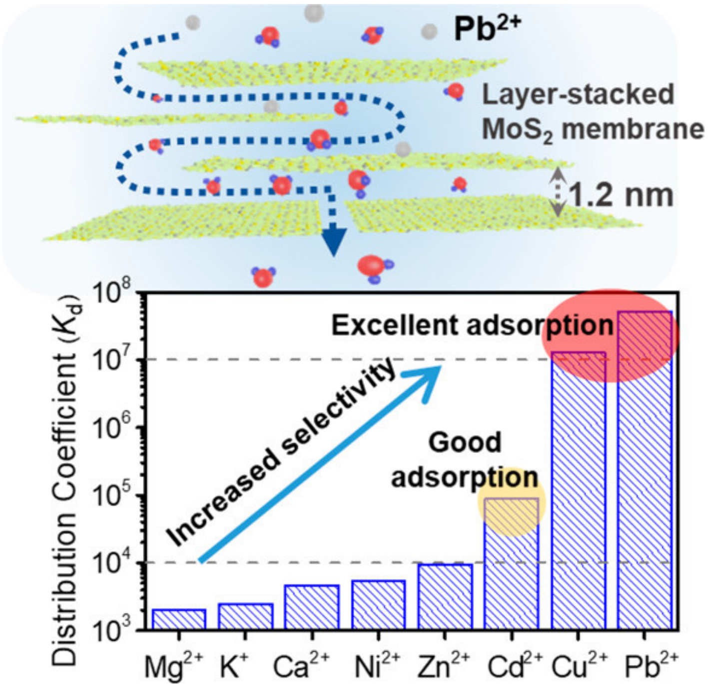

Figure 2: Adsorption quality of Stacked MoS2 Membranes. *MoS2 membranes are a POU device designed to remove lead from wastewater due to its high adsorption selectivity.*

a big improvement to the current practice, which is to release the concentrate to the environment without any treatment at all.

BSJ: What are some common contaminants found in water?

DS: Traditionally, when people talked about wastewater and its possible effects on the environment, they were concerned with both nutrients—because these could cause excessive algal growth through eutrophication—and metals like copper, nickel, and mercury because they can be toxic to fish at low concentrations. More recently, over the last 20 years, people have become more interested in the trace amounts of organic chemicals that remain after the wastewater treatment process. When it comes to wildlife and aquatic ecosystems, I can give you two examples of chemicals that are particularly interesting to us. One is an antibiotic called sulfamethoxazole. It is a common antibiotic, and it partially survives the sewage treatment process. The levels of sulfamethoxazole in RO concentrate may be high enough to cause stress or damage to not only the fish but also the insects that live in aquatic environments. Another chemical that has been interesting to us in our studies has been fipronil, which is an active ingredient in flea shampoos and topical products used on dogs and cats. It is also sometimes used for controlling ants around the house. The levels of fipronil in RO concentrate are high enough to be of concern to wildlife.

When it comes to wastewater and using it as a water supply, we are not only concerned about the effects of the concentrate on the environment but also about chemicals that might make it through the treatment process and find their way back into the drinking water supply through potable water recycling. Most chemicals are removed, especially if you have a reverse osmosis membrane which only really lets water molecules through. If a compound has a charge on it—and many, many chemicals in wastewater do—they are very easy to keep out. However, some of the uncharged compounds, especially those that are of low molecular weight, can work their way through the membrane in the same way as the water molecules do. We have been particularly interested in a chemical called NDMA or nitrosodimethylamine. This is a potent carcinogen at very low concentrations, but reverse osmosis membranes typically remove only half of it from wastewater. Luckily, for most of the water recycling projects here in California, there is an additional treatment step after reverse osmosis using an ultraviolet lamp. There, NDMA molecules absorb UV light and break down into benign byproducts.

BSJ: Would point-of-use (POU) devices be a potential solution for these contaminants that are difficult to remove?

