EPA OW

DECENTRALIZED WASTEWATER

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Maureen Tooke: Dr. Buchanan will be presenting today on Wastewater 101. He's an Associate Professor and is on faculty with the Biosystems, Engineering and Soil Plants Department at the University of Tennessee. He has 21 years of teaching, research and outreach experience in the areas of onsite wastewater management, water quality, storm water engineering and agriculture waste management. Dr. Buchanan has a B.S. and an M.S. degrees in agricultural engineering and a Ph.D. in civil engineering, all from the University of Tennessee.

John is a member of the Water Environment Federation, Soil and Water Conservation Society, and is a registered Professional Engineer in Tennessee. Dr. Buchanan is a member of EPA's MOU Partnership, representing the consortium of institutes for decentralized wastewater treatment.

And again, my name is Maureen Tooke from the U.S. EPA, Office of Wastewater Management, and we're going to do a poll before we get started, to see how many people are in the rooms of the registered participants, because you may have multiple people in the room with you. So if you can go ahead and click how many folks are in the room with you, we can get an accurate count today.

Okay. Okay. I'm looking at the poll here. We have -- let's see. Most folks are one person in the room, but we have a few -- we've got 9% of the registrants, there's three or more people in the room, which is great. So we've probably got about 60 or so folks online today.

So with that, I will let John get started on the webinar.

Dr. John Buchanan: Okay, great. And just in case you can't hear me, obviously, if you can't hear me, then you wouldn't be able to know to type in the "chat box," but hopefully, everything is going okay. And this is pretty neat technology. I'm excited about it.

As I was telling Maureen and Ryan at the beginning yesterday, I spent quite a few hours on the road just to talk to 20 people, and today, sitting at my desk, I'm talking to 60-plus people, and that's something I get pretty excited about.

I've got a very simple agenda for today, for this webinar -- Wastewater Basics 101. It's not meant to offend and it's not mean to overwhelm. It's just Wastewater Basics 101, okay? So I’ve got a notion in mind of what I want to try to accomplish in the next hour, hour and 15 minutes or so, is I want the folks who promote and talk about water quality to understand what it takes to get a certain level of quality, okay?

So when I put a program like this together, I think about my target audience being policymakers and leaders and planners. Policymakers, leaders and planners are multi-talented folk. They talk on a wide range of issues and talk to a wide range of folks and they can’t be expected to know it all, okay, to integrate detail. That’s why we have specialists, okay? But when folks get on TV and they represent a watershed, they represent a concerned group, it doesn’t always look good on them if they don't understand the basics, okay?

And so that’s what we’re really going to focus on today is talking about the basics of wastewater, human-derived wastewater. So this presentation is going to focus on converting wastewater back to water, okay, wastewater back to water. So we’re going to use the hydrologic cycle to do that, as we have done for many, many years in the past.

So the major focus is what is in wastewater and how do we get it out, okay? There’s something in that water that we find undesirable, or something in that water that smells bad. There’s something in that water that tastes bad. How do we get these things out such that it’s water again?

Now, we also have to understand that water that we find desirable has stuff in it also. If you look at a bottle of bottled water -- I used to really be offended by the concept of bottled water because we have so much good water coming out of the tap, but I must admit I find bottled water convenient, but if you look at the ingredients on bottled water, well, duh, it’s water, but there’s also minerals added because those minerals make it taste better.

So we have to understand that water that we find desirable has constituents in it, but water that we find undesirable has constituents that we need to remove.

So we’re going to focus on organic matter and we’re going to focus on nitrogen and phosphorus because those are two hot-button issues these days, especially with the Chesapeake Bay with lakes and with streams and so on, with eutrophication. And please also understand that eutrophication just means to enrich. The word by itself implies that we've got a big outgrowth of some kind of green plant, but the word “eutrophic” just means to enrich. Well, we are enriching that water with excess nutrients, but we’ll get back to that later.

Now, the minor focus of this is to realize that wastewater treatment fundamentals is independent of scale, all right? Now, this webinar series represents the Memorandum of Understanding between the EPA’s Program for Decentralized and Onsite Wastewater Systems, so there is a hint of focus in my voice, and on my slides, that we are talking about small community systems. However, wastewater treatment is universal. The means that we're going to remove undesirable constituents from water carries above scale.

So there are many, many types of pollution, industrial pollution, storm water-driven pollution, but our focus is on domestic wastewater -- domestic wastewater, water that has the constituents of our metabolic waste. Oh, boy, that really sounded scientific, didn't it? Okay. It's better saying that we (inaudible) in it and we (inaudible) in it, okay? We did something in the water; we used the water to clean us off.

But it's also water that has the residuals from cooking, cleaning and/or bathing that comes from our house, so it's domestic. We're not worried about industrial waste. That's a whole different topic for a different day. Our focus is on domestic wastewater, and it's a fact -- it's a given fact, the more water you have available to you, the more wastewater you will generate.

It's a given fact that in our modern environment that if we have more pressure available at the tap, we will use more water, and that water goes down the drain. And that water comes in contact with waste and therefore, becomes wastewater.

The Romans knew this. Look at this cool picture out of antiquity. All of those cute little seats there, think how comfortable those would have been. The privacy is not very good, but at least you had a place to sit and take a movement of the bowels, all right?

Now, those trenches underneath there are waterways, so the Romans knew that if you provided water, and that you carried the waste away, it smelled a lot better. They didn't understand pathogens; they really didn't understand diseases and so on like that, but they understood smell and water was a good thing, as long as you weren't downstream of them.

Now, if water is not available -- uh-oh, oops; ah, there it is. If water is not readily available, you don't generate much wastewater, okay? So look at this technology -- nothing wrong with this technology. The benefit is you'll add an additional 2 to 5 gallons to the system every time you have to relieve your bladder or relieve your bowels. So there's not the extra carriage water involved. This is the original low-flush toilet -- nothing wrong with this technology, maybe a bit uncomfortable.

