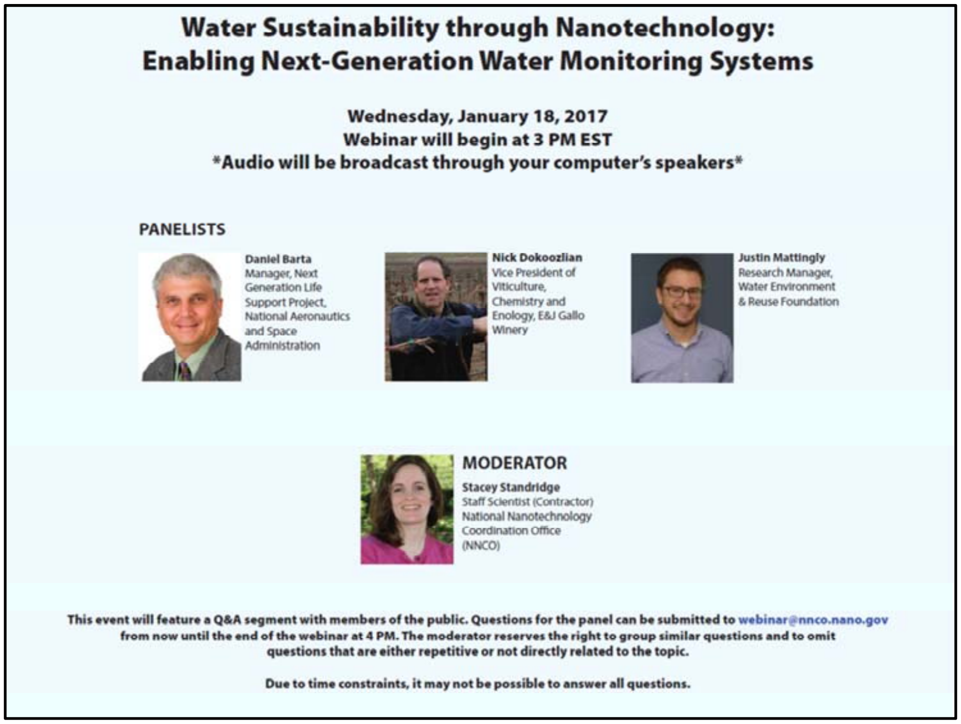


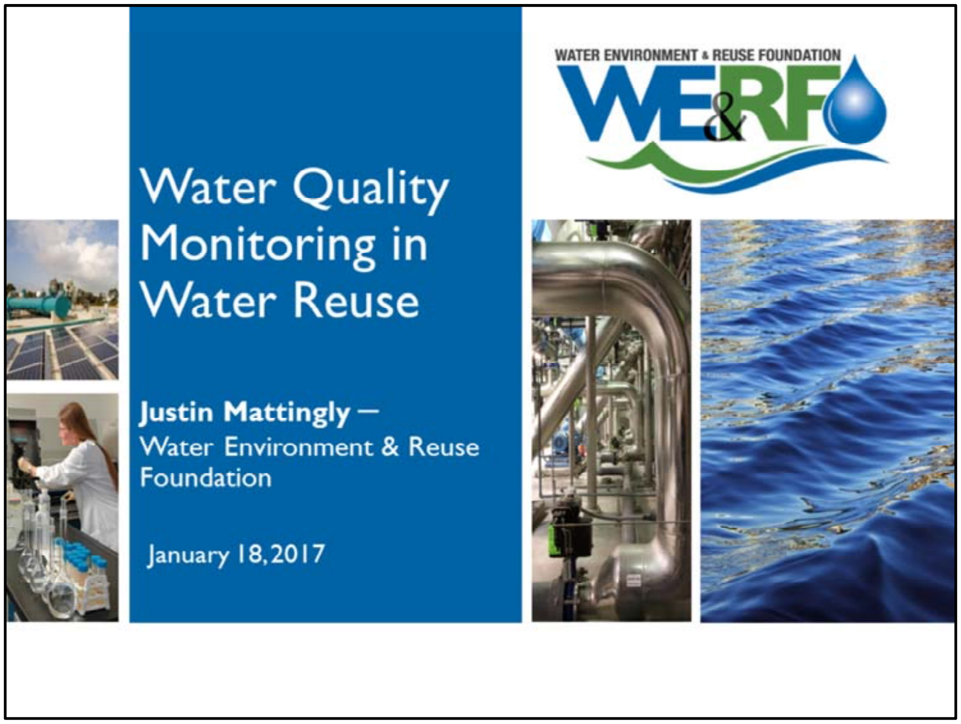
>> Stacey Standridge: Good afternoon and welcome to today's Water Sustainability through Nanotechnology webinar. My name is Stacey Standridge. I am a Staff Scientist at the National Nanotechnology Coordination Office, and I will be your moderator today.

Today's webinar is hosted by the National Nanotechnology Initiative's Signature Initiative: *Water Sustainability through Nanotechnology*, and this event, focused on water monitoring systems, is the third in a series exploring the intersections of water and nanotechnology. An archive of the first webinar, which provided an introduction of the Water Sustainability through Nanotechnology Signature Initiative, is available at www.nano.gov/publicwebinars, and the archive of the second webinar on technologies for increasing water availability will be posted soon.

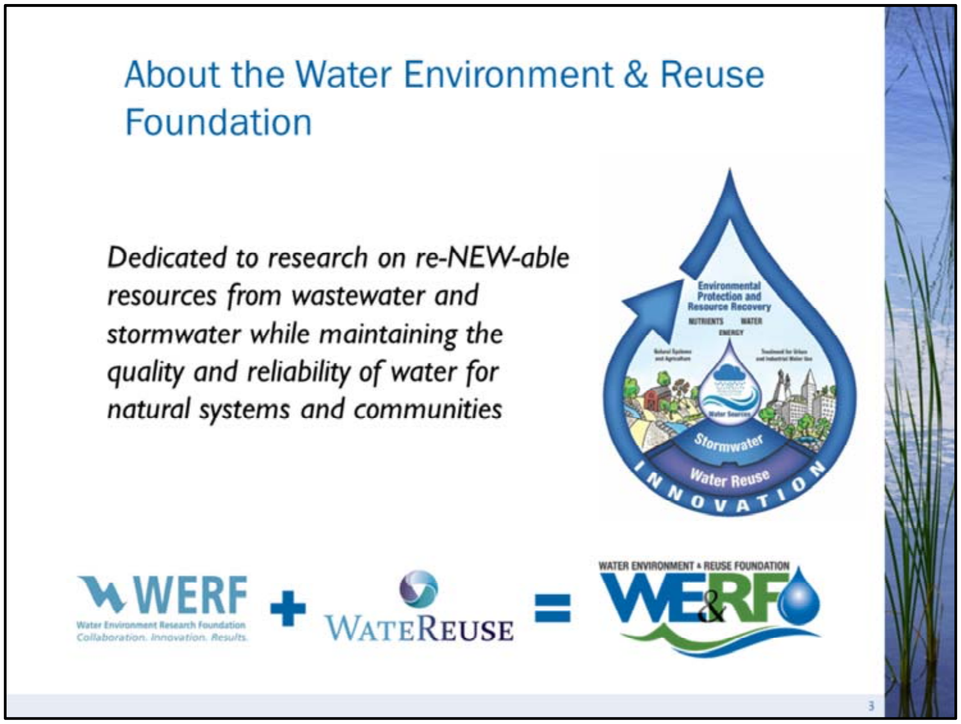
As I mentioned, today's webinar will explore topics related to sensors for water monitoring, and we have a great panel of speakers for you today. Justin Mattingly from the Water Environment & Reuse Foundation will start with a broad overview of water quality monitoring for potable reuse, and his talk will be followed by two case studies. I heard a representative from John Deere speak at a sensors workshop a few years ago, and he mentioned that John Deere's motto is "feet on the ground, eyes on the horizon." The case studies presented today will echo that trajectory, starting with a talk on agriculture and concluding with a talk on spaceflight. Nick Dokoozlian from E&J Gallo Winery will discuss studies they have done using sensors to improve irrigation efficiency in their vineyards, and Dan Barta from NASA will discuss water monitoring needs for long-duration human spaceflight.

If you have questions during these presentations, please feel free to submit them via the "submit your questions here" box in the webinar interface. Time permitting, we will conclude the webinar with a brief Q&A session.

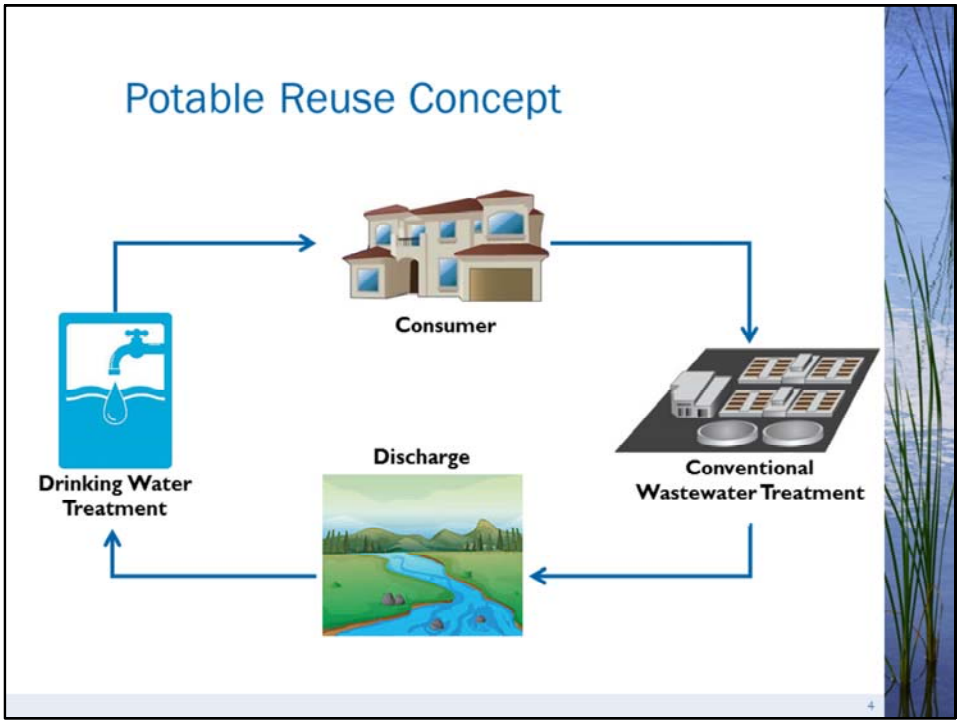
Without further ado, I will hand the floor over to Justin.



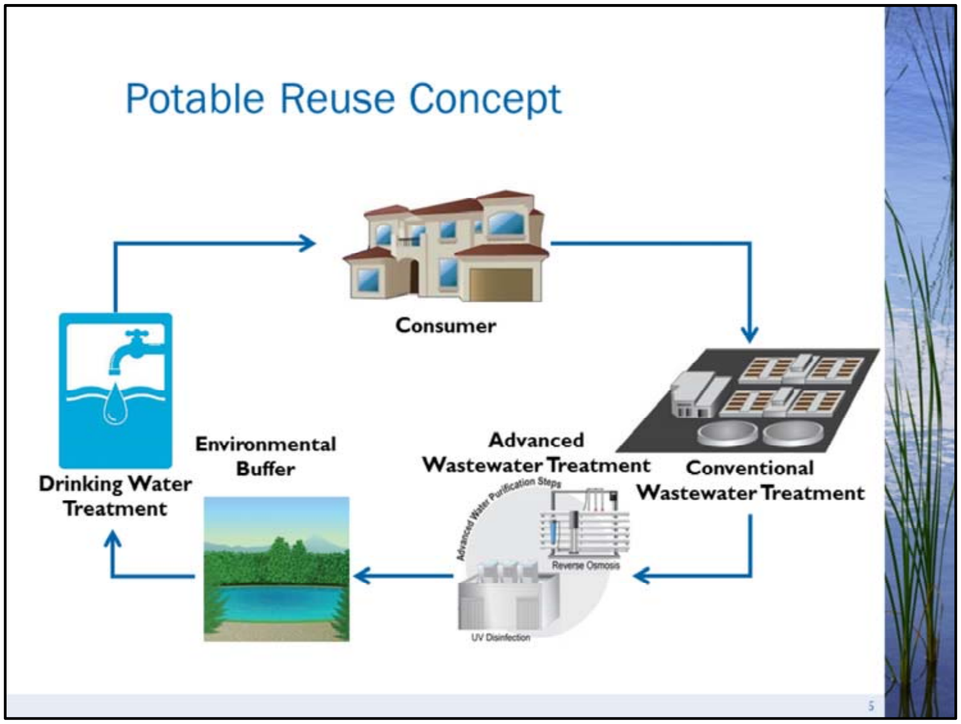
>> Justin Mattingly: Great. Thanks, Stacey. As Stacey mentioned, I will be talking about water quality monitoring in water reuse.



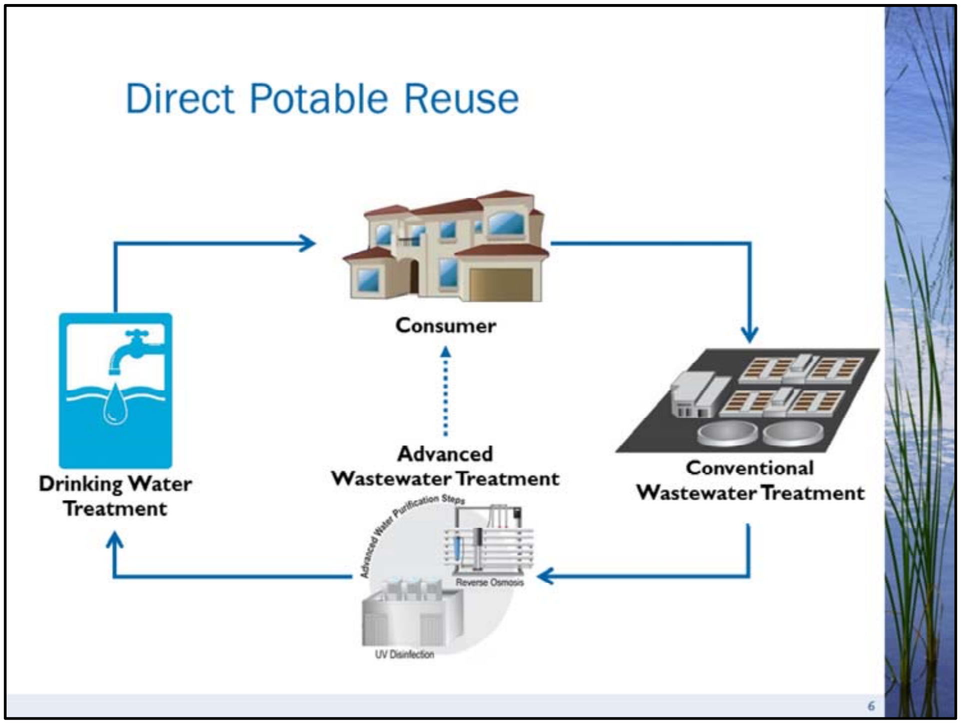
>> Justin Mattingly: Just a brief background of who we are at the Water Environment & Reuse Foundation. We are the culmination of a merger between two organizations: the Water Environment Research Foundation and the WateReuse Research Foundation. We are a non-profit research foundation and our subscribers are various public utilities, technology providers, and engineering and consulting firms. And we fund applied research in the world of waste water treatment as well as water reuse, which is where my focus has always been.



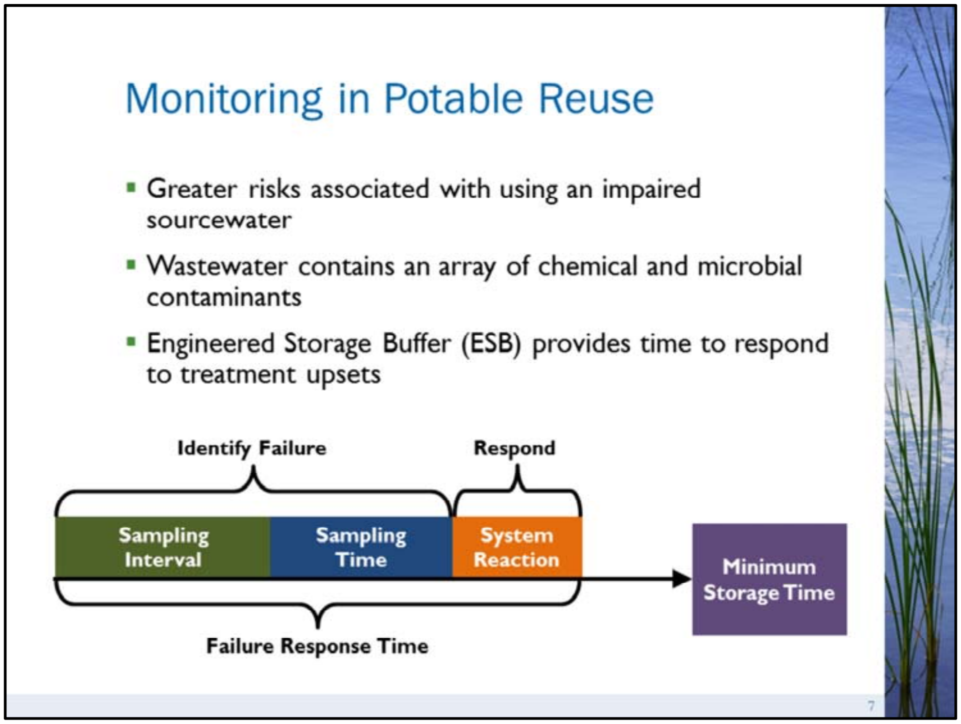
>> Justin Mattingly: So first, I briefly want to talk about the potable reuse concept. What you see on the screen here is really a very simplified version of the urban water cycle. You start of with a consumer who uses water. The waste water then goes through conventional waste water treatment and is discharged, in this case discharged to a river. At some point along that river downstream, it'll get picked up again through drinking water treatment; and back to a different consumer.