DS: Yes, POU water treatment systems are another emerging way to think about water treatment. We are all somewhat familiar with the very simplest of POU treatment devices. Many people have household-scale reverse osmosis units, especially if you live in a place where the water is quite salty. People may also be familiar with water filters like the ones marketed by Brita. These examples demonstrate this idea that we can take water quality into our own hands and purify the water right before use, which is essentially what POU devices do. From a societal standpoint, it is probably better to treat everyone's water and not get to a point where only people who are wealthy enough to afford treatment devices are protected. However, in many circumstances, people still feel the need to have a POU water treatment system. For example, folks who do not live in cities often have private wells. Those private wells typically have little or no water treatment, so if your home is supplied by a well, a POU treatment system may be a very effective way to protect yourself. In low- and middle-income countries or in parts of the US where the infrastructure is not well maintained, people often feel compelled to take matters into their own hands. For example, the "under-the-sink" reverse osmosis market has taken off in places like China and India where people cannot rely on the safety of the water coming out of the tap.

"It would be incredibly unfortunate if people's health depended upon whether they could properly operate one of these systems."

BSJ: Would you say POU devices have good long-term potential for general wastewater treatment rather than being used solely by individuals?

DS: The big challenge with POU water treatment systems is that we need to find a way for them to get into everyone's hands. One of the things that I like most about our existing centralized water supply system is that no matter your income or personal attitude toward water quality, every individual gets the same quality water. If we move to POU systems, some people may not have enough money or technical skill to operate these systems while others may not care enough to do so. It would be incredibly unfortunate if people's health depended upon whether they could properly operate one of these systems.

I am not saying that it is not possible to make an inexpensive, reliable POU device. When you think about our homes, we have gas furnaces in the basement that, if not properly operated, could set the house on fire or poison us with carbon monoxide gas. It seems like we figured out how to make a gas furnace that is reliable enough where you do not have to have a great deal of expertise or resources to operate it. Someday, I think we could see these POU devices as standard fittings on faucets and sinks in addition to a system for maintaining and replacing them that takes the user out of the equation. But for now, those who have been thinking about this are quite concerned about the need to make sure everyone's water quality remains protected.

BSJ: Although 2D (molybdenum disulfide) MoS_2 is the most selective for lead, it is also highly selective for copper. Does this make MoS_2 more or less ideal as a candidate for POU lead removal?

DS: I have been working with my colleague here in Civil & Environmental Engineering, Professor Baoxia Mi, on these molybdenum disulfide filters. What is really interesting about them and other types of novel materials is we are trying to go beyond reverse osmosis, which is generally an all-or-nothing kind of approach: either you take all the salts out or you take none of them out. Instead, we develop these tailored membrane materials that selectively remove contaminants of concern. The MoS_2 membrane is very good at removing so-called "soft metals" that have lots of electrons in their valence shell. These metals, like lead and mercury, are often the ones that we are most concerned about in regards to human health, so MoS_2 is an ideal candidate for use in POU devices. If it does prove to be something that can be manufactured inexpensively and robust enough to be left in a home water system, it might become the preferred way to selectively remove lead, which is one of the largest concerns as far as contaminants in drinking waters go.

BSJ: How do you remain optimistic about climate solutions and the water revolution?

DS: My optimism for water systems is based upon seeing places like Los Angeles, Singapore, the Bay Area, Atlanta, and a host of other cities where there have never been serious concerns about running out of water. The places that are getting it right never make it into the news. It is only the places where people have not been paying enough attention and failed to make investments to forestall water crises that make the news. I think that in wealthy countries, there is no reason that people should ever have to worry about the security of their water.

In low- and middle-income countries, we are reaching a point where water security is going to get easier and easier. Even though there are some startling statistics about the number of people who lack access to clean water, the situation improves every year. With the UN Sustainable Development Goals, we are starting to talk about a day when everyone on the planet has access to safe water. Climate change is going to throw a lot of curveballs at us, and we are going to have to be able to adapt. But seeing the creativity of people, not just in technology but also in conservation and policy makes me optimistic that most seemingly permanent water crises stem from a lack of imagination and a lack of will and not an intractable problem. How is that for optimism?

BSJ: Your book *Water 4.0*, published in 2014, details the past three "water revolutions" that have enabled the modern use of water. If you were to write a follow-up to this book today, what new information would you include?

DS: The book talks about the "fourth revolution" that is currently going on. Since I wrote it, in 2010 to 2013, a lot has changed. I am currently in the process of writing a sequel to that book. *Water 4.0* was focused on my experience in wealthy countries. This new book is a little broader. It not only addresses wealthy cities but also discusses more generally how we get water to grow food, how we treat water to protect the environment, and how people in lower and middle-income countries are going to transition to secure water sources. In every case, I find reasons for concern but also lots of reasons for optimism, and I am really excited to share them with people.

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