So really, our focus is on carriage water, water used to carry materials away from us. Now, away is a notion of public health, away because we're getting the pathogens and diseases away from us. Away is a notion of environmental health. Man, it smells a lot better when you can carry that stuff away. You just don't want to be downstream.

But we use water. There's no other substance that can transport waste like water can. Now, obviously, we have to have it for our own metabolism, and part of that metabolism is to clean out the inside of our body as we form urine and discharge it. It cleans the outside of our body as we bathe and wash our clothes. It carries away our materials.

Now, I had a major professor once upon a time that would beat up somebody just about verbally that used the word “away” too frequently, because really, there’s no such place as away. It all goes somewhere, and we’re part of that somewhere. We’re going to take this material somewhere else and remove those waste constituents out of the water and make water out of it again, make drinking water out of it again possibly.

In high-population densities, water is the best means to collect and transport waste away. Why is that, though? What is it that makes water unique? The single phenomena that makes water unique is the oxygen and hydrogen bonding. And if you notice on this slide, you have this great big red oxygen molecule, and you have two hydrogens hanging off to the side, but what makes it unique is those two hydrogens are kind of at an angle. I believe it’s 102-degree angle instead of it being a 180 degrees perpendicular apart from one another or in a straight line from one another.

What happens here is you provide a polar region. You have two pluses that are kind of close together and they're going to attract negatives outside of that molecule. You have that great big negative sitting there kind of on one end and it’s going to attract positives.

So using the example of this slide, if you have sodium chloride -- salt -- it gets into water and it disassociates. So you see the great big green negatives with the water molecules around it and the water molecules are oriented such that the positives are kind of closer to the big green negative. You see the positive, the sodium, and the water molecules are oriented such that the negative, the oxygen, is kind of oriented in that direction.

So you have this means of desolving, dissolving, materials in water. You also, with all this electro-chemistry, have means of suspending materials like clays. You also have an additional means of transporting materials because water is heavy, very, very dense material. So water is a very, very powerful molecule.

Fortunately, we have a pretty good supply of it, but it’s really our goal, as folks who advocate water quality, and advocate wastewater treatment, it’s our goal to make sure that we continue to have a good supply of high-quality water.

The other properties that make water unique for transporting waste is its density and its viscosity. Density, working in English units, 62.4 pounds per cubic foot, so if you can imagine a cube as 12 inches by 12 inches by 12 inches full of water, it would weigh 62 pounds. Think about that milk carton if it was full of water, about a gallon. That’s about 8.3 pounds. So water is heavy and therefore, it has power when it moves.

So when you have velocity and you’ve got that energy brushing against whatever is in the way, it has the power to move it. So we can pick up a lot of material. It can scour materials. With that density, you have buoyancy, so if you have a material that’s once it’s submerged in the water is less dense than the water, it’s going to float. If it’s more dense than the water, it’s going to sink, and therefore again, that makes it a magnificent transport media when it comes to dealing with waste.

But our chore is to get the waste out of the water, such that it becomes desirable again for productive use. So a question becomes is it difficult to get the waste out of water? And the answer is decidedly, yes, it is. Think about that dissolved salt a moment ago on a previous slide. We physically cannot reach in there with a pair of tweezers and pull those sodium and those chloride ions out. So if we have material that’s dissolved in the water, we cannot reach in there and get it.

But we've got a pretty good support team, a real good support team, billions of microorganisms, and we have some forces that are available to us, gravity and the sun. Now as you note on there that I’ve got gravity and the sun being the drivers of the hydrologic cycle, I don't think anyone can dispute that, but also gravity provides separation. We have that buoyancy that’s gravity-driven and so we can separate out waste constituents.

The sun, of course, provides everything, all the energy that we have had, all the energy that we’re going to have in the future, and all the energy that we have right now, eventually can be traced back to the sun. The microorganisms are available in good, healthy soils and then again, we have the soil, the basis for all wastewater treatment.

So when I say that, I’m not limiting ourselves to just onsite wastewater treatment by any means. What I’m saying is all the mechanisms that are available in the soil for the degradation of waste constituents are what we mimic when we build a wastewater treatment plant, okay? So our fundamental knowledge of what goes in terms of wastewater treatment started with the soil.

All right. Wastewater, specifically domestic wastewater -- by weight, if you go take a sample of it, it’s 99.9% water because remember, water is heavy, 62.4 pounds per cubic foot at standard temperature and pressure. And so it’s that .1% that we have to work pretty hard to remove. Doesn’t sound like much mass; it isn’t much mass, but it’s difficult to remove from the waste -- I mean, from the water.

So that .1% contains organic matter, contains microorganisms, a few of which are truly pathogenic, and has inorganic compounds. So for those of you who have familiarity with wastewater systems, you will note that I have broken it out into these three groups. I haven’t tried to say solids, I haven’t tried to say fats, oils and greases, I haven’t tried to say pharmaceuticals and personal-care products, okay? All those fit within these three. Solids can be organic and solids can be inorganic. Microorganisms are microorganisms and again, a few of them are truly pathogenic.

So when we think about converting wastewater to water, we have some measures. We have some indicators that say we are improving the quality of water. One of our most important ones is oxygen demand. You'll frequently hear the acronym BOD, biochemical oxygen demand. So when I see you on the news and you say “It’s biological oxygen demand,” I’m going to say, “You didn’t listen to this seminar. I’ll be watching.”

Okay. Biochemical oxygen demand -- so we have microorganisms that are going to enjoy the organic compounds that are in our wastewater. They don't care about us; they really don't, but they really like that organic matter because it's a food and energy source to them, so they can produce and reproduce and continue to degrade organic matter and remove that from our water, but the problem is as they do that degradation, they consume dissolved oxygen. We'll discuss that in depth in a few moments.