>> Justin Mattingly: This is essentially known as *de facto* potable reuse. But with planned potable reuse, you are eliminating that discharge and going through advanced water treatment into an environmental buffer—that could be a surface water reservoir or an aquifer—back through drinking water treatment and back to the same consumer. This creates a closed-loop system for water supply. This can be especially useful if you are located along a coastline. Whereas instead of discharging your waste water into the ocean, you're keeping that water within the community as a means to supplement your water supply. What you're seeing here on the screen is the indirect potable reuse concept.



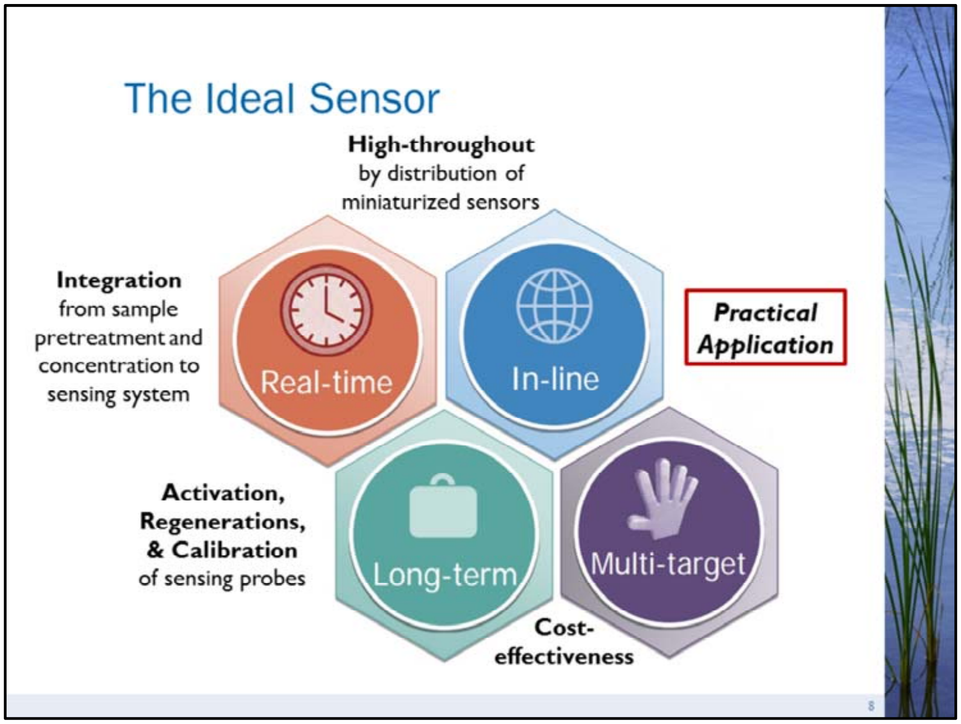
>> Justin Mattingly: If we move to direct potable reuse, you are eliminating the environmental buffer. In this case, waste water goes through conventional waste water treatment to advanced waste water treatment. This is followed by drinking water treatment or, potentially in the future, directly back to the consumer. This advanced waste water treatment can be in a number of different forms. What you're seeing on the screen is reverse osmosis followed by UV disinfection. Reverse osmosis-based treatment is currently seen in many places in California; however, there are also other options for non-reverse osmosis treatments.



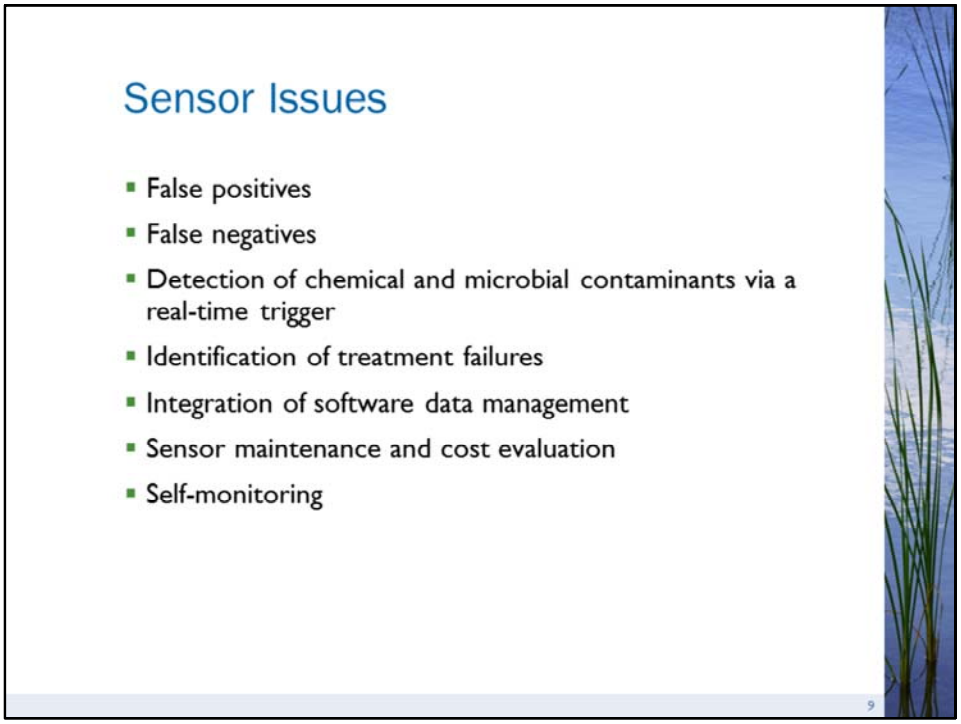
>> Justin Mattingly: So how does monitoring play into all this? As you can imagine, there are greater risks associated with using an impaired source water as drinking water. This is because waste water contains an array of chemical and microbial contaminants that must be removed before going to the consumer. To ensure that the waste water has been properly treated, an engineered storage buffer is used to ensure that there is time to respond to treatment upsets.

The diagram on the bottom shows how the minimum storage time is determined. First, a failure must be identified. The time needed to identify a failure is determined by how often sampling is done and how long it takes to actually do the sampling and the testing. And then you have your response time, which is how long it takes to correct a failure after it has been identified. The combination of those three steps is the failure response time. For example, if it takes 24 hours to identify and correct an upset, you would need 24 hours worth of storage time.

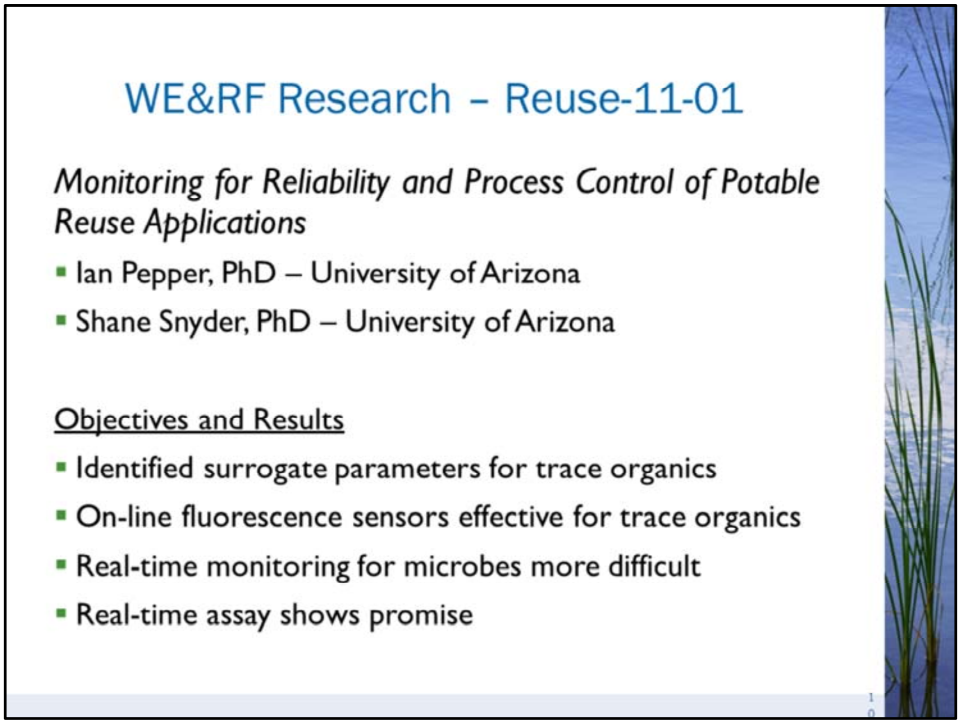
Monitoring can play into this if we can shorten the amount of time it takes to identify the failure. This would allow a reduction in the amount of storage needed. That can greatly reduce costs as well as increase reliability in the system.



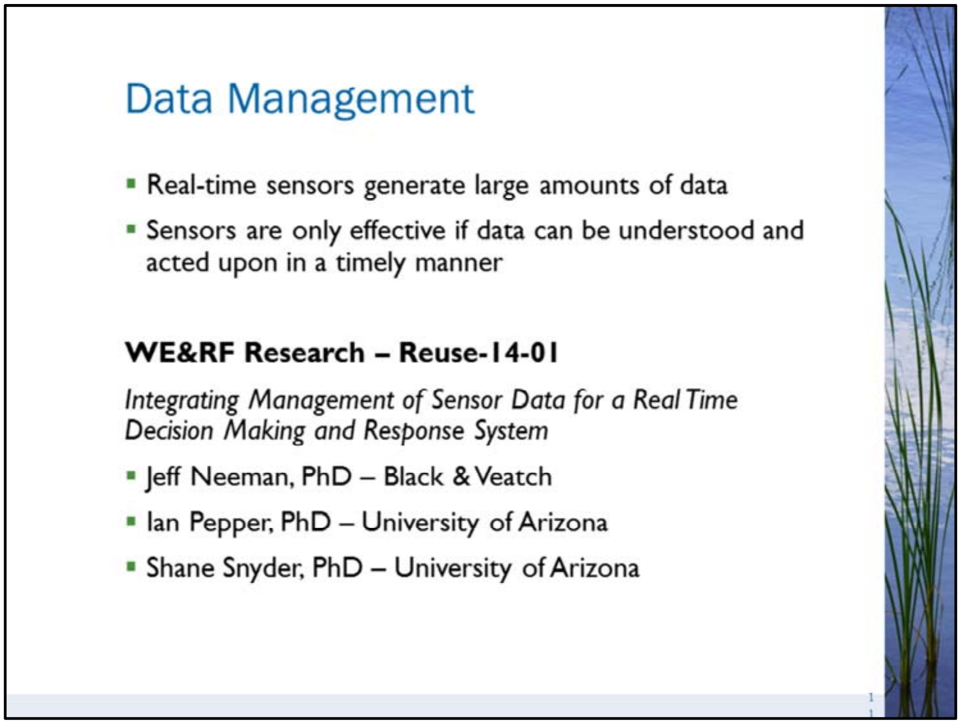
>> Justin Mattingly: So what is an ideal sensor? First, you want to have sensors throughout the entire treatment process to create a system of sensors that are integrated from pretreatment all the way to the end in distribution. They also need to be multi-targeted. You can't just monitor for one constituent. You want to make sure that what you're monitoring for is comprehensive of the full risk inherent with water treatment.



>> Justin Mattingly: So what are some of the issues with sensors? Obviously, you have false positives and false negatives. Neither of which are good, and both have consequences. Ideally, you also want to detect chemical and microbial contaminants via a real-time trigger. This is what we're really looking towards in the future. Instead of doing grab samples that may take quite a bit of time to determine results, if you can use a real-time monitor, that will greatly decrease the amount of time needed to detect an upset. This would all be aimed at the goal of identifying treatment failures and how to respond to that failure. The integration of software data management—and I'll be talking about that in a little bit—that's a very important aspect. And then, of course, you have sensor maintenance and cost evaluation. If the sensors aren't cost-effective, utilities aren't going to have the capacity to purchase them and install them in their systems. Along the same lines, these sensors need to be able to be maintained by staff. Utilities are generally strapped for funding as it is, and any sensor system has be cost-effective and easy-to-use.



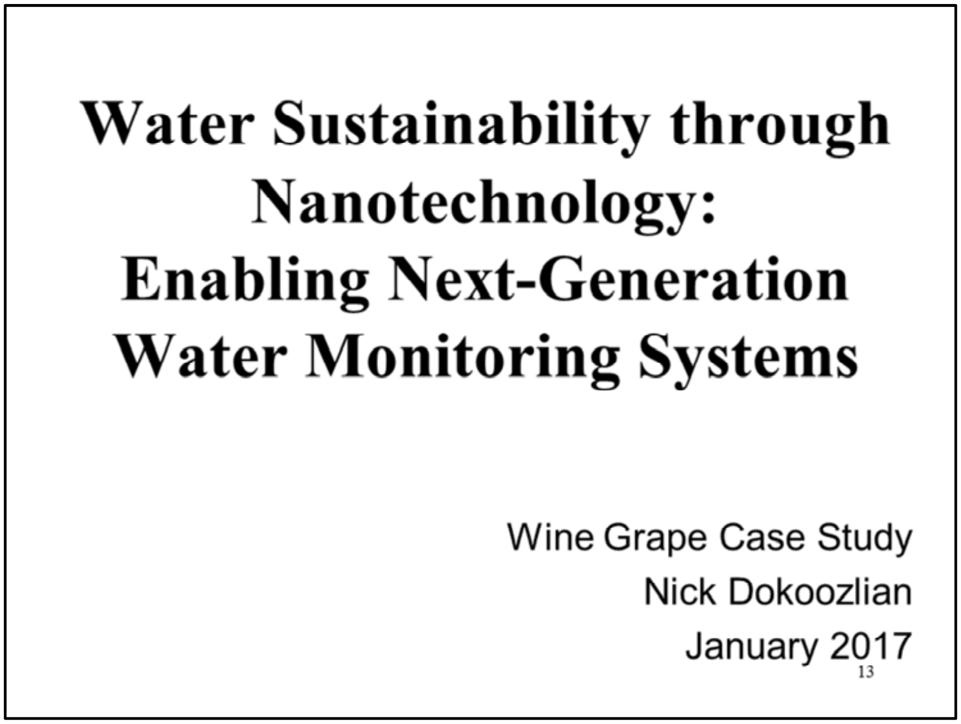
>> Justin Mattingly: So what is some of the research that we at WE&RF have been doing? This first project I want to talk about here is project Reuse-11-01: *Monitoring for Reliability and Process Control of Potable Reuse Applications*. This looked at a number of lab-scale, pilot-scale, and even full-scale advanced treatment facilities, and evaluated how they currently do monitoring and the potential for some real-time monitoring applications. In the investigation, they identified some surrogate parameters for trace organics. While there are not sensors available for every specific organic compound, you can identify some surrogate parameters that can be monitored on a real-time basis. One of the ways that this can be accomplished is through an online fluorescence sensor. There is not an image here, but by doing a fluorescence scan, you can determine the amount of trace organics still in that water after treatment. One of the other outcomes from this study was an evaluation of real-time monitors for microbial constituents. It was found that real-time monitoring for microbes is a bit more difficult, in part because it's very difficult to determine whether any microbes are actually viable. However, a real-time assay did show some promise.