A second way of measuring oxygen demand is chemical oxygen demand, or sometimes referred to as COD. I'm not going to focus too much on that. We have indicator organisms and we'll often hear fecal coliform and fecal coliform are a very important indicator because they are in us. They are in us, in our gut, helping us to break down our food. They simplify the food breakdown process, so that we can get more of the nutrients out of our own food, and then as they grow and reproduce, we excrete them as part of our metabolism. So our stool would contain many million fecal coliform.

So when we test water to see if it has sewage in it, we would suggest that if we find above a certain number of fecal coliform in there, there's a very high probability that this water has been infected, or is part of a sewage strain. If we do not find these indicator organisms, then we say, maybe it's just water. We still may disinfect, but it's still just water.

I think it important to note, especially in this age of food quality, and whether or not we have pathogens in our food, that E.coli is a broad definition, a broad group or family of microorganisms. Now, if you talk about E.coli 0157:H7, you have a true pathogen, and when the food shows up with that particular microorganism in there, you need to have a food -- you need to have a recall. Folks are going to get sick, but otherwise, we're just talking about indicators of the potential for contamination with sewage.

Solids content, we expect there to be solids in wastewater. Yes, we contribute some solids, but there's -- and those are organic, but we also put other things in the waste stream. We unfortunately put hygiene products in there. Q-tips and other tissues and toilet paper and other paper products end up in the waste stream and they become part of the solids content. An amazing number of people put kitty litter down the drain and that becomes part of the solids content that becomes difficult to deal with.

Other measures of our ability to remove waste from wastewater -- chemical analysis, ammonia and nitrate. From a surface water standpoint, we're very concerned about the ammonia compound because it's a toxin to aquatic species. We're concerned about nitrate because it's a nutrient. We're concerned about phosphorus and the portion of the phosphorus that can become a nutrient is referred to as reactive phosphorus. We're concerned about where there's acidic or basic or the PH. We're concerned about the alkalinity which really just means the resistance of PH change or resistance to become acidic alkalinity.

Volatile compounds, these are the compounds that smell, okay, associated with odors. A lot of these are from dissolved gases.

So these two slides have provided a basis for use to make measurements about how well we are doing in terms of removing waste constituents out of water, so we can make true water out of it. And I want to focus on a couple of these. I've already introduced oxygen demand and I want to spend a little bit more time on there because it's an important measure. It's an indicator of the mass of dissolved oxygen needed by microorganisms to degrade organic and some inorganic compounds.

Now, we mentioned BOD and COD and we use those measures as an indirect indicator of the organic content of a water. So a wastewater that has not received any treatment yet would have a BOD somewhere 280 to 300 milligrams of oxygen demand per liter of wastewater. Now, it's important when you're looking at wastewater to do a BOD and a COD to make sure you're dealing with domestic wastewater because we're pretty comfortable with what domestic wastewater is in terms of its strength.

Sometimes we get into other process waters that can have a much higher COD than BOD and that's an indication you're dealing with a more difficult water, but that's a topic for a different day.

We're going to focus on BOD as an indicator of organic content. Now, I've got a (inaudible) ammonia, which is inorganic, but it also creates an oxygen demand as it's converted to nitrate and we'll discuss that specifically when we get into the nitrification component of this presentation.

So right now, for this slide, I want to know how much dissolved oxygen is going to be consumed out of the water while the natural microorganisms degrade the waste products.

So here's the formula. I'm an engineer; I can't help it. I have to have an equation. I'm determined. But look at it. It's really quite simple. You've got organic carbon and you've got oxygen. Now, both of them need to be dissolved into the water. Now you have aerobic microorganisms that are going to be the facilitators of this process.

The process is going to convert that organic carbon into energy, which might be heat or it might be a chemical form of energy. It's going to convert some of the carbon in the carbon dioxide, Co2, and it's going to convert some of the oxygen and hydrogen into water, and then there's going to be some residuals.

Now, as I've got this equation drawn -- see, there's a down arrow there. Part of that energy is going to go into making new microorganisms. They're going to reproduce. They're going to consume more organic carbon in that process and they're going to consume more dissolved oxygen in that process and they're going to create more energy, more Co2, more water, more residual.

Now, we've got another arrow in the process, so it builds on itself. As long as there's sufficient carbon, organic carbon, and sufficient dissolved oxygen, we're going to build that microbial population until we hit a limit. The limit is either going to be the dissolved oxygen or it’s going to be the food source, the organic carbon.

Okay. So when you add all this oxygen up that it takes to degrade these organic compounds by these microorganisms, then you have the oxygen demand and the biochemical oxygen demand. Okay. Now, wastewater engineers love to provide that oxygen. We love to move oxygen out of the air and into the water and we’re going to talk about that in a moment.

Okay. So that organic matter -- you think of organic matter, we think of carbon, hydrogen and oxygen, the three main components, but it also can contain nitrogen compounds, phosphorus compounds, sulfur compounds and many other compounds can be linked into an organic compound.

Let me go back a slide and reinforce this equation for a second. Think about your automobile. Whether it’s gasoline, diesel or natural gas, that’s an organic carbon. You're going to pull in oxygen through your injection system -- what used to be a carburetor, dare I show my age. So you're going to pull oxygen in. You're going to ignite that combustion and you get energy. That’s what makes the car go forward.

So this equation that I’m showing you right now is the same whether it’s microorganisms digesting organic carbon in the presence of oxygen or whether or not you're doing a combustion inside your internal combustion engine. You get carbon dioxide, you get water and you get some other nasty things that come out into the air that becomes part of our air pollution, okay?

So we’re going to focus on what happens in the water. We’re going to release the nitrogen, the phosphorus and other compounds that are part of the organic matter. So when the microorganisms break down proteins, for example, that come out of our body, protoplasm, cell wall material that comes out of our body, it contains phosphorus, it contains nitrogen. And these are released into the water stream and typically, convert into an inorganic form. Inorganic means it’s no longer a carbon-based compound.

So for example, nitrogen becomes ammonia or ammonium. There’s an equilibrium between those two compounds and an important point to make is that creates an additional oxygen demand, as that ammonia/ammonium is converted into nitrite and then nitrate. We’ll talk about that in a second.

Phosphorus becomes orthophosphate, one of the -- depending on the PH. It depends if it’s dihydrogen or hydrogen orthophosphate. We’ll talk about that more in a few minutes.

So the reason that we really want to focus on nitrogen right now is that this is when it gets converted to ammonia or ammonium, not so much that it’s an oxygen demand, but because at this stage when it’s ammonia, it’s part of the nutrients that can cause eutrophication. Ammonia is a plant-available nutrient and ammonium, of course, is an environmental toxin.

So part of the process that we trick wastewater treatment plants into doing is to convert ammonia and ammonium to nitrate. Right now, we're just focused on the part that we call [ammonification], the breakdown of organic compounds and the release of ammonia and ammonium, okay?

So if we keep providing oxygen to the system, dissolved oxygen, then another set, another pair of organisms will jump in there and say, hey, we got an opportunity to contribute to the party now. We like ammonia and we like ammonium. We're going to break that down further with oxygen and create nitrite, which is the No2 in the top equation and then convert nitrite to nitrate, which is in the bottom equation.

But the important component there is not the name of the microorganism; don't worry about that. The important concept is they use dissolved oxygen in that process, so again, we've got to take the summation of the oxygen demand for breaking down the organic carbon with the summation of the oxygen demand to do nitrification. That's ammonia to nitrate. We've got to take those two sums and be prepared to provide that much dissolved oxygen to the system. That much dissolved oxygen has got to be added to the system, so let's go back to the bigger picture.

We got pretty focused there for a while; let's go back to the bigger picture. We have wastewater with organic matter and it's got other stuff in there and believe me, stuff is a much more polite "S" word. However, we haven't really gone through the first treatment step yet.

So when I think about putting a presentation like this together, I combine that with the fact that I'm an engineer and I'm also an educator, and the engineer in me wants to be very linear in how I go about things, but you really cannot do this with wastewater. It's not a linear process.

So here's the first step. We're going to do liquid-solid separation and the reason it's not a linear process is because liquid-solid separation removes a lot of the oxygen demand, a lot of the oxygen demand. And liquid-solid separation, you get a lot of bang for your buck. You need a tank and you let the water sit in it for a couple of days and you remove about half the oxygen demand. So it's a very inexpensive treatment process.

Now, I'm going to call this preliminary/primary treatment because that's what all the engineering techs call this, the first level. It's the first treatment that we did as a human society in the conversion of wastewater back to water, primary treatment.

What really separates preliminary treatment is the separation out of trash, okay? So it's amazing what people can flush down a toilet that has nothing to do with metabolic waste. If we can take a lot of that material out, we call that preliminary. Primary becomes the smaller, more difficult solids that we can get out.

And gravity is our primary energy source and gravity is cheap. You've got to like it. You've got floaters and sinkers. Yes, go ahead and giggle, okay? Just get it over with; get it out of your system. Based on buoyancy, waters are very dense, okay? And so we have that difference in buoyancy that allows materials to rise. We're going to call that scum -- how unique -- and we have materials that are heavy, more dense and they're going to settle. We'll refer to those as sludge, okay?

So think about some of the materials that rise. Fats, oils and greases really come to mind and they are difficult to work with. These are more complex organic materials. There's a lot of double bonds between the carbons and double bonds between the carbons and the oxygens. So those double bonds mean a lot more energy is available there and so it takes a lot more energy from the microbial population to break those bonds, and so they're more difficult to break down.

But the good news is we can separate those out from a liquid-solid standpoint and skim it off the top, so fats -- that's your lard, that's the good stuff, okay? Think grandma's cookies -- umm-hmmm. So that material is going to rise. Oil is vegetable based, all right? More healthy, more healthy, good stuff, but grease is petroleum based. Now, we use grease as a generic term, but if we want to keep our terminology fairly succinct, fats are animal based, oils are vegetable based, grease is petroleum based.

Now how in the heck do you get petroleum-based grease into your wastewater system? Well, it's quite simple. All your skin creams are oils -- I'm sorry -- are greases. They're petroleum based; it's basically petroleum jelly. Many of your detergents are petroleum based. Look at the ingredients. The ingredient level label is very long on a lot of your detergents.

So the organics that sink are your bacteria cells. They're slightly more dense than water and will sink when they die off. Food waste, if we have a grinder in the system, a good grinder, coffee grounds, eggshells, all those kind of things, they end up sinking to the bottom.

So we have these products that are fairly easy to separate out of the stream by gravity. That's the good news. So having a little bit of a flavor towards small systems, here is one of the most important unit processes of a small system is a septic tank and its primary purpose is liquid-solid separation.

So we're going to form a scum layer on top, we're going to form a sludge layer on the bottom and we're going to use baffles to move water through the system out of the clarified zone. Now, clarified may be too strong of a term, but that is the term that we use. It is much clarified compared to what went in there.

So here's our basic assumption about primary treatment. We had a 50% reduction in oxygen demand by removing the materials that will rise to the surface or sink to the bottom. There is a significant accumulation of organics in that tank, so it didn't go downstream. It didn’t go to the next treatment process. Wow, 50% reduction in strength and we didn’t put any energy into it other than gravity. That’s pretty cool.

So we also have a tremendous reduction in suspended solids. Now, I didn’t put a number there; I didn’t put a number there on purpose because it’s really hard to associate in versus out in terms of suspended solids, but there’s only very minimal bio-transformation. There’s only very minimal conversion of organic matter into inorganic matter because we’re in an anaerobic environment.

When you have an anaerobic environment without oxygen, you do get a degradation. We have anaerobic microorganisms that can degrade organic matter, but it’s very, very slow and it’s very incomplete, but that’s not all bad. That’s not all bad because we use anaerobic processes to create methane. We use anaerobic processes to create alcohol. All this business about creating ethanol, we’re just making whiskey, okay, but that’s an anaerobic process.