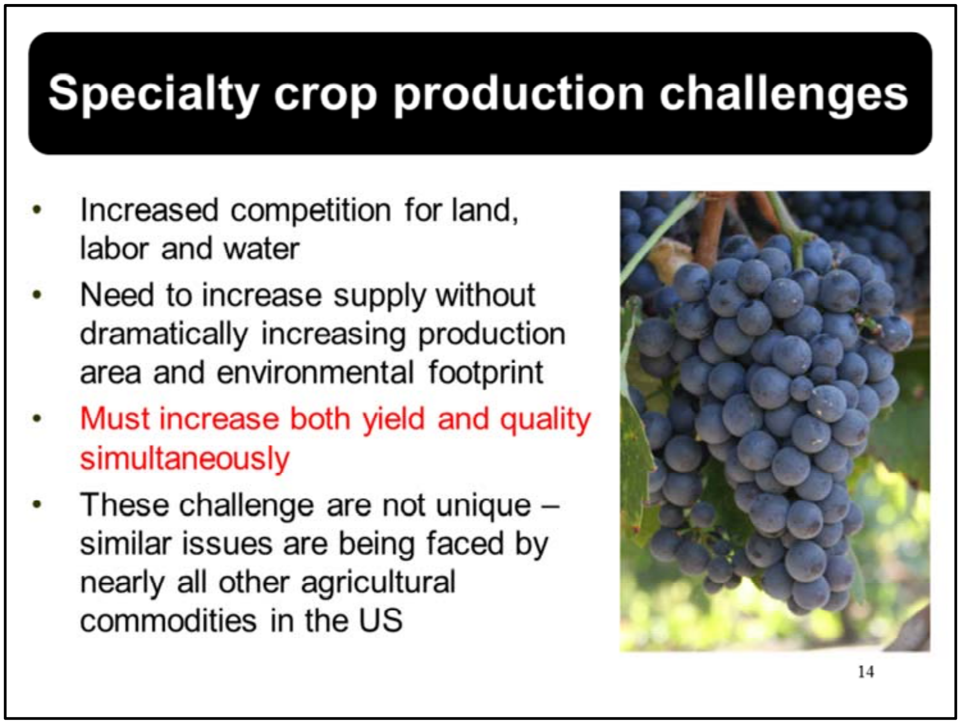
>> Justin Mattingly: Another issue that I briefly want to talk about is data management. Real-time sensors generate extremely large amounts of data, and sensors are only effective if the data can be understood and acted upon in a timely manner. If you have mountains and mountains of data and no way of actually understanding it, then that data is essentially useless. We have an ongoing project right now called *Integrating Management of Sensor Data for a Real-time Decision Making and Response System* being led by Black & Veatch and the University of Arizona. They're developing a tool to integrate a lot of this data into everything from SCADA systems and other operations systems to allow for real-time decision making based on all this data. This study is taking all these new innovative sensors and actually making the rubber hit the road to make sure that these sensors can be implemented and the data that they generate can be acted upon to protect public health.

>> Justin Mattingly: So that's all I have right now. I will be on the line at the end for any questions you have. So I will hand things back off to Stacey.

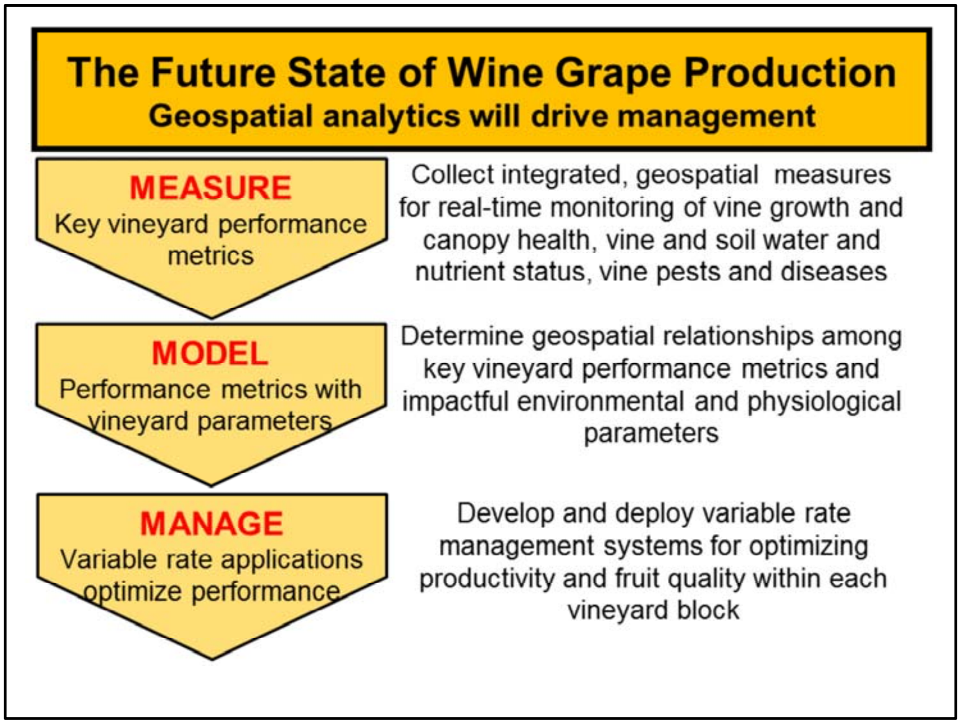
>> Stacey Standridge: Thanks, Justin. That was a great overview. Nick, the floor is yours.



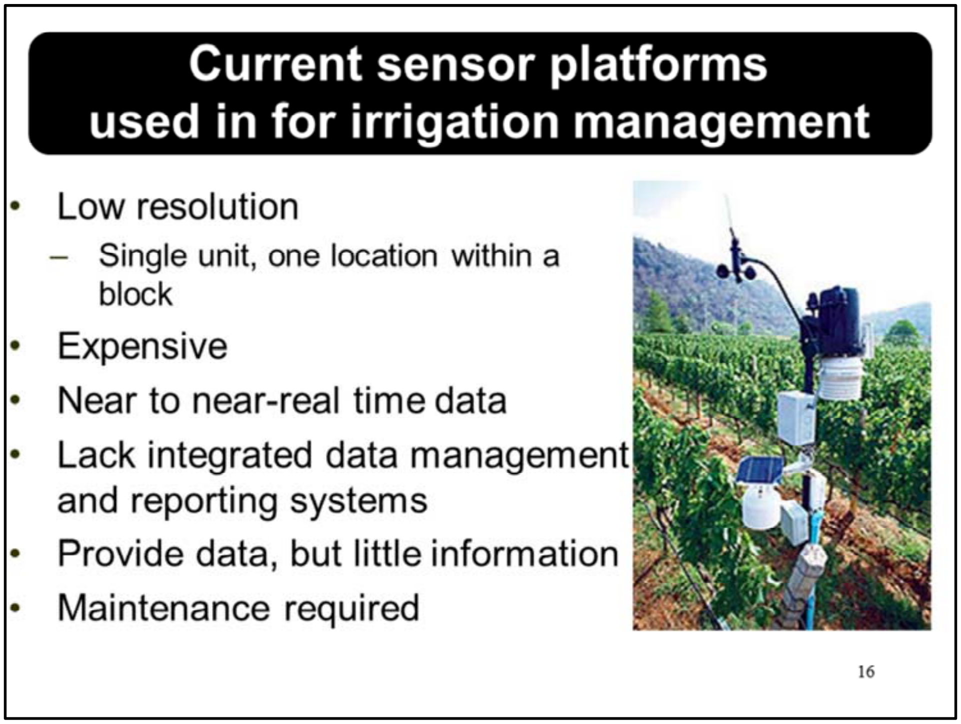
>> Nick Dokoozlian: Thank you very much. I want to thank everybody for the opportunity, and thank you for calling in to listen to our case study.



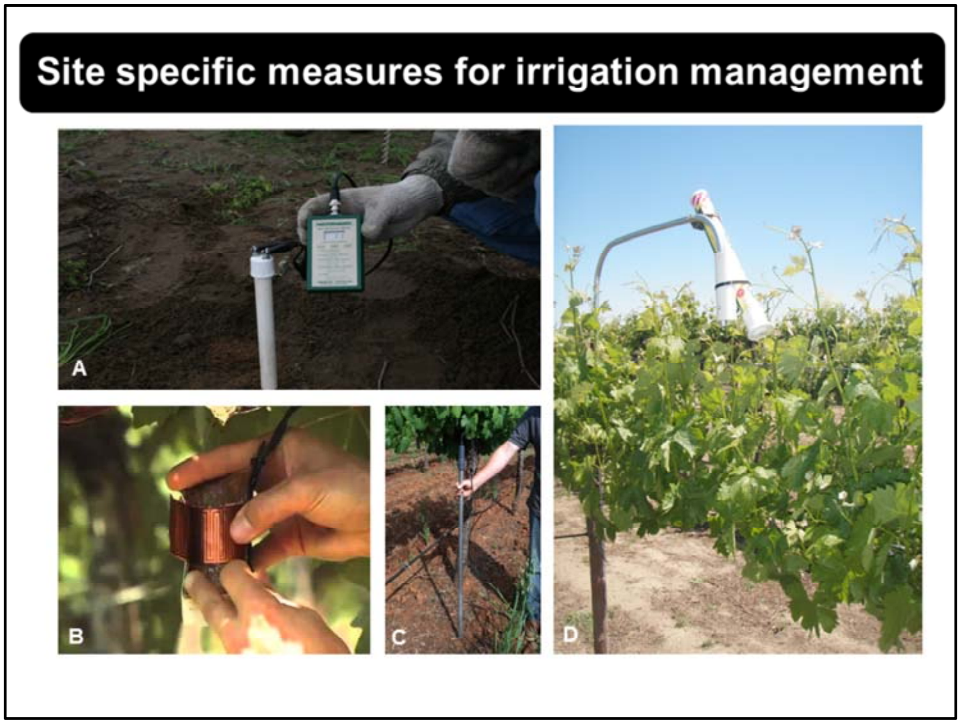
>> Nick Dokoozlian: I'm presenting this case study on behalf of specialty crops. My particular business interests are around wine grapes, but I think we can use this generically around any of our specialty crops. So not surprising, land, labor, water—in particular here in California—we have increased competition for these resources. I think what's very unique about specialty crops is that we have a quality component in specialty crops. Wine grapes are a great example. But just about all of our specialty crops have very specific either chemical or physical or visual metrics around their quality. And so I think the importance of water for maintaining and improving quality and yield is, of course, very critical. And I think these are similar to challenges produced by all of our specialty crop commodities.



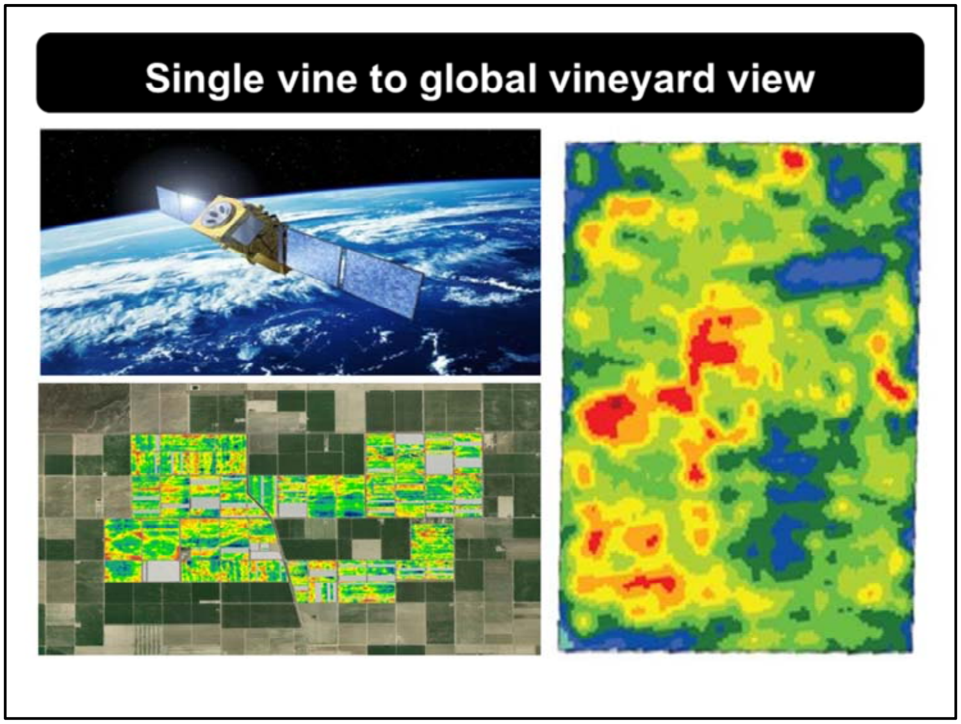
>> Nick Dokoozlian: I think our task here, in terms of sensor technology, is really to help us do this schematic. Measure, model, and manage. We want to measure the relevant parameters in our system. Use that data to model. And then, of course—ultimately, and I think our biggest gap today—is to use the data that we collect in order to create variable rate management applications. What's exciting to me about the sensor space today is that with sensor technology and the automation of data collection, we're able to collect data on a resolution that was just not possible in the past, and also at an accuracy that just was not possible with manual measurements. This is allowing us now to make our models much, much more robust than they were even just a few years ago. It's a very exciting time for us, but agriculture is still catching up with many of the other industries.



>> Nick Dokoozlian: One of our biggest problems today is that our current sensor platforms really aren't robust enough to do the kind of modeling and measuring that I think we need for the long-term solutions for our problems. These are generally low-resolution sensors. There is an example of one in a vineyard hanging there on the trellis system, you can see right above the canopy. They tend to be very expensive. We have a single unit maybe for a 40-acre block or 50-acre block, so, obviously, there is a scaling issue. It's not adequate for modeling purposes, and in most cases we lack the systems to integrate these kind of data with other data that we collect. We tend to be very data rich but relatively information poor. And, of course, there's constant maintenance there. That is something that is certainly a challenge.

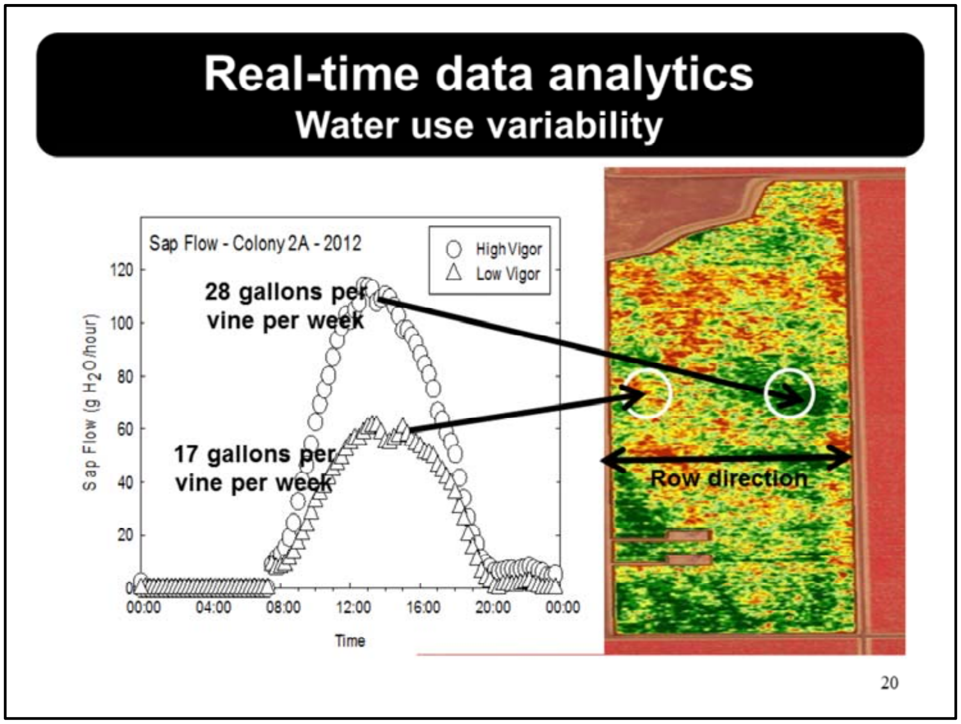


>> Nick Dokoozlian: And these are some examples of some of the sensors that we use in our field specifically to monitor irrigation requirements. There's some examples of some soil sensors there in photos A and C. Those are soil sensors either that stay *in situ* in the case of A, or things that we slide up and down through an access tube in the case of picture C. Picture B is a slide of a sap flow sensor, which goes around the trunk of a grapevine or tree and measures based on heat sensing the amount of water that's travelling to the grapevine and relates to transpiration. And on the right-hand side, you see the IR sensor that measures canopy temperature in real-time.

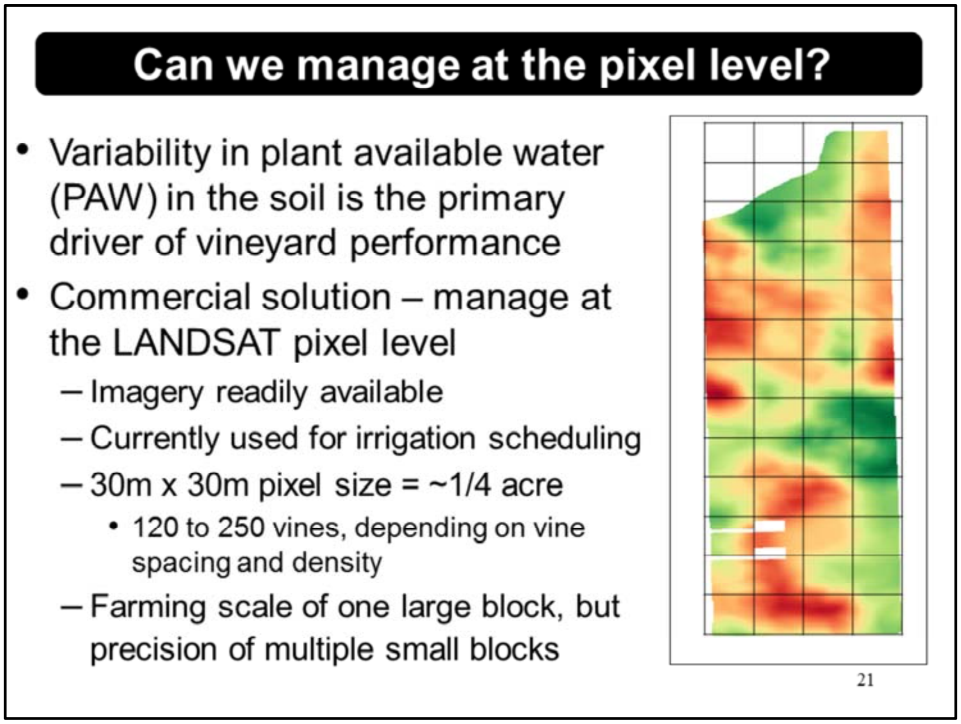


>> Nick Dokoozlian: Those are some examples, but those are very site-specific sensors. What we're really trying to move from is this single vine view, where in the previous slide you saw sensors that are really just accurate for the very, very small part of the canopy or a very, very small part of the root zone that they might be monitoring. And it's a real leap of faith to take that information and cascade it to some kind of recommendation on a block level. So we're really today trying to move from single vine measures to more global vine measures. Today remote sensing is the probably the most common way we do that only because we don't have proximal sensors in general that are as economically viable as using either LANDSAT or some type of fixed-wing aircraft taking overhead images of our vineyards using various types of sensors.