One of the byproducts that an anaerobic system cannot do is further degrade those alcohols, methanes, high-energy components. So anaerobic is a good thing, but it’s not necessarily a good thing when it comes to wastewater treatment. So our goal right now is to get the remainder of that oxygen demand out of that wastewater on our path to convert it back to water.

Our engineering society has referred to this as secondary treatment. From a societal standpoint, that was the second really major process we had to go through to, well, satisfy regulatory, okay? We said, we cannot tolerate putting all that oxygen demand out in the rivers, out in the lakes, out in the oceans, because it was taking the oxygen away from the microorganisms and the macroorganisms out there, okay?

So we’re going to take the rest of it out now in secondary treatment. So secondary treatment is the removal of oxygen demand. I’m not going to put numbers here and say, secondary treatment is complete when we have 20 milligrams per liter of BOD because the literature is not concise on that. The literature doesn’t agree on what secondary treatment really is, but we’ll say that it focuses on removing oxygen demand.

Okay. So two questions for you -- when it comes to oxygen demand removal, my two questions are how much land do you have available and how much energy are you willing to purchase? And the reason I ask these two questions is we have to provide the dissolved oxygen. We’re going to put the oxygen back into solution so the aerobic microorganisms have access to it to work at a high rate.

So if I ask how much land is available, then my approach is going to be we can use the soil as a secondary treatment process. We’re going to do that in the next couple of slides, but we also use unit processes, tanks and reactors from a larger engineered scale to provide oxygen.

Now, think about this. Oxygen is only 21% -- I'm sorry -- air is only 21% oxygen, so we've got to move a lot of air through that secondary treatment device to get sufficient oxygen transfer to drive the system. The good news is that oxygen readily dissolves in water. Remember what water is. It's hydrogen and oxygen. You get an accumulation of water molecules, you get that bonding between the hydrogens and the oxygens, and there's plenty of room for some more oxygen molecules in there. So it readily dissolves into water. So if I want to have a low-energy oxygen transfer system, I'm going to need a fairly large footprint. I'm going to need a fairly good-sized area for just the natural movement of air into water.

So I've got two definitions -- passive and mechanical. If I have a passive aeration system, I'm essentially moving air over the water surface and oxygen is going to migrate across that interface between the air and the water surface. It's going to migrate across it, but if I have a mechanical system -- now we're getting into some engineering [laughs].

Now, if I have a mechanical system, I'm going to blow air through the water and so I'm going to greatly increase the surface contact, the surface area contact between that air bubble and the surrounding liquid. So I can greatly enhance the transfer of oxygen.

So let's contemplate this for a second. If I'm going to use the land to provide secondary treatment, then the land has to be available for oxygen transfer. So we need to apply that wastewater fairly close to the surface so that we can have gas transfer. So that's going to take quite a bit of land. It's a slower process.

However, if I'm going to use a mechanical system, and I'm willing to pay for that electricity and generate that big blower, then I can have a much smaller footprint for my secondary treatment system because I can more rapidly transfer oxygen into a solution.

So secondary treatment devices -- the soil. It's an attached growth system. Let me define that. We've got particles in the soil, soil particles, mineral and organic. We've got a layer of water that surrounds now. Microbial digestion takes place in water, and so it has to be in water for our degradation to take place and we've got a layer of water attached to soil particles.

So as we move -- as Mother Nature moves that air through the soil profile, oxygen transfers into that film, so we have an attached growths. It's passively aerated, but we've got to have a very low organic loading rate. We have to be very careful of how we distribute the organic carbon across that soil surface or within the soil profile because we have to prevent an excessive growth of bio-solids.

In your mind, go back a few slides where I had that oxidation equation of organic carbon and dissolved oxygen being converted to Co2 and new bacterial cells. That's going to be our bio-solids, the new bacterial cells.

So if we grow new bacteria cells so fast that it plugs up the porosity of the soil, we have a failed system. If we grow that microbial population so fast in the soil that it plugs up the porosity of the soil, we can no longer transfer oxygen and Co2 and we can no longer move water through the soil. That’s problematic.

Now, if we don't want such a big footprint, then we can go with more mechanical systems like trickling filters which is also an attached growth. We have some type of artificial media in there that microorganisms are growing on and we’re bringing the water to them. We are bringing the food to the [bucks].

Now, as this water trickles down through the media, it is in the presence of air and therefore, you have oxygen transfer, so it’s passively aerated. And we’re less concerned about the growth of the bio-solids because as that layer thickens, it can slough off and be collected down to the bottom of the treatment system. So we’re not as concerned.

So as I said earlier, all our treatment methods are based on what happens in the soil. Well, a trickling filter just upgraded that, just took it one step up and said, we can provide oxygen transfer at a higher rate by pumping the water -- that’s our energy source -- pumping the water, letting it trickle down and we don't have to worry about plugging because we can collect the bio-solids.

Well, now it’s the next step. We need a really small footprint. We've got a city; we've got a major metropolitan. We need to transfer that oxygen into solution just as fast as it can be transferred, and so we’re going to blow it in there with our aeration system. And we’re going to talk about suspended growth. The microorganisms that are degrading the wastewater are suspended in solution and so the process of blowing that air through the water provides mixing and it provides aeration, two components.

So in this case, we’re mixing the food with the [bucks] for a very high rate of degradation, and you know what? We’re not worried about those bio-solids at all because the activated sludge is the bio-solids.

So the next step down the line, down the treatment line, would be a clarifier which would remove the bio-solids out of suspension, and when you remove the bio-solids, you remove a great deal of carbon out of the system. Organic carbon, yes, but you're removing it out of the system and you can do further digestion, land apply it, or take it to a landfill. So that’s part of our treatment process.