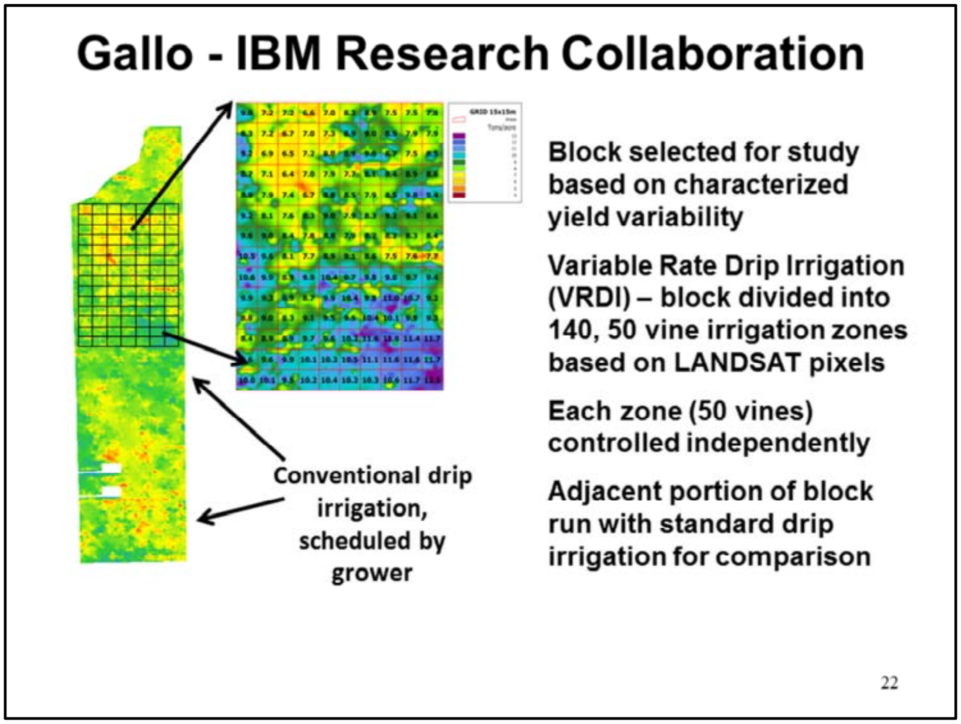
>> Nick Dokoozlian: Slide number 19 shows our vineyard row. I just threw this into the presentation to show you this is typically what our production system looks like. A row of vines or a row of trees with a single hose that's applying water. The hoses have emitters plugged in. Usually we have one or two emitters that actually emit the water at each one of the vine or tree trunks. But when we flip that switch, all of those emitters with our current systems apply the exact same amount of water to every vine or every tree within the row. Today with our current infrastructure there's no way to control the amount of water and really customize it to a vine or a tree based on that vine's specific requirements or canopy size.



>> Nick Dokoozlian: And if you look at slide number 20, this shows you the problem that we have in the way that our systems are currently designed. This showed a sap flow sensor that's measuring the amount of water being lost from the vines. Here I have one sap flow sensor pointing to the area of the field that's quite green with this particular imagery. That means that vine is very large. I also have another sensor that's pointing to a vine that’s in red. That means that that canopy is very small. And you can see within the same vine row literally within several hundred feet of one another we have vines that are using twice the amount of water compared to a vine at the other end of the row. But when we flip the switch, we apply the exact same amount of water to every single vine. So this is our challenge in order to really look at optimization of a critical resource such as water. How do we customize applications in order to achieve that and apply exactly the amount of water that each one of these vines needs?

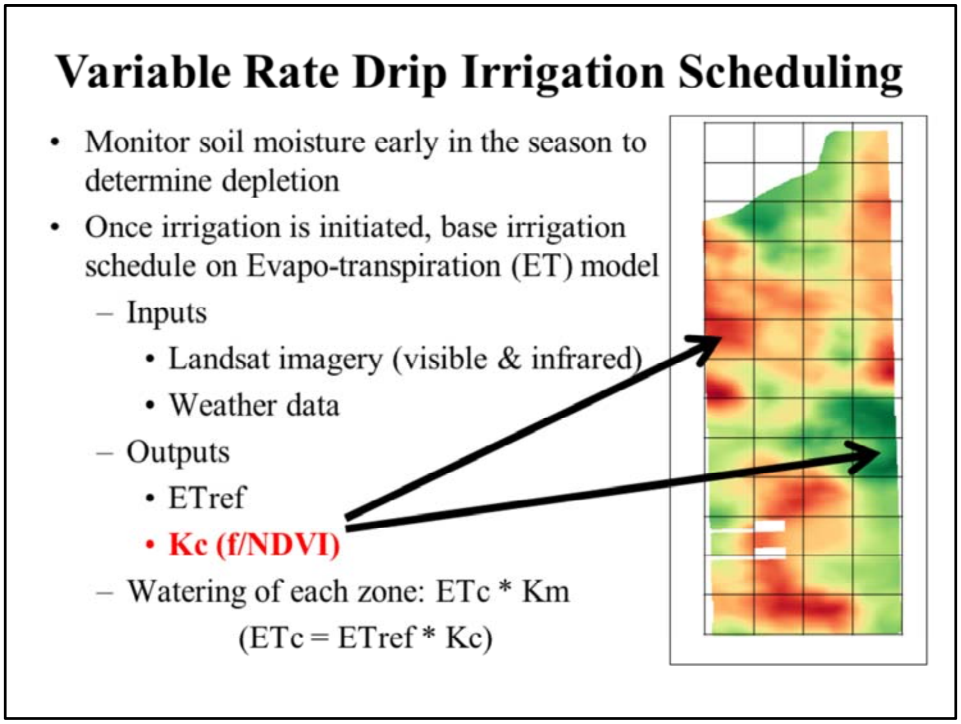


>> Nick Dokoozlian: Well, we started to do this today at a pixel level using LANDSAT. We know that that variability I showed you in the previous slide is driven primarily by differences in plant-available water content, which is a function of soil texture, soil rooting volumes, soil depth. So this is a very, very important parameter that we characterize in our vineyards using a sensor suite. And once we understand that, we can then understand how we can manipulate the vines based on their specific location in the vineyards in order to optimize water. What I'm showing is a vineyard where we have taken a LANDSAT image, that's just a Normalized Difference Vegetation Index (NDVI) from LANDSAT. The green areas are obviously larger vines; the red areas are smaller vines. We have just lined up a pixelated map with LANDSAT. And if we started to think about this in more detail, if we could somehow apply water at this pixelated level, this would allow us to optimize water based on inherent vine vigor.

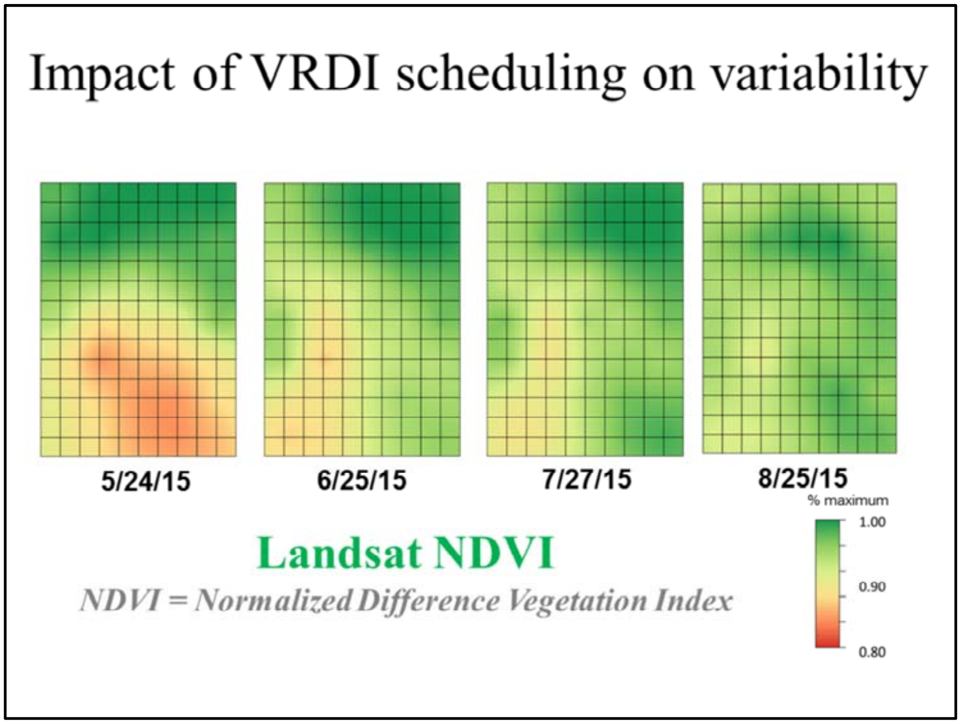


>> Nick Dokoozlian: We’ve done exactly that. We did a research collaboration that was completed a few years ago, and we're now commercializing a technology with several of our drip irrigation manufacturers to do something we're calling Variable Rate Drip Irrigation (VRDI). Simply, what it is is taking a vineyard or an orchard and breaking it into pixels based on vine density, based on planting density, and based on a 30 by 30-meter pixel from LANDSAT. We can then measure the specific irrigation requirement of that pixel within our vineyard. And the irrigation system, now when we flip the switch, instead of all the vines at the same rate, we actually can irrigate each one of those pixels individually. We can go anywhere from applying no water to a full water complement depending upon the vine needs and the vine application requirements.

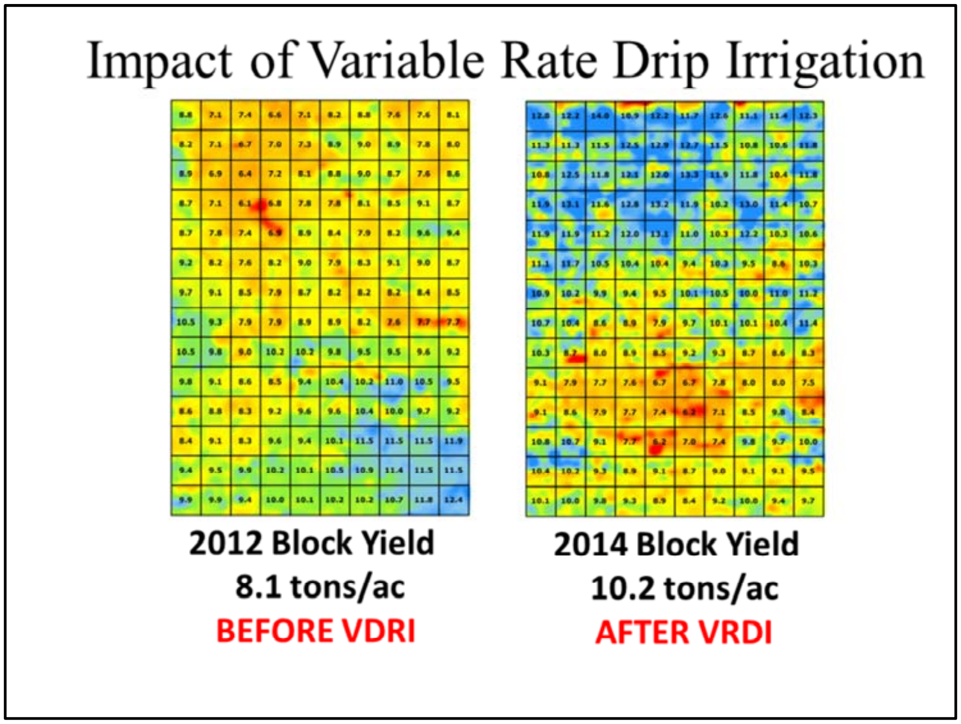
>> Nick Dokoozlian: Slide number 23 shows you an example of the variable rate system. Very simple. We have a live line there on top and we have sensors that actually control the water that's applied to each individual vine based on its evaporative demand. We've done that either using LANDSAT pixel, higher-resolution imagery, or in some cases even soil sensors to control the flow of water.



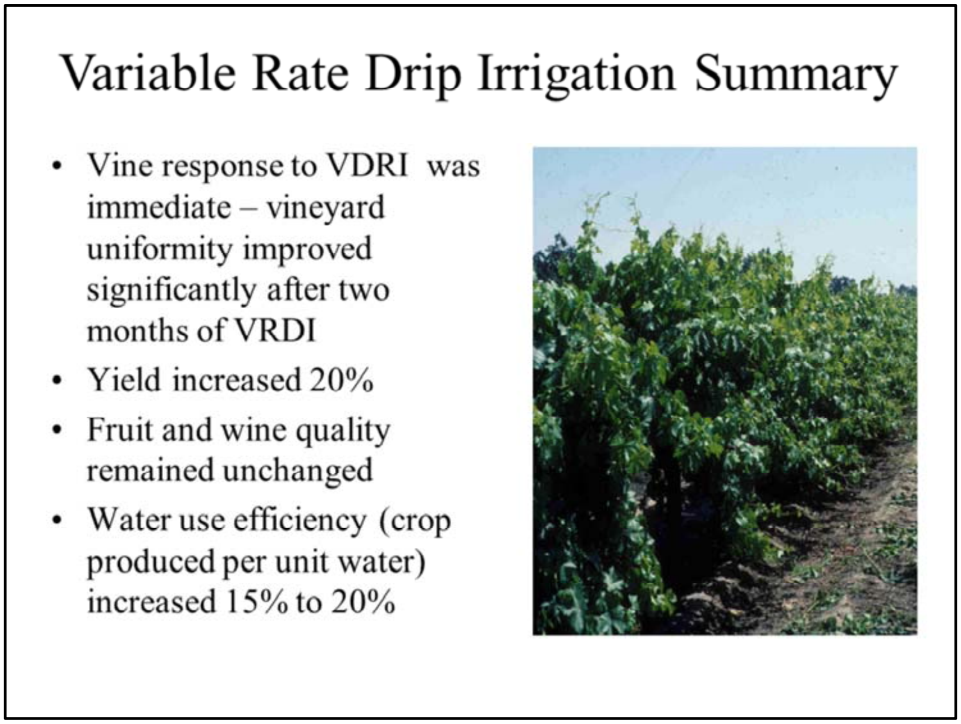
>> Nick Dokoozlian: If you look at the next slide, this just shows you our scheme in terms of how we use variable rate irrigation scheduling, some of the inputs that we put into it. Basically, we're using some weather data. The size of the canopy is probably the most important component. That's a function of the NDVI. And we calculate something called the Kc, or crop coefficient. In any event, I just threw this in to show you we do have a very analytical way to determine the specific requirements of each one of those pixels. Depending upon the vine or tree density, that may include anywhere from 50 to 150 vines per pixel.



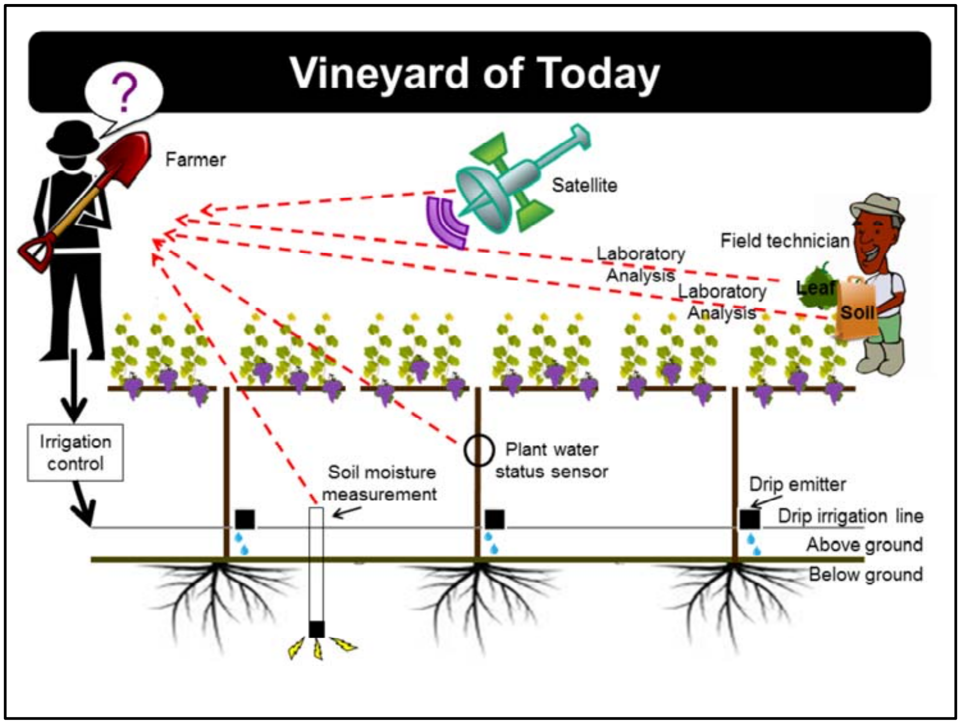
>> Nick Dokoozlian: The next slide shows you the impact of this variable rate irrigation. So, if you look at the LANDSAT image all the way over on the left, the NDVI shows you it in the third week of May, that we have some very stark differences in that field—again, being driven by soil variability. But our sensors are able to connect with that variability, and you can see over time as we get to August, what we have been able to do is increase the amount of water we apply in that red area. And early in May, when those vines start showing the weakening because they're running out of water, we're able to increase the amount of water applied to those vines, without significantly increasing the amount of water applied to the remainder of the vineyard. And by the middle of August, we have a very uniform vineyard with very high quality and much higher yield.



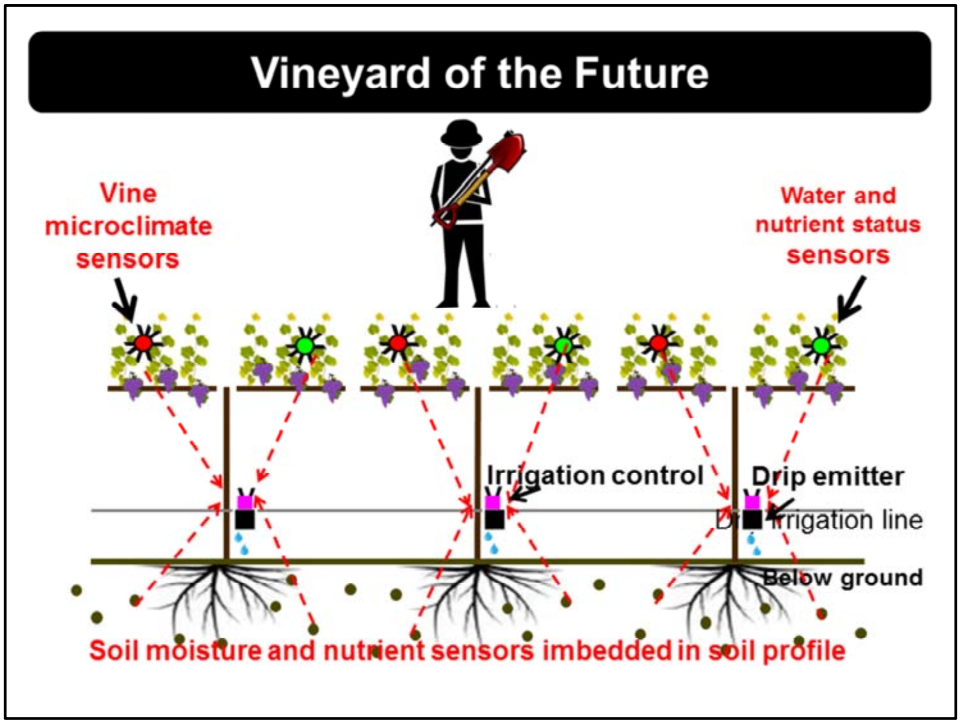
>> Nick Dokoozlian: If you look at our yield records from the last few years, you can see that we have dramatically increased yield. We show the block in 2012 before we initiated variable rate drip irrigation, and then after a few years of variable rate drip irrigation. The project's been quite successful, and it has allowed us to differentially irrigate and optimize our drip irrigation amounts.



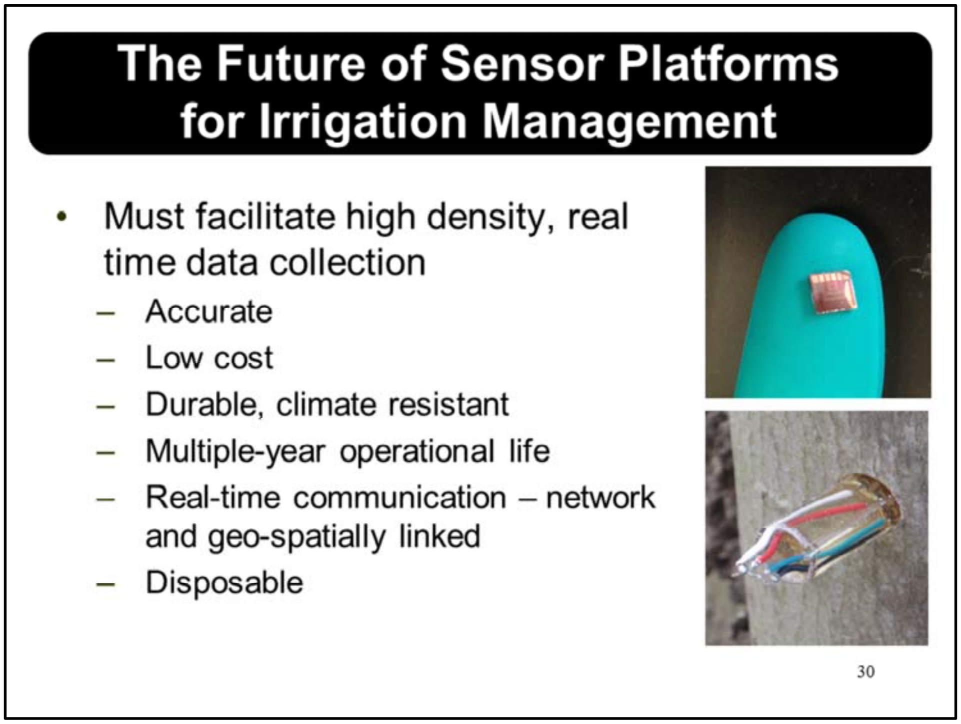
>> Nick Dokoozlian: I think that this project was very successful. We ended up over the period of four years, the length of the trial, with about a 20% yield increase. And probably most importantly for us, we increased the amount of crop produced per unit of water by 15 or 20% as well. Both the yield improvement, quality was maintained, and great, drastic improvement in water use efficiency.



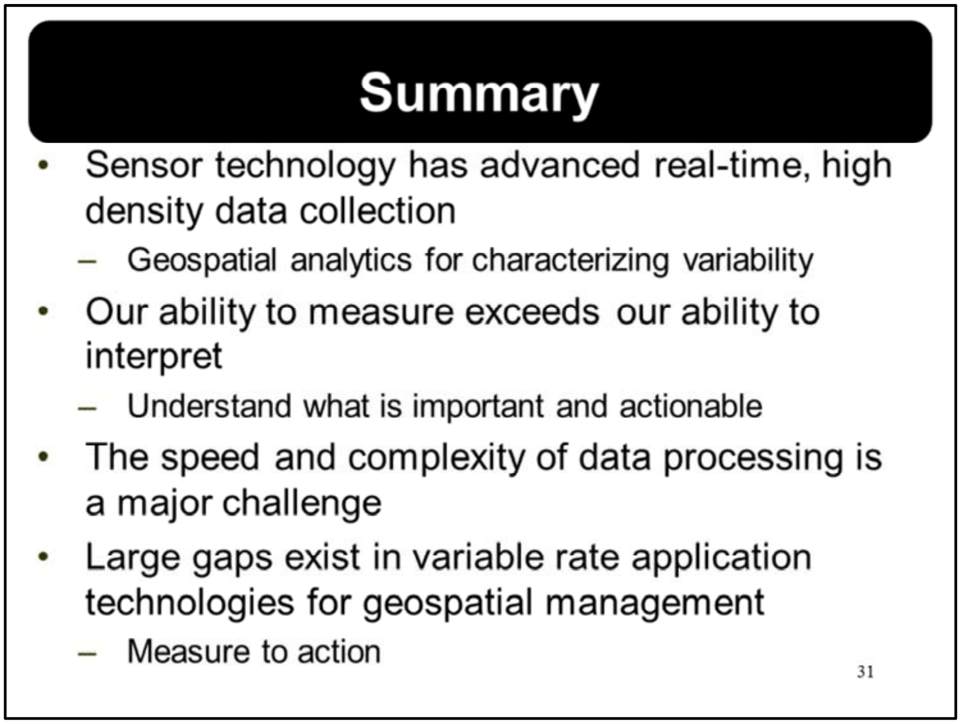
>> Nick Dokoozlian: So if we look at the vineyard of today, it's a very simple schematic there. We have a farmer who's taking in a whole bunch of information. We have sensors today, and we have satellite imagery today. We have soil water sensors. We have sensors that we can go out and apply spot measurements in the vineyard, a vine water status. We have technicians running around collecting soil and tissue samples. All this information goes to the grower. And, of course, he's got to act on that. Some of it's real-time. Some of it is not real-time. Some of it is out of sequence with the growing season. It's extremely challenging, our current matrix.



>> Nick Dokoozlian: We have a vision, though, for the future using nanotechnology: that sensors would be small enough, cheap enough, and easy enough to deploy; that we would have them in the vineyard and actually connected and talking to one another, including stem to, perhaps, even embedded in the soil profile, in and around grapevines, continually monitoring with ranges to actually control systems so that the farmer would be making decisions at the beginning of the season, setting ranges for desired soil and plant water status, and then simply reacting when things go a little bit off track. Much more manageable scenario for the grower.



>> Nick Dokoozlian: What do we see as the future of these platforms? Really, I think it's probably what everybody's been asking for from the scientific community. We really need very inexpensive, of course, relatively accurate sensors; durable, that are climate-resistant, multiple-year operational life, and I think for us the ability to communicate. Especially having these sensors geospatially linked with the suite of tools we have for precision agriculture. That's essential. Maybe sensors that work for a few years, and then we redeploy.

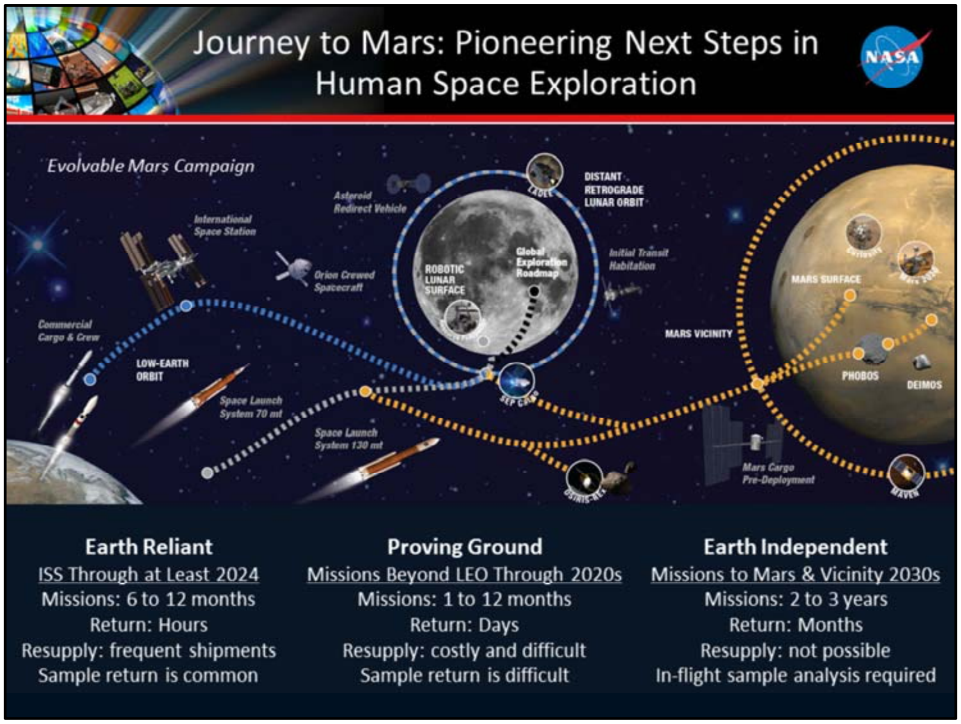


>> Nick Dokoozlian: I think there's lots of opportunity in this space, but at the moment, I think we're really struggling to find out how we can advance sensor technology in a practical way so that our data no longer exceeds our information. Probably today our largest gap in all of this application is the speed and complexity of data processing. It just isn't sophisticated enough today for us to have real-time measures and metrics controlling our irrigation systems. And lastly, there are just very large gaps between what we're able to measure and what we're able to act upon. Part of that is in the previous point about the complexity of data processing. But part of that is just we don't have the systems in place to take the information and have a viable option to act on. So, again, I think that's another area that is very important and an area where sensor technology can certainly help us advance. That's it for me, Stacey. Thank you.

>> Stacey Standridge: Great. Thanks. Your bullet point saying, “Our ability to measure exceeds our ability to interpret” reminds me of a talk I saw not that long ago from someone who’s doing nanotechnology for cancer diagnosis and detection and treatment. And they actually said almost exactly the same thing. We can measure one or two cancer cells, but we don't know what that means functionally for treatment and diagnosis. Maybe they'll go away, maybe they'll grow. But it's exactly the same ball game for the nano cancer realm as you're mentioning for sensors in agriculture. So that's really interesting.

>> Stacey Standridge: Our next and final speaker for this webinar is Dan Barta from NASA. He's going to talk about water monitoring for water reuse in human space flight. The floor is all yours, Dan.

>> Dan Barta: Thank you very much, Stacey. And thank you to all of you who are listening today. My topic is spacecraft water quality and monitoring needs for long-duration human missions. Because of limited time, I don't really have time to address a lot of nanotechnology applications specifically. This time will allow you to reflect on where nanotechnology may have application, and I certainly would appreciate your feedback on that for NASA. I will address briefly a couple of investments we're making in nanotechnology. And I'd like to acknowledge those who contributed to the content of my talk, and a lot of what I'm saying is available online in documents that I've listed on page 45.



>> Dan Barta: NASA's ultimate mission is to go to Mars. And so when we look at really what are the future technologies that we're going to need, we really need to look ultimately at what we'll need for such a mission and then how can we then use current missions and flights, such as the space station, to try to prove those technologies. A Mars mission is going to be about two to three years long. Resupply will not be possible unless it is already pre-deployed at our destination site. So we'll pretty well need to bring everything with us on the mission. And in the case where we have contingencies or anomalies, how do we resolve those in flight? And I hope I will be able to build a case during this presentation that we need on board a spacecraft a complete miniaturized water analysis laboratory capability for future missions. We'd like to test those that we develop on the International Space Station, which we hope to be flying at least through 2024. And then in a proving ground in cislunar space, where we hope to test those Mars vehicles before we deploy them when the time comes.