Okay. Time to take a deep breath, all right? This is where we’re at right now. We’ve gone through secondary treatment and we've removed a lot of the oxygen demand, perhaps most of the oxygen demand. We've removed a lot of the suspended materials. This takes place in the soil, this takes place in mechanical systems.

Now, just because we have moved our bad organisms, our pathogens -- and a reminder, not all fecal coliforms are bad -- but we have taken the microorganism that came out of us and taken them through an environment that's not as conducive to their survival. And therefore, we have put a hurt on the pathogen population.

Now, if we're in a situation where we're not concerned about nitrogen and phosphorus, all we've got to do is disinfect and let go of the water. Now, hopefully, you'll never hear me use the word "wastewater disposal." Oh, gosh, it's in all the literature, "wastewater disposal." My preference for you, as you talk to other folks, is to say wastewater dispersal because we're putting it back into the hydrologic cycle. We're going to disperse that water back into the cycle. All right. I got off on a soapbox for a second. I apologize.

If nutrients are not an issue at this point, then often, we just disinfect and let it go. We disperse it back into nature, into the hydrologic cycle. In a soil system, we typically do not add a disinfection component because the soil itself is a very powerful disinfectant. Again, we're putting microorganisms that like us and we are at 98 degrees Fahrenheit and we've put them in the soil at 40 or 50 degrees Fahrenheit and they're not feeling so good all of a sudden.

We're taking microorganisms that are traditionally pathogenic, that are typically anaerobic, and putting them in an aerobic environment. All of a sudden, they're not feeling so good. So the soil, or the natural environment, is a pretty powerful disinfectant, but if nutrients are an issue, and they are for today, then we need to look at the third level of treatment. We often refer to this as tertiary.

Now, I laugh about tertiary because the engineering literature and the regulatory literature doesn't always agree on what tertiary means. For today -- and this is me talking -- tertiary treatment is going to mean the extra step required to remove nutrients, nitrogen and phosphorus specifically. Now, carbon is a nutrient, magnesium is a nutrient, zinc is a nutrient. All those micro-trace nutrients that we put on plants as fertilizers, they're coming out of us too. We require them, calcium and so on like that.

But we focus on nitrates specifically as a nitrogen species, because we assume that ammonification has taken place and full nitrification has taken place and phosphate, specifically, because they are the indicators of the potential for eutrophic conditions to occur. So again, we can create -- let me back up. The reason we're concerned about eutrophic conditions is because we have these nutrients out there and they create an excessive growth of green plants and algae. Well, that crowds out the other natural aquatic species that are out there.

Then when that limiting nutrient goes away, when it becomes limiting again, then that biological material starts to decay and it creates its own oxygen demand. So you can see the negative circle of events we could get into.

So we like to talk about de-nitrification. We did nitrification previously when we converted ammonia or ammonium into nitrite and then nitrate. Now, we're going to de-nitrify. We're going to take that nitrate ion and convert it to nitrogen gas so that it can evolve into the atmosphere. Our atmosphere is 78% nitrogen. Adding a little more to the atmosphere won't make much difference.

We've got microorganisms that can do this job. They do this job very, very well, but we've got two issues to address. We need anoxic conditions and we need the right set of microorganisms. The second part is easy. Those microorganisms are there. They're there, but we've got to create the environment from which they will work well.

Anoxic condition -- as a scientist, I really don't like this term “anoxic.” It’s either aerobic or anaerobic in my dictionary, okay? But anoxic has got to be an -- has come to be an engineering term that relates the fact that denitrification can occur; reducing conditions can occur.

So we’re looking at a very low concentration of dissolved molecular oxygen -- in other words, anaerobic, okay? And we’re looking at the fact that dissolved organic carbon is available for this group of heterotrophic bacteria to use as a food source. So part of the degradation process is that they're going to consume organic carbon as they reduce nitrite -- and nitrate, I mean, to nitrogen gas.

But this creates some issues. So let’s look at this equation. I think it’s a totally cool process. I think it’s really neat. Look down at that equation and see that first term, nitrate. You got an “n” and three “o’s”. You got heterotrophic bacteria that would really prefer to work in the presence of oxygen. They really would be much happier if they had plain old, good old, molecular oxygen available dissolved in the water, but they don't. We’re going to make the situation for them such that they do not have that.

But they're pretty creative. They look at that nitrate, O3, hanging there and they say, that’s oxygen, and they have the ability to remove the nitrogen from that oxygen and use that oxygen for their natural processes. Is that not cool in terms of trying to accomplish the removal of a waste constituent? But here’s the rub -- we have to make sure no molecular oxygen is available and we also have to make sure that organic matter is available.

So let me change slides here. Here’s the rub. We have built this system depending on dissolved oxygen for the purpose of removing organic carbon. So we sound like we’re kind of going backwards, so our process must consume all the oxygen now before it gets to the denitrification side, but it’s got to leave a little organic carbon in solution so those microorganisms will have an energy source. So this makes it a bit more difficult to achieve denitrification under natural conditions.

So let’s go to the soil for a few minutes. The soil system is very good at secondary treatment, removing organic carbon, as long as we can keep that system aerobic, okay? The microorganisms are there to provide organic carbon degradation under both aerobic and anaerobic conditions. So the system is available to provide denitrification, but it’s much more difficult to do this on a performance basis.

Okay. Here's our weakness with using a soil system. We're going to be depending on that organic carbon to be in the soil, but we're going to depend on that interaction to take place deeper in the soil where we have saturated conditions and presumably, no dissolved oxygen. That is much more difficult to guarantee; that's much more difficult to assure that's going to take place in the soil system.

Now, that's where swampy ground is really good for denitrification. That's where wetlands are just excellent for denitrification, okay? So truly, if we could follow, in a soil-based system, if we could follow the nitrification and the BOD removal with a wetlands situation, saturated soil situation, with some additional organic carbon -- in other words, add plants to it -- we'd get pretty good denitrification, pretty dependable denitrification.