Possible Types of Water on Spacecraft

International Space Station

Ground Launched Water
- U.S. – Iodine residual disinfectant
- Russian – Silver residual disinfectant

Wastewater
- Humidity condensate
- Urine, urine flush, pretreatment
- Water processor distillate and brine

Recycled water
- Humidity condensate
- Urine, urine flush, pretreatment
- Water processor distillates and brines

Other sources
- Medical water
- Flight experiments & science samples

Possible Additions - Future Missions

Wastewater
- Hygiene, laundry, dishwasher
- Water recovered from solid wastes
- Biological life support (nutrient solution)

Extraterrestrial water
- Water from In Situ Resource Utilization (ISRU)
- Science - planetary sources, asteroids & comets

Nominal Wastewater Generation by Mission

Parameter	ISS	Transit Vehicle	Early Planetary Base	Mature Planetary Base
	Kg per Crew Member per Day			
Urine	1.20	1.50	1.50	1.50
Urine Flush	0.30	0.30	0.50	0.50
Subtotal	**1.50**	**1.80**	**2.00**	**2.00**
Oral Hygiene	-	-	0.37	0.37
Hand Wash	-	-	4.08	4.08
Shower	-	-	2.72	2.72
Laundry	-	-	-	11.87
Dish Wash	-	-	-	5.87
Food Prep.	-	-	-	TBD
Subtotal	**0.00**	**0.00**	**7.17**	**24.45+**
Condensate	2.27	2.27	2.27+	2.90+
Total	**3.77**	**4.07**	**11.44+**	**29.35+**

Data derived from "Life Support Baseline Values and Assumptions Document" NASA/TP-2015–218570

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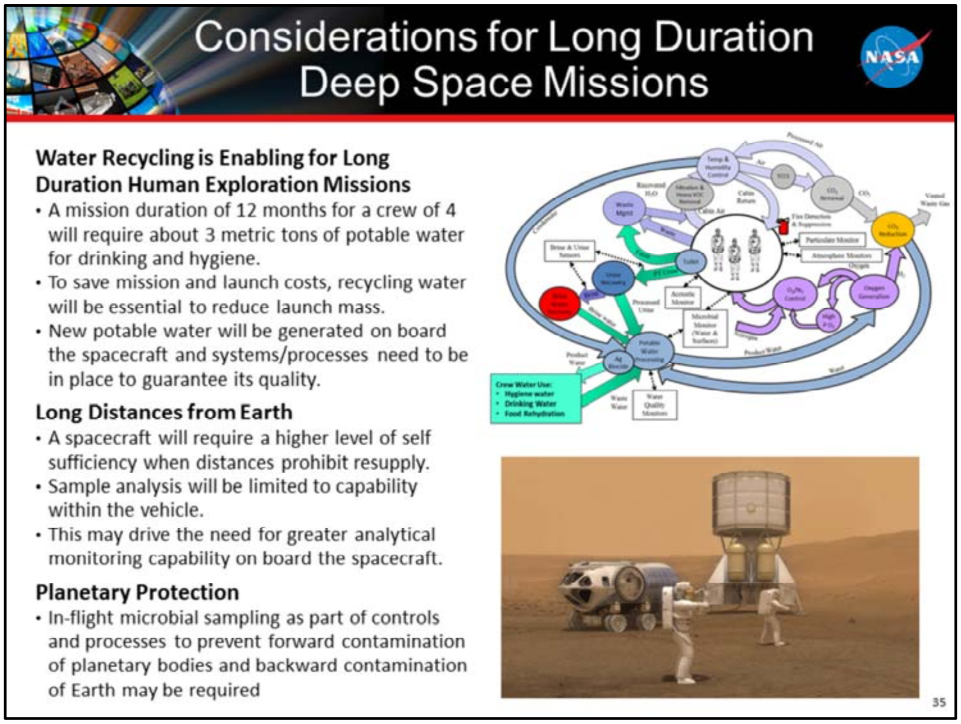
>> Dan Barta: So what kind of waste water do we have on spacecraft? What types of source water do we have? Well, we bring water from the ground. Much of what we drink is brought. At least initially, we use some of that water. We crack it and get oxygen from it and use it to breathe as well. And then we try to recycle most of the waste water that we generate. Also on the space station, we really don't have a lot of types of waste water sources that you might have typically on Earth. We don't have a hand wash, we don't have showers, we don't have laundry. Pretty much when astronauts clean themselves, they'll wipe themselves with wet towels and then hang those towels up to dry. Eventually throw them away. We don't launder. And a lot of our waste water gets essentially generated as humidity in the air of the cabin and then it get condensed as humidity condensate. We do recycle urine and humidity condensate on board currently.

On future missions we may need to have additional sources of water because, for instance, it may be prohibitive to only use clothing a few times. We may want to reuse it continuously, save mass on the mission, therefore have a laundry system. If we're on a planetary surface and there's a lot of dust associated with maybe working or extravehicular activity, space suits and taking samples and exiting the vehicle and coming back, we may want to have better hygiene and shower capability as well. And then there may be other water that we collect locally such as maybe getting some water from soil, which might be considered an *in situ* resource. Or maybe there's planetary sources where we'll get water. We may need to do some analysis on that.



>> Dan Barta: But water reusage rates in flight, generation rates of waste water, are pretty low compared to what we typically have on Earth. And only perhaps 4 to 29 liters a day per crew member. But that small amount of water really does add up. Duration that's about 12 months long with a crew of four might require about three metric tons of potable water for drinking and hygiene use, which is quite a lot. And to save mission costs to really enable a mission because it would be cost-prohibitive really to launch all that, we definitely do need to recycle water. And we do do a lot of recycling water on the International Space Station. When we recycle water, we'll generate potable water, and just as the first speaker was talking about, we'll need to be able to have sensors or systems in place to guarantee the quality of that water that we generate. And as we go away from Earth we will need a higher degree of self-sufficiency in the vehicle. We don't have the ability to send samples back to Earth. And so any analysis that we do in flight will be limited to what we bring with us when we launch. So we have to make sure we have the capability that will be needed. This really drives to have a better analytical capability for future missions than we actually do on the International Space Station right now. And another issue to consider is called planetary protection. There's maybe a very remote, but a possibility that there may be life on another planet. We do not want to contaminate that life with Earth-based life, as well as bring some of that life back accidently to Earth. And so we'll need to have at least in-flight microbial sampling capability for that to meet the requirements we have for planetary protection rules.

Spacecraft Water Exposure Guidelines (SWEGs) for Potable Water

Considerations

- Protection of Crew Health
- Strengths & susceptibilities of astronauts
- Spaceflight relevant chemicals
- Consider exposure durations critical for spaceflight
- Account for higher drinking water consumption rates
- These drive design goals for water recycling, but are purposefully not so stringent to cause over-design

Two Exposure Groups

- Acute Exposure – for contingencies
- Prolonged Consumption - drives requirements for water processor design

Selected Chemicals (list is not complete)	Concentration (mg/L)			
	1 day	10 days	100 days	1000 days
Acetone	3500	3500	150	15
Alkylamines (di)	0.3	0.3	0.3	0.3
Ammonia	5	1	1	1
Antimony (soluble salts)	4	4	4	4
Barium (salts), soluble	21	21	10	10
Benzene	21	2	0.07	0.07
Cadmium (salts), soluble	1.6	0.7	0.6	0.022
Caprolactam	200	100	100	100
Chloroform	60	60	18	6.5
Di-n-butyl phthalate	1200	175	80	40
Dichloromethane	40	40	40	15
Ethylene glycol	270	140	20	4
Formaldehyde	20	20	12	12
Formate	10,000	2500	2500	2500
Manganese (salts), soluble	14	5.4	1.8	0.3
Mercaptobenzothiazole	200	30	30	30
Methanol	40	40	40	40
Methyl Ethyl Ketone	540	54	54	54
Nickel	1.7	1.7	1.7	0.3
Phenol	80	8	4	4
Silver	5	5	0.6	0.4
Zinc soluble compounds	11	11	2	2

Spacecraft Water Exposure Guidelines (SWEGs), JSC-63414, 2008 36

>> Dan Barta: So what do we currently need to monitor, we think? What are some of the water quality standards that we currently have? Well, NASA has what we call Spacecraft Water Exposure Guidelines. And these are concentrations that are really in different exposure groups of short- or long-term exposure durations, which are really directed at spaceflight-relevant chemicals. Things we think we expect to see and that we want to protect against. They consider the durations that are likely in spacecraft. They account for higher drinking water consumption by astronauts. There is a danger of developing kidney stones due to bone demineralization. So astronauts have to drink a little bit more water to prevent that. And the water guidelines drive design goals to process and recycle our water. But we try not to make them too stringent to cause really excessive overdesign because that would cause additional mass and complexity of the equipment we bring.

International Space Station Water Monitoring Capability

Inorganics
- Process water from Water Recovery System is monitored for electrical conductivity
- No capability exists for determination of constituent ion concentrations
  - Samples must be returned to Earth.
- Exception – Iodine as a residual disinfectant.
  - Colorimetric Solid Phase Extraction (CSPE) Water Biocide Monitor

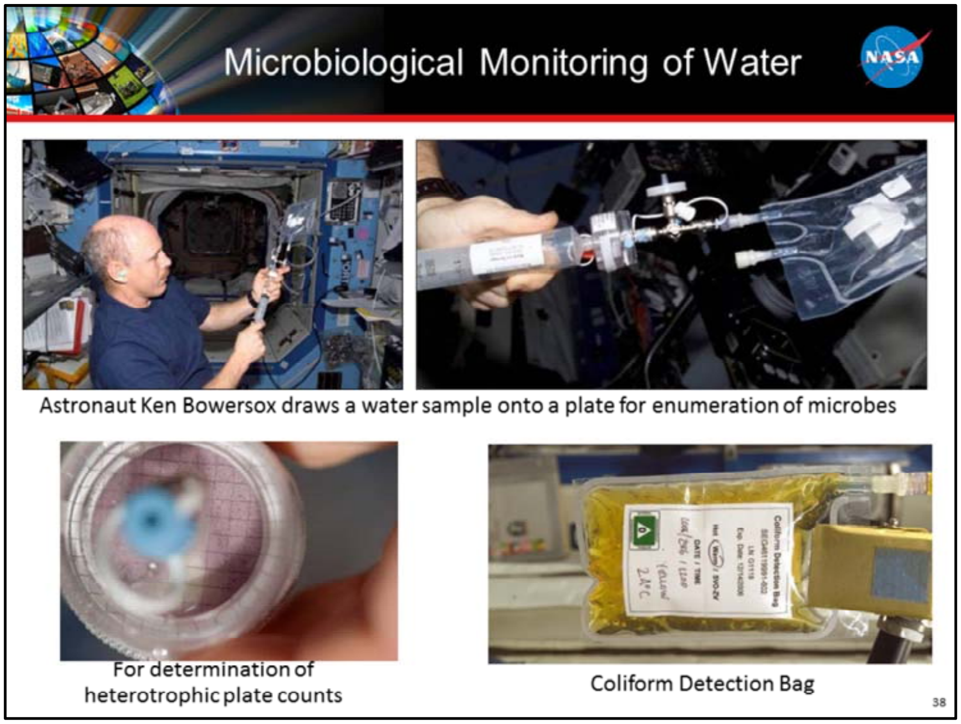
Organics
- Water Recovery System process water is monitored for Total Organic Carbon
- No capability exists to determine levels of specific organic compounds
  - Samples must be returned to Earth.

Microbial Monitoring
- Total heterotrophic plate counts
- Total Coliform
- For identification & enumeration of specific organisms, samples are returned to Earth

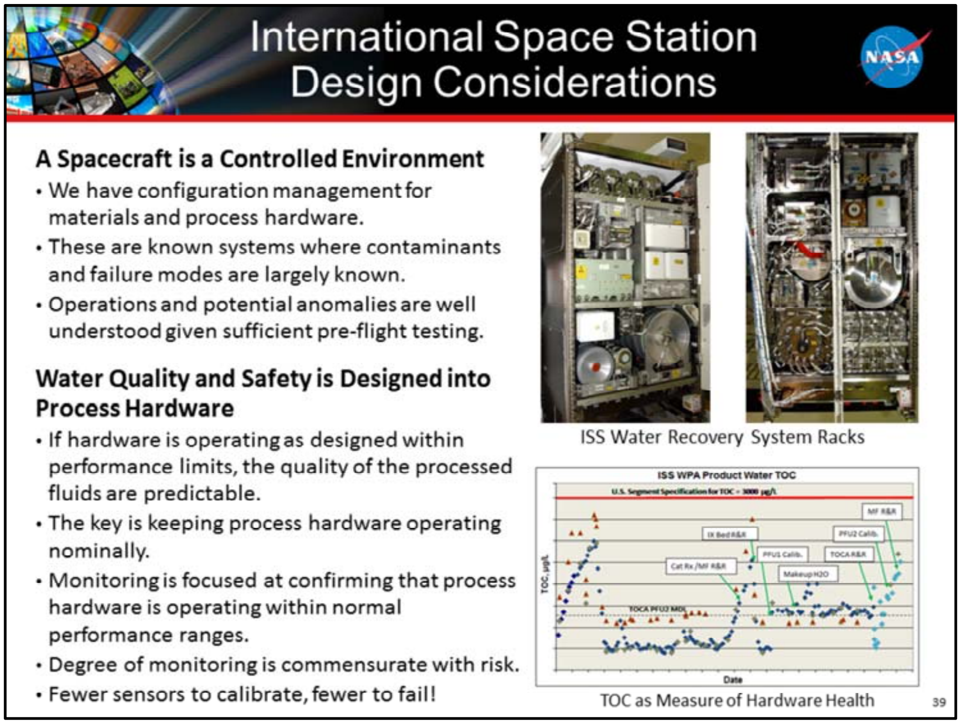
Total Organic Carbon Analyzer (TOCA) on the ISS with Astronaut Don Pettit.

Parameter	Acceptability Limit or Range
Total Organic Carbon	3 mg/L
Iodine, potable water	0.2 mg/L
Iodine, biocidal	1 – 4 mg/L
Silver, potable, biocidal	.05 – 0.4 mg/L
Heterotrophic plate count	50 CFU/ml
Total coliform bacteria	0 CFU 100 ml

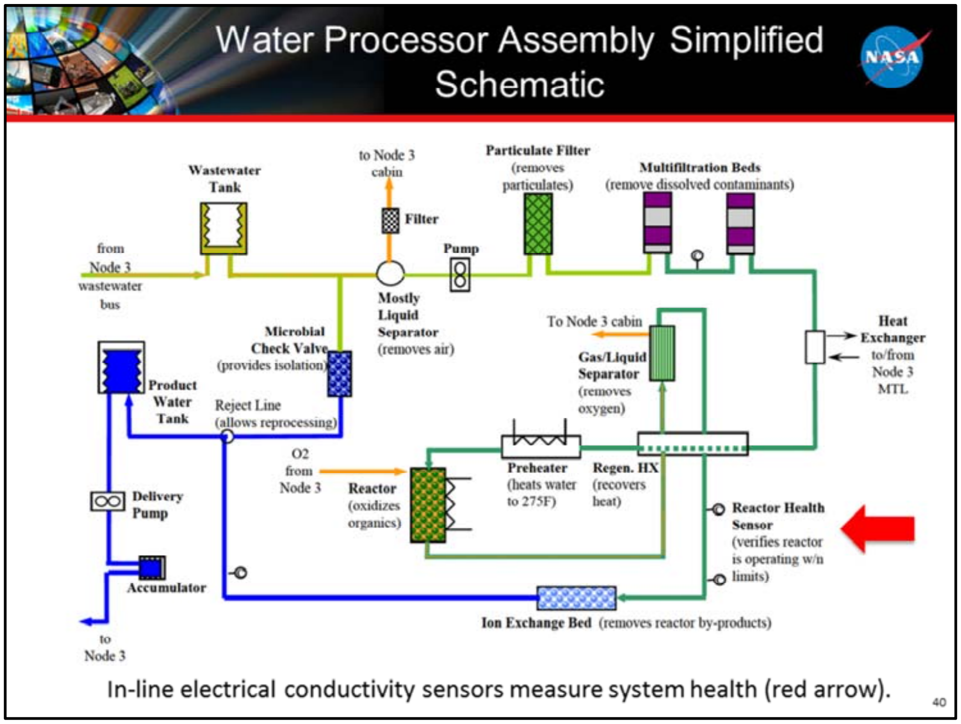
>> Dan Barta: So what's our current capability? Well, we have minimal capability on board our International Space Station. For inorganic monitoring, essentially we're limited to electrical conductivity. We cannot sample individual constituent ions. To do that we have to bring samples back to Earth. The exception is for residual disinfectants within our water, such as iodine or silver. We have some colorimetric methods, test kits, that we can use. For organics, we're limited to carbon measurements. And, again, we don't have ability to measure constituents and must bring samples down to Earth for that. For microbial monitoring, we can measure total plate counts and total coliforms. But once again, to get identification and enumeration of specific organisms we have to bring samples down to Earth. The bottom right-hand corner there has a list of some additional water quality requirements.



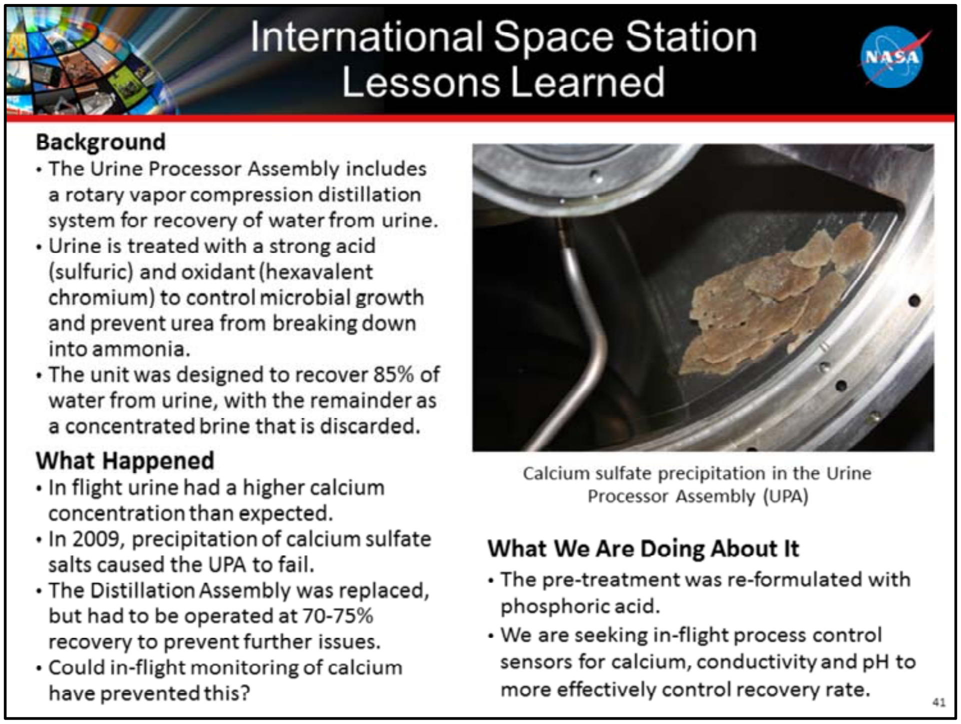
>> Dan Barta: This chart just shows some of the techniques for doing plate counts on board. And then there's a colorimetric kit for coliform detection.



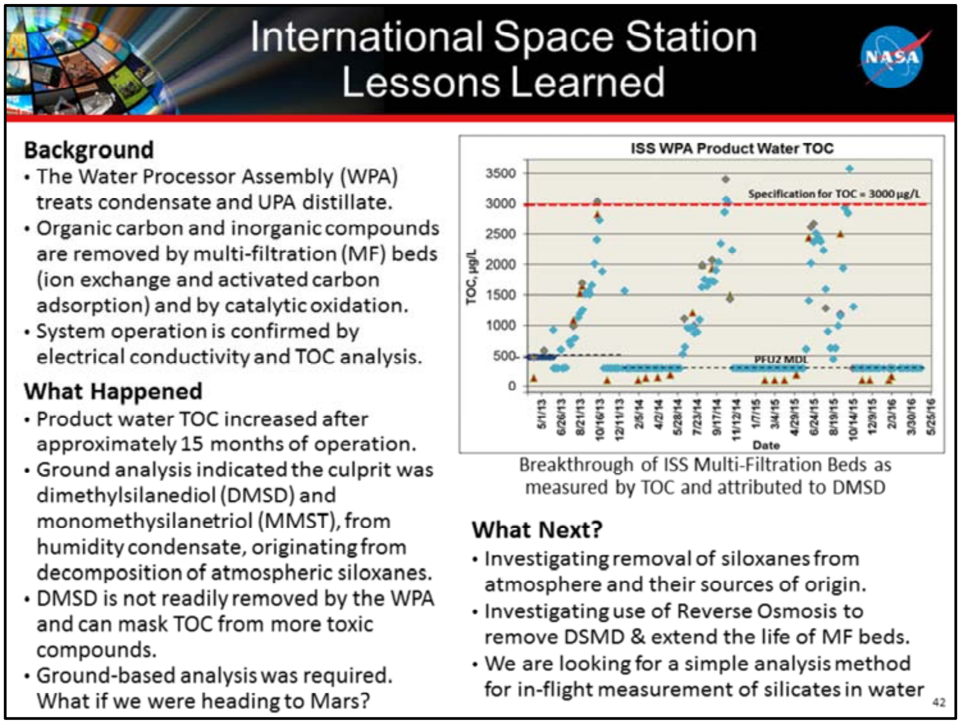
>> Dan Barta: So actually right now in terms of water treatment, we really try to design out the need for monitoring. The fewer sensors we have, the fewer that will fail. Sensors typically need calibration that requires crew time and requires standards and more difficulty. So what we've tried to do in space, we have configuration management of our materials and our hardware. We know what we have. Therefore we know typically what contaminants and failure modes might happen, as well as operations and possible anomalies. We kind of understand them. So we kind of know what to expect. Hopefully there are no unknown unknowns that are out there. But I'll talk about a couple case studies in a moment on that. So what we try to do is if the hardware is operating and at design performance levels, we expect it to process the water with predictable results, predictable quality. And so what we do is impart some process monitoring sensors that make sure that the hardware is operating nominally. If there's a trigger that something is wrong, that means the quality could be degraded, and we have to troubleshoot and see what's going on. But our level of monitoring is really commensurate with the risk that we think is present.



>> Dan Barta: So just an example of this. The water processer assembly that takes in condensed water from our heat exchangers, as well as distilled water from urine, runs that water through particular filters and multifiltration beds that take out most of the organics and inorganics. And then there's a polisher, a high-temperature oxidizing reactor, that the water goes through. And then there's essentially what you call a reactor health sensor. And this is electrical conductivity. If something is breaking through the columns or is not getting oxidized, we see a spike in electrical conductivity. That says that something is not working right and we probably have to maybe replace a bed or fix the oxidizer or something like that.



>> Dan Barta: A couple lessons learned. The distillation system that is used to recover water from urine is a rotary vapor compression distillation system, which basically means it boils water at room temperature. And we also treat urine with a strong acid and oxidants to control microbial growth and prevent urea from breaking down to ammonia. And we designed it to recover about 85% of water from urine. If we go any higher than that, the concentrated brine may form precipitates and the systems would fail. Unfortunately, what we found is we had precipitation occurring before we even got to 85% recovery. So the brine was not as concentrated. And we found out that the urine that was collected in space flight had a higher calcium concentration than was predicted, and that's from bone demineralization. The calcium reacted with the sulfates in the acid treatment and formed the precipitates. And if we had in-flight monitoring of calcium, maybe we could have been able to predict this. But we are looking for some additional process control sensors for calcium, conductivity, pH to be added to the system to try to better control recovery rate. If we see, for instance, a batch of the urine coming in that is higher in calcium, we may not go to a higher recovery rate, predicting that we may get precipitation. So we want to be able to perhaps be more flexible in the process operations.



>> Dan Barta: Another lesson learned. So I mentioned previously there are a number of multifiltration beds that the process water goes through to remove organics and inorganics. Well, we started to see that there was some breakthrough happening, and our total organic carbon started to increase. And due to the fact that we were able to bring samples down to Earth, we found that this was due to some breakdown products of siloxanes that were in the atmosphere of the Space Station, and likely came from caulking and maybe some other sources like that. We hadn't seen it typically, but a lot of our testing was really short-term testing. Here we have accumulations and breakdown over a period of months. We started to detect these issues. So what if this happened in a mission going to Mars and we exceeded the standards of these chemicals in our water? Would we even know what we had if we didn't have a capability on board? So really anomalies are driving some of the needs we have for monitoring. And we are looking now for some easy ways to detect these issues we have, but it's really just to address the specific issues.

Water Monitoring Needs and Current Investments

Function	Capability Gaps	Transit Habitat	Planetary Surface
Water monitoring	In-flight identification & quantification of species in water (organic and inorganic)	X	X
Microbial monitoring	Non-culture based in-flight monitor with species identification & quantification	X	X

Work at NASA Field Centers

"Organic Water Monitor (OWM)", expands existing gas GC/MS capabilities to address water analysis. To identify and quantify organic species in water samples using gas chromatography mated to a miniaturized thermal conductivity detector.

"Microbial Monitoring", investigations of commercial Polymerase Chain Reaction (PCR) systems and Biomolecular DNA Sequencing for flight use.

SBIR Investments

2017 Solicitation (closes January 20) includes requests for "In-Line Silver Monitoring Technologies" and "Sample Processing Module for the ISS Microbial Monitors".

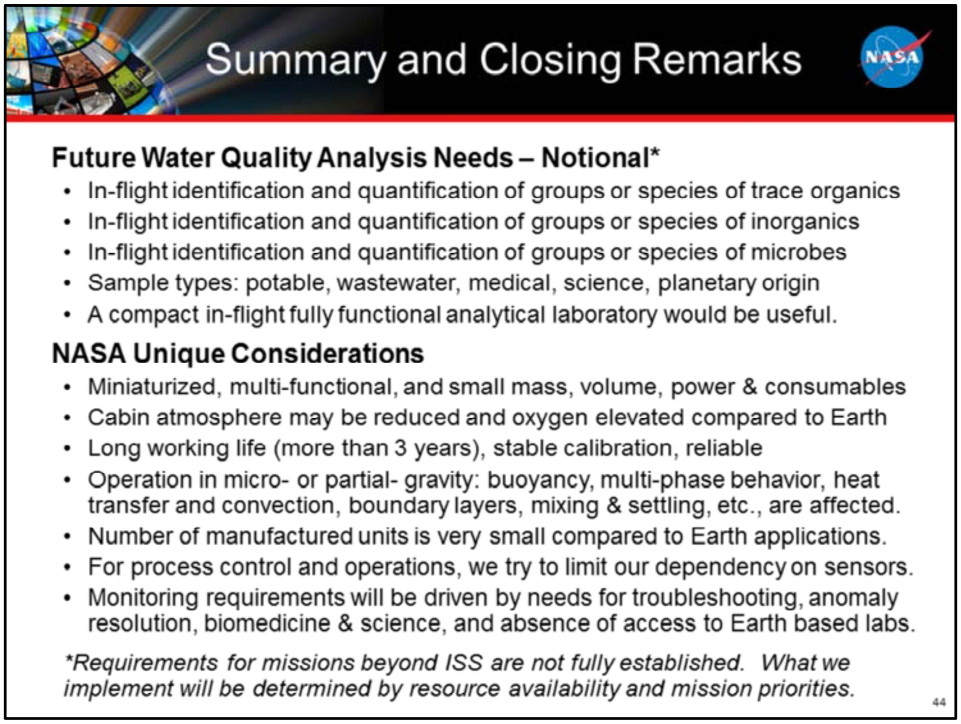
2016 Phase I Award: "Compact Chemical Monitor for Spacecraft Water Recovery Systems", Intelligent Optical Systems, Inc., 16-1-H3.01-7755

2016 Phase I Award: "Miniaturized Sensor Array Platform for Monitoring Calcium, Conductivity, and pH in Urine Brine", Polestar Technologies, Inc., 16-1-H3.01-7659

2015 Phase II Award: "Microchip Capillary Electrophoresis for In-Situ Water Analysis", Leiden Measurement Technology, LLC, 15-2-H3.01-8900

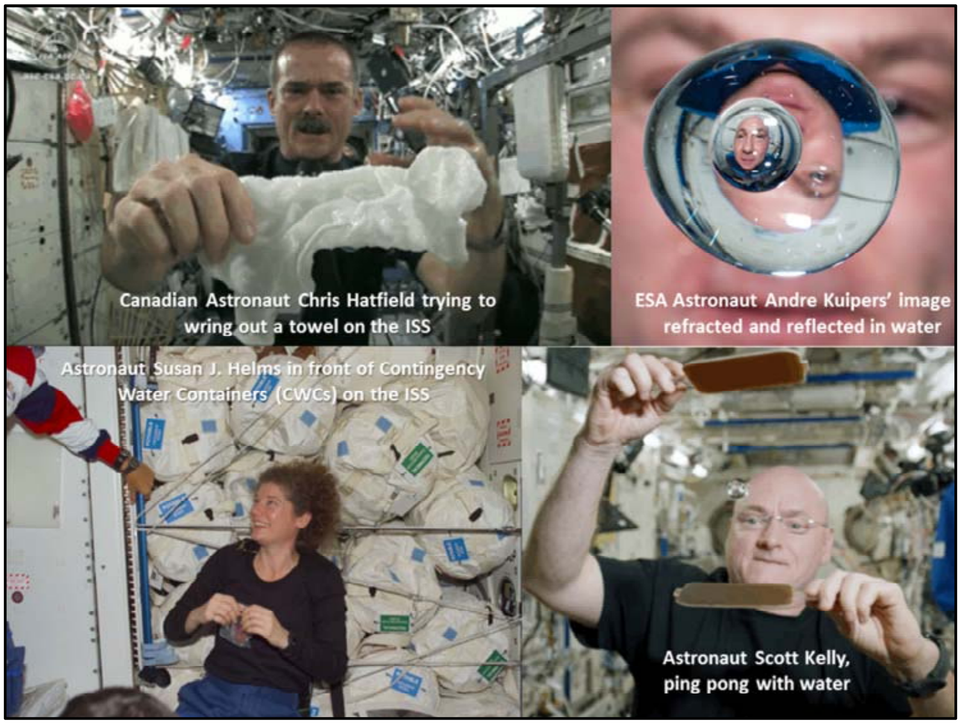
2015 Phase I Award: "Rapid Concentration for Improved Detection of Microbes in ISS Potable Water", InnovaPrep, LLC, 15-2-H3.01-9921

>> Dan Barta: Well, what are our needs particularly? What do we see? And I mentioned we want to have kind of a laboratory in flight. And really this includes identification and quantify indication of species in water, both organic and inorganic, as well as essentially full capability for monitoring microbial species. We are doing some work in this area, maybe perhaps some novel work. We believe we will have a very miniaturized small gas chromatography mass spectrometer available, which particularly is used for gas analysis. But could we put a front end to that that takes samples of water and runs that water through for organics? We are working with a company funded through Small Business Innovation Research (SBIR) that has a microchip electrocapillary system that maybe we could use to discriminate and separate the peaks of organics. We're doing some work looking at some more conventional polymerized chain reaction and DNA sequencing for microbial monitoring. And we're also working with SBIR companies to try and look at collection and concentration and processing the samples for those kinds of systems. And there's an SBIR-funded company called Polestar Technologies that's looking at and using some nanotechnology for developing some sensors for monitoring calcium conductivity and pH, which is really getting at the issue we had with precipitation of salts in our distiller and trying to have a better control of our water recovery.



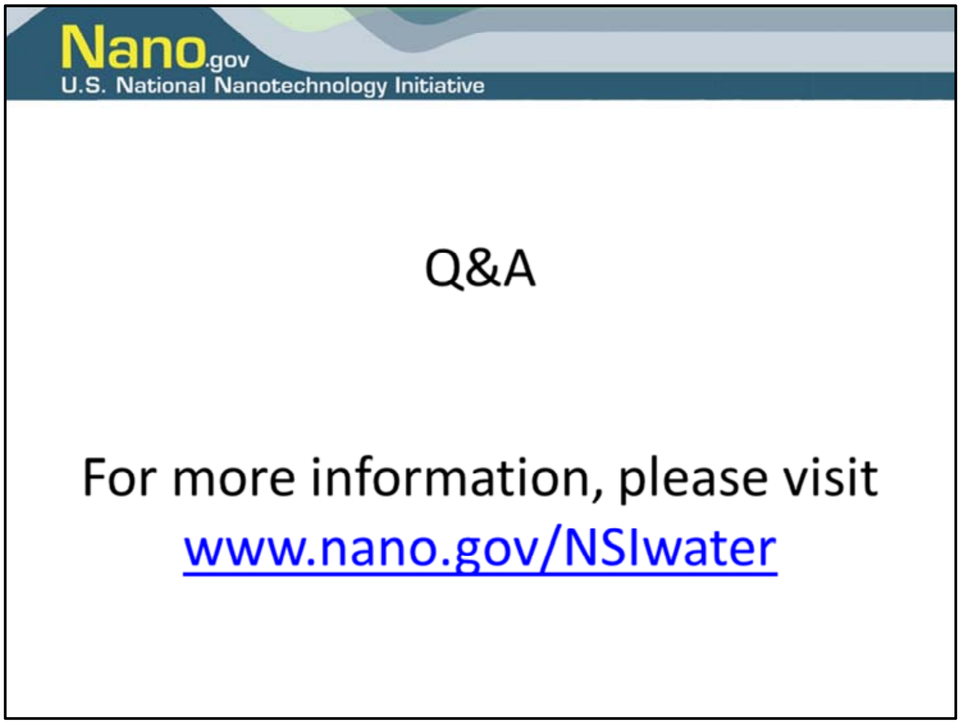
>> Dan Barta: And so as a last closing slide, NASA does have a lot of unique considerations for sensors; though a lot of the sensor characteristics that were discussed by our first speaker do apply. But we do need things that are small and multifunctional, have limited power and mass. These things just help make space flight more affordable. Our cabin atmosphere may be at reduced pressure or oxygen level depending on the mission and its constraints. We do need sensors that have a very long working life, more than three years. Some of these missions will be out for a long period of time. And we could perhaps have several that we stow if the life is shorter than that, but that means more mass, more hardware we have to bring. And they have to operate in microgravity, where you have issues with buoyancy, multiphase behavior, heat transfer, boundary layers forming that don't normally under Earth conditions where there's some convection. So we have to consider all of this when flying. So in closing, if we can have a laboratory in a box—I mean, literally a very small container that can do a lot, maybe we're dreaming—but at least that's how we would like to push and drive the technology. And nanotechnology, because it is small, could really help us out.

>> Dan Barta: This slide, 45, has a lot of citations that were used and contain information that you could dig into further. And at least everything but the last one, I think, is available on the Internet for free.