But one of the ways that we can do this with a mechanical system, either on an individual home or in a municipality, is recirculation. So let's take a bit of that secondary treatment water, which is going to have nitrate in it, because it's been through ammonification, it's been through nitrification. So it's going to have nitrate in solution.

Now, let's take a fraction of that water and recirculate it back to primary treatment. The assumption is going to be that that primary treated water is anaerobic. It hasn't been mechanically aerated and there's so much organic carbon in solution that it has consumed any dissolved oxygen out of the water. So the presumption is we can take some of that nitrate water back to primary treatment and have denitrification take place.

Well, there's an obvious hitch there; there's a hitch. We can't recirculate all the water back or we'll never finish the treatment process. So we've got to figure out a balance of how much nitrate we can allow to go downstream, or to further processes versus how much of the water we can recirculate back for denitrification, so there's a balance there because we're going to balance how much organic carbon is available without aerating the water. So we can denitrify very significantly. It's very difficult to remove -- almost impossible to remove all of the nitrate.

Now, if we're going to the soil with that water, then we've got plants that'll take a good bit of that nitrate up. That's a nutrient. The rub there is we need to harvest that material because as the grass goes through senescence and then decays, it releases that nitrate back in some form of nitrogen. So we need to harvest that material. So we do have some -- a very robust biological system that can remove nitrogen out of our wastewater and not let it go downstream. So that's a major, major waste component -- phosphorus removal.

And if you're watching the clock, we're getting pretty close to the end here.

Phosphorus is our other major concern. Now, we often use the expression that nitrogen is a greater concern in estuaries and coastal areas and phosphorus is more of a concern in inland aquatic systems. That does not hold true. I'd really just as soon that phrase would go away. I live here in Tennessee. I am a proud Tennessean, but the geology underneath my feet is [coursed], a lot of limestone, and the type of limestone that we have has a lot of phosphate mineral in it.

So our aquatic systems from our streams and our springs and so on like that already have all the phosphorus in them they want. Our limiting nutrient here is nitrogen. So we get a little extra nitrogen in the water, we'll get a [balloon]. So knowing which nutrient is limiting is specific to the water chemistry that occurs naturally.

It generally holds true that nitrogen is limiting in estuaries and so on like that; phosphorus is generally limiting in natural --- in the country-type systems, but it's not 100% true. So it really depends on what the water chemistry is at your specific location as to which nutrient is going to be more limiting.

Something I didn't mention, something I almost forgot about -- the ion nitrate can be a human toxin, can create a toxic condition in infants. I really didn't include it in the slide because I just now thought of it, but it can create a condition referred to as blue baby syndrome where the excessive nitrates can get into the bloodstream and tie up the oxygen's ability to attach to hemoglobin within the blood.

There's a very long name associated with that condition. It's got methol and it's got hemoglobin and it's got a few other terms associated with it and I will not embarrass myself by trying to pronounce it. I do enough to embarrass myself as it is.

Fortunately, that's pretty much a condition in infants, that kind of toxicity, and not too uncommon an occurrence where we use a lot of fertilizers and we have very shallow ground water. Okay. Enough about nitrogen.

Let's focus on phosphorus, okay, what most folks refer to as "pee" and if I don't shut up pretty soon, I'm going to have to go do that myself. Now, phosphorus -- typically, the way we handle phosphorus is with a chemical treatment. You see that phosphate ion there, that Po4-3 minus, and that's going to be the natural form of phosphorus in water as phosphate.

We didn't use to talk so much about phosphorus because it binds very tightly with soils, so we used to didn't worry too much about phosphorus because if you had phosphorus in a soil system, the majority of the phosphate was bound to the calcium, the aluminum and the iron that naturally occurs in clay soils -- not in sandy soils, but in clay soils and silty soils. And so from an agricultural perspective, we didn't worry too much about it because only a very small fraction is actually in solution, or the reactive phase.

Unfortunately, it's that very small component that is needed to do eutrophic effects and it just doesn't take much. I've seen studies where folks report phosphorus addition to a water body on the less than milligram per liter basis, and that's pretty small. Very, very low concentrations can cause problems.

So for the most part, our soil-based wastewater treatment systems do an excellent job of phosphorus removal, as long as there's not too much sand there. Sand is silicon and quartz, not very handy for bonding with phosphorus. You need the calcium, the aluminum, and the ferric ions in there to do that binding. You see, they're all [CAT] ions. Now, that's a problem for Florida folks that depend on soil-based systems and have shallow aquifers for phosphorus contamination.

Now, we're going to do this both as a chemical addition of calcium, aluminum and iron in municipal systems, and of course, we depend on the natural occurrence of these kinds of ions in natural systems. In each case, you form an insoluble precipitant that takes it out of solution.

Now, this is kind of interesting; I find this very interesting. It's a very controlled poly-technical engineered method of removing phosphorus. There is a biological means of removing phosphorus. Phosphorus is part of our metabolism; it's part of our protoplasm; it's in our cells; it's in all cells. All right. So we need it. It's a nutrient, that's why we need it.

But there are times when we can encourage the luxurious uptake of phosphorus within microbial cells in a wastewater treatment system. We might play with the acids a little bit; we might play with the alkalinity a little bit. We might make some tweaks to the water environment that makes those microorganisms kind of get concerned.

They're starting to get uncomfortable. Something is changing. I might need more nutrient and they start sucking up more phosphorus. Now, I have greatly oversimplified that, but that's the best way I can understand it, I assure you.

But before they get too carried away and realize they have taken up more phosphorus than what they really need, they we mechanically get in there and clarify those microorganisms out of suspension. And therefore, we have removed a great deal of organic matter and a great deal of phosphorus out of solution. It's no longer dissolved in the water by biological means.

Now, for your very small systems, this is just not going to happen on an individual home and probably in most decentralized smaller community systems. This requires a great deal of control, both in knowing what comes into the wastewater treatment plant, how you can remove it, and almost no shocks to the system. So it only happens under very, very controlled conditions.

Oh, boy, misspelled words -- Spellchecker didn't catch that one, but I won't point it out to you. You'll have to find it on your own.

Now, big picture again, big picture -- our goal is to convert wastewater back to water and so there are certain undesirable things in the water that we want to remove before we consider it water again.

And I ask this question -- how big is your hydrologic cycle? I'm here in Knoxville. My hydrologic cycle is pretty big. We get the bulk of our drinking water out of the Smoky Mountains and there's very few towns and cities between the mountains and Knoxville. So our water, by the time it gets here in the Tennessee River, is not too bad.

So we put it into the water treatment facility. We go through all the processes to turn it into potable water, drinking water, safe water. We use it for cooking, we use it for cleaning, we use it for drinking and washing. We turn it into wastewater.

It goes through our wastewater treatment plant to where it becomes an acceptable tertiary quality water and it goes out into the Tennessee River again. Well, the hydrologic cycle is a pretty good size because the next town that takes it out of the river is 10 miles downstream. So it takes it a couple of days to get there.

Now, if you're in an international space station, your hydrologic cycle is pretty small, okay? They recollect your urine. They squeeze the moisture out of your feces. They condense the air, because you've released moisture as you speak and you sweat. They condense all that water back down, treat it and drink it again. Umm, boy, I'm glad I've already had lunch.

Now, we can do that here on earth. The technology is coming along. We call them filtration systems or micro-filtration, where we pass that water through very, very, very, very, very small pores and most of the waste constituents that we want to remove from that water cannot fit through those pores. We might hear those referred to as -- oh, I'm drawing a blank; I hate this when it happens. I'm going to blame it on having a senior moment, but I'm really not quite that senior yet.

But membrane bioreactors -- there we go. My brain hasn't completely quit on me -- membrane bioreactors. So you have membrane systems that can physically and chemically separate waste out of water. Now, that's what they're using in the space station. We may have to go to that someday because we've got this other stuff that we put in water that's a waste constituent -- these pharmaceuticals and personal care products.

So I'm going to pick on these specifically for a few moments, and I am a contributor. Don't get me wrong; I am a contributor of these materials. I drink caffeine; we're running on caffeine right now, I promise you. All right. Unfortunately, I have acid reflux, so I take the antacids. I have allergies, so I take other pharmaceuticals and so on like that. So I have -- I am a contributor of pharmaceuticals to the stream.

I'm going to pick on my wife for a few minutes. She likes things that smell good and those are chemistries, okay? I really don't like all those things that smell good and one of the reasons I don't like them is because they contain an anti-microbial called [triclosan], which goes out into the environment.

So we put other things downstream with our medicines, our hormone replacements, or just our natural hormones that come out of our bodies, anti-microbial soaps and so on, that we're going to be focusing more on in the future. We're starting to -- we're only just really starting to focus on this and I have to ask the question -- in the future, are we going to call this [quaninary] treatment? I will say that I coined a phrase if need be.

So the ultimate question -- and we're going to open it up for questions and so on like that -- at what point does wastewater become water? We work very hard to take a lot of the negative constituents out of the water. We have some very basic processes which do that. We have to create the environment for those natural processes to work for us.

They don't care about us. All they care about is food, okay? And if we can work within their metabolism, the cycling of nitrogen, the cycling of organic carbon, and of course, the cycling of water, we can remove those constituents out of the water without going to highly engineered processes.

So at what point does wastewater become water? Are you willing to consume recycled water? Well, you are. It really just depends on the size of the system, okay? But in reality, as our population increases, that hydrologic cycle is getting smaller. We're going to have to change our notions about how close our connections are between the discharge of wastewater treatment plants and the intake of water treatment plant.

Really and truly, the science is good enough to have that connection be pretty close together, and it is in some communities, and it's going to be so in all our communities as time progresses.

So I hope, with this presentation -- it's a presentation I've been wanting to give for quite some time, and I'm really pleased that the MOU Group allowed me, but I think it's pertinent that we all use the same language, and all talk the same talk when it comes to how we remove waste constituents out of water. We've got to understand that we really desire a high-quality water, but we've also got to understand what it takes to achieve it.

With this, I'm going to turn this back over to Maureen and Ryan and we'll answer questions.

Maureen Tooke: Okay. Thank you very much, John. That was incredibly thorough and enlightening. We actually didn't get any questions come in through the chat feature, I think, because you were so very thorough.

If we can, Ryan, either use the raising-hand feature or just open it up to any questions -- we only have a few minutes left here, and if you can -- hopefully, you can hear me.

Dr. John Buchanan: I can hear you.

Maureen Tooke: Okay. Okay. Should we just open the floor? I mean, there's only five minutes left, so if anyone has any questions, we can -- you can unmute everyone, Ryan.

Unidentified Speaker: (Inaudible).

Maureen Tooke: If you can identify yourself and feel free to ask a question. If you aren't speaking, you can mute yourself by hitting the little microphone [button]. Is there a question?

Ryan: I think it was some background noise.

Maureen Tooke: Yes, I think we're just getting background noise.

Dr. John Buchanan: Okay. Well, the silence is deafening.

Maureen Tooke: Yes. Well, we'll just -- if there are no questions -- if there are any -- Ryan, can you mute everyone now?

Ryan: Yes.

Maureen Tooke: Going forward, we're going to make this webinar available on the Septic Wiki if you are already registered for that. If not, we can get you the information for that. We have the list of attendees for this and we will make it available for you to view again or share.

If you have any follow-up questions for John or myself, feel free to email us when you get the information from this and we will make it all available for future use. And feel free to send it around to those that you think might benefit from the information that John has given us today.

So with that, I will say thank you for attending and look for our next webinar that we will have in the next couple of months. Thank you very much. Bye.

Ryan: Bye, thanks.

Maureen Tooke: Thanks. Thanks, John.

Dr. John Buchanan: You're quite welcome.