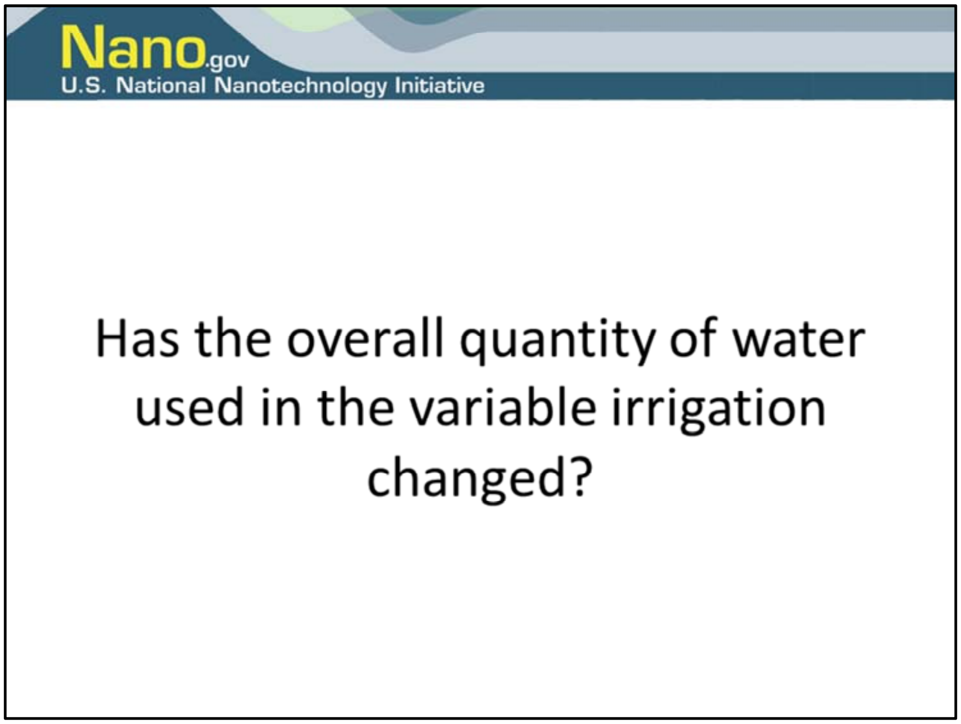


>> Dan Barta: And then in closing, here's a little bit of a slide showing some physical issues with water in flight, or how to maybe have some fun with it. Thank you very much.

>> Stacey Standridge: Great, thank you, Dan. Particularly interesting to hear about some of the siloxane issues you mentioned and how there were sort of long-term issues that have come to the fore after the International Space Station has been up there so long.



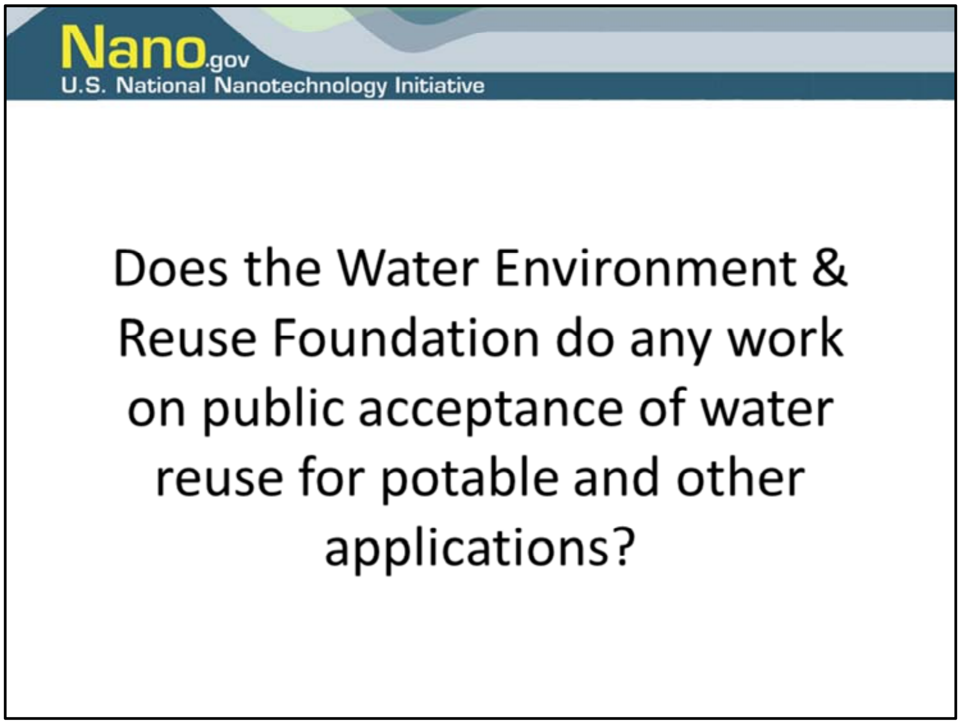
>> Stacey Standridge: We're now at the point of our webinar where we invite all of the listeners to ask questions of our panelists. As we mentioned before, you can submit your questions in the AdobeConnect webinar interface in the “Submit Your Questions Here” box.



>> Stacey Standridge: And we have already gotten a question while the speakers were talking. And this question was actually for Nick. And one of our listeners was wondering if the overall quantity of water used in the variable irrigation has been decreased, or has it remained the same?

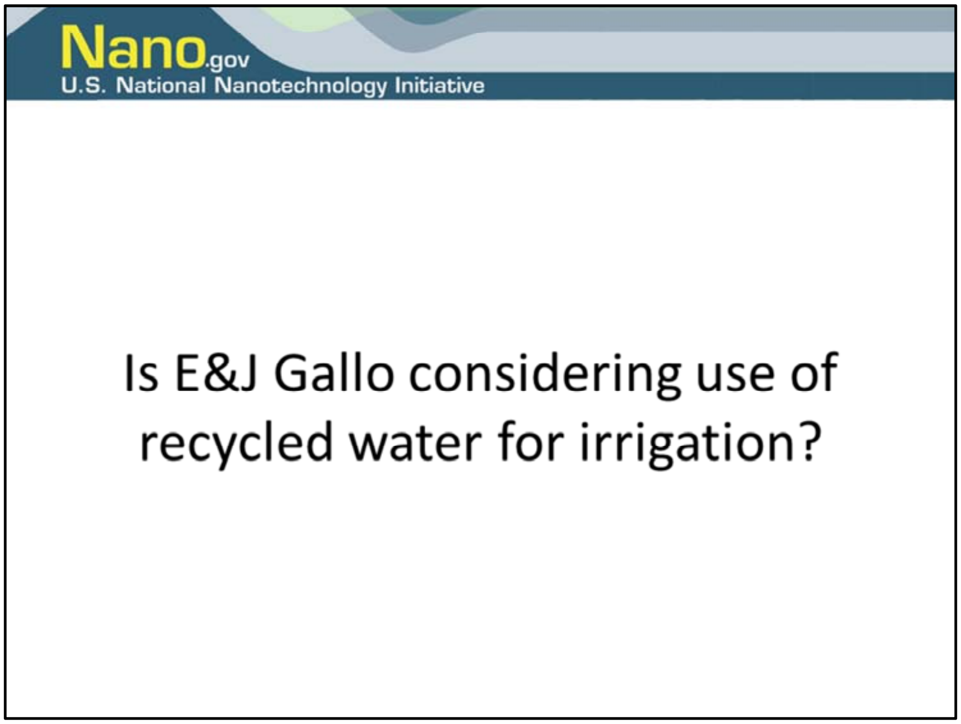
>> Nick Dokoozlian: The overall quantity of water used has decreased, primarily because of the factor of optimization. And the system that we have could be used to drive further water savings. If water were in even greater demand or shorter supply, this system gives us flexibility to ratchet it down even further. I'd say it can be used for a variety of different reasons, but absolutely for water savings for sure.

>> Stacey Standridge: Thank you.



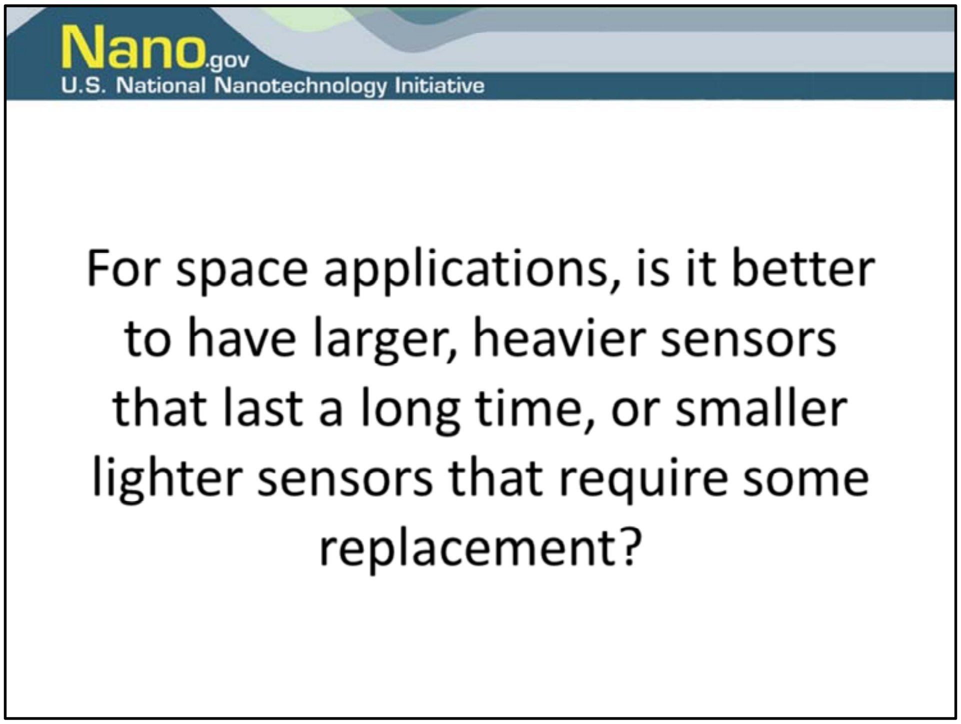
>> Stacey Standridge: And next up is a question fur Justin. And the question is, does the Water Environment & Reuse Foundation do any work on public acceptance of water reuse for potable and other applications? For example, agriculture?

>> Justin Mattingly: Well, the quick answer to that question is absolutely. Public acceptance has long been a bit of a road block in some locations for potable reuse. A number of years ago there was some push in Southern California for potable reuse that got stymied due to public perception. So we have worked with quite a few utilities in California as well as Australia to develop some public outreach materials and strategies. Everything from brochures to short videos. One recommendation is to have an open door policy between the utilities and the public. When combined with other strategies, we've seen a positive impact in regards to public perception.



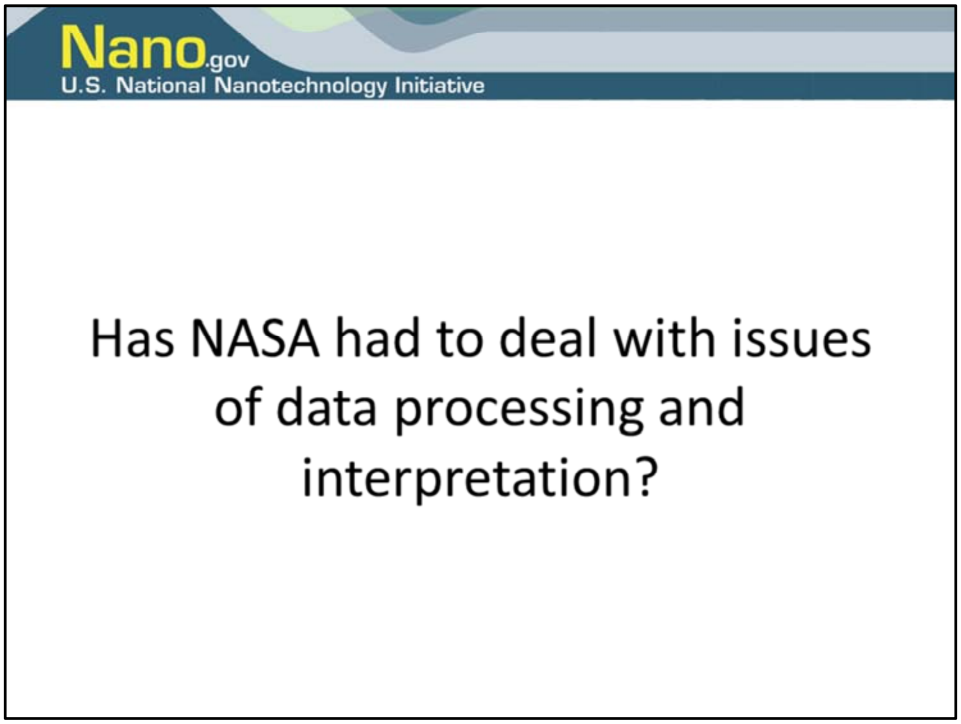
>> Stacey Standridge: And in a similar theme, I was wondering, for Nick, if E & J Gallo is thinking at any point of maybe water reuse for the vineyards or thinking about water monitoring for the quality of water and not just the quantity?

>> Nick Dokoozlian: We currently reuse water now. We get water, for example, obviously treated water from various municipalities, that is completely clean. And we also monitor both our wells and ground water continually for many of the same components that were discussed today. So it's an ongoing part of our overall water management scheme.



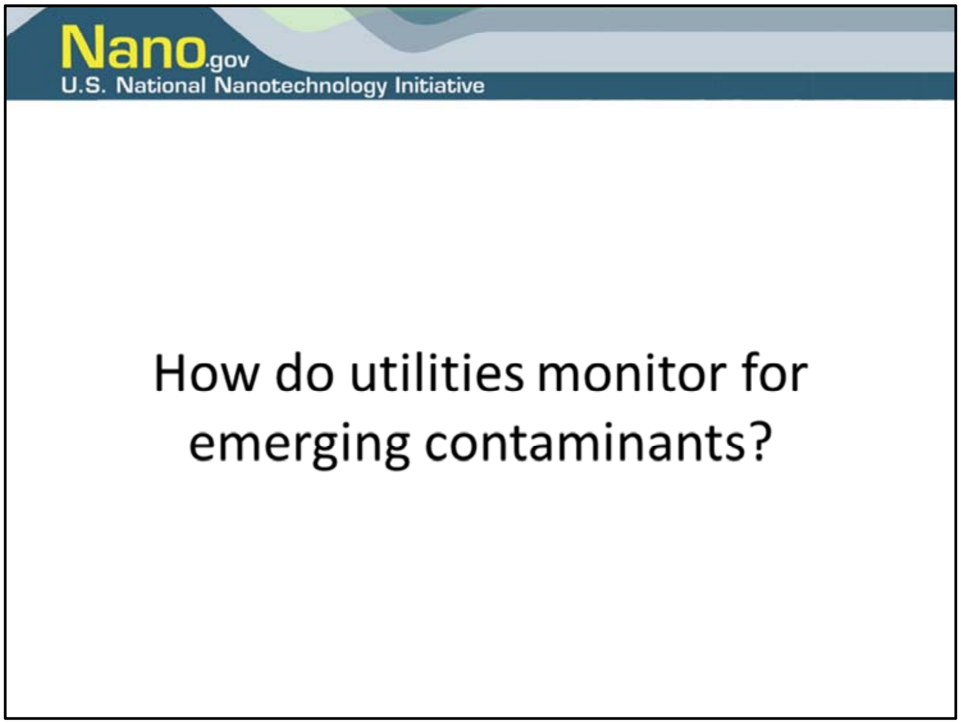
>> Stacey Standridge: Our next question is for Dan, and this came in from one of our listeners. And they were wondering, for space applications, is it better to have larger, heavier sensors that last a long time, or smaller lighter sensors that require some replacement?

>> Dan Barta: I think that what's most important is to have reliable sensors. And if you have a sensor failure, having the backup. And for critical things, we need two or three maybe levels of backup. So even for heavy sensors, if it's truly a critical function, we’ll have to have several backups of that. But that's a tradeoff that we always look at. It's really a mass tradeoff. And so it really depends on the particular installation and really how massive it is. That's a good question. We deal with those questions every day when we trade one technology against another.



>> Stacey Standridge: Our next question is for you as well, Dan. And the question is, both of our first two speakers spoke about issues of data processing and interpretation. And is this an issue that NASA has had to deal with as well?

>> Dan Barta: It certainly is. And also when we get data in—I mean, we probably don't have, you know, hundreds of sensors like maybe in a field of grapes—but we do worry that if we see a reading, is this a false positive? Or a false negative? Or is this a calibration issue? One of the good things we have is that we do have a lot of other information about the operation of the process hardware. We have things like temperature, readings of catalytic furnaces, we have flow rates and things. We can actually sometimes look at a measurement and against the other processes and kind of determine if that measurement is accurate or not. But always we do try to have more than one sensor present if we can.



>> Stacey Standridge: The next question I have is for Justin. You were talking about utilities and their water monitoring in your presentation. One of the questions that came up is how do utilities monitor for emerging contaminants such as microbeads or endocrine-disrupting chemicals?

>> Justin Mattingly: Well, one of the things I said in my brief presentation is that there really isn't any way to do real-time monitoring for any specific chemicals, which is why utilities use surrogates. And those surrogate parameters can be anything from turbidity, to conductivity, or total organic carbon. And that will get at, in a broad sense, what's in the water. You can then make inferences to determine if things like endocrine-disrupting compounds are in that water. Now, some of the more advanced monitors that aren't necessarily widely used, something like fluorescence, that can narrow it down a little bit more. But there really isn't any sort of a real-time monitor at this point for any specific compound.

>> Stacey Standridge: Well, thank you. And I think we've just about reached the end of our hour. So I would like to thank all of our panelists for taking the time to participate and for their great presentations today. I'd also like to thank the audience for tuning in. We will post the transcript and the presentation slides for this webinar at www.nano.gov/publicwebinars in the coming weeks, along with information on other upcoming webinars. With that, again, my thanks to our panelists and participants. And that concludes our webinar for today.