COMMUNITY MATTERS

WATERSHED HEALTH
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ON THE COVER
One of the College of Engineering’s strategic goals is to lead research and innovation to drive breakthroughs that change the world. Clean water is one of the targeted strategic areas in which the college has existing competitive advantages.

ABOVE
Ph.D. candidate Ashley Berninghaus prepares anaerobic digester samples for ammonia analysis (see story on page 12).

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Photo on pages 10 and 11 is courtesy of Mandy Michelsen.
Collaboration fosters sustainable clean water solutions

Water is one of the world’s most abundant resources, yet in many regions clean water is in critically short supply — endangering the economy, public health, energy production, and food supply.

Thanks to a $3.28 million gift from Jon and Stephanie DeVaan, Oregon State is launching the Clean and Sustainable Water Technology Initiative. The venture will build a collaborative community of faculty and students working together to solve one of the greatest challenges engineers face in the 21st century.

Lewis Semprini, distinguished professor of environmental engineering, will lead the initiative, building on the university’s strengths to become a national leader in clean and sustainable water technology solutions.

Several College of Engineering scholars are recognized nationally and globally for innovative research on water systems. They specialize in improving access to clean water, treating wastewater, strengthening upstream processes, and improving the infrastructure needed to manage water sustainability.

In this issue, we look at several exciting College of Engineering research projects that are improving our ability to treat polluted water, and how students in cross disciplines put their engineering training, research skills, and passion to work in solving this critical global problem:

• Industrial discharge, chemicals in household wastewater, and seepage from municipal dumps and landfills, combined with run-off from agricultural fertilizers, gradually contaminate groundwater that feeds into our streams, rivers, and oceans. Lewis Semprini is working on bioremediation strategies to clean up contaminated groundwater through anaerobic bacteria and microorganisms capable of detoxing chlorinated organic solvents.

• One approach to reducing costly water cleanup is to employ effective strategies upstream to minimize contamination before it gets to wastewater treatment plants. Meghna Babbar-Sebens, an associate professor of water resources engineering, has developed software to improve watershed health in a collaborative effort with stakeholders who live near watershed areas.

• Worldwide, one in 10 people lack access to clean drinking water according to the World Health Organization. Without proper treatment, water can carry a host of pathogens that lead to disease. A team of researchers, led by Nordica MacCarty, an assistant professor of mechanical engineering, partnering with a nonprofit organization, has developed and tested a novel water purification product that can produce enough safe drinking water for 1,000 people per day while significantly reducing the amount of wood fuel needed to heat water.

• Water is especially important in arid climates. The U.S. Army Engineer Research and Development Center Environmental Lab is addressing a problem that began in the 1960s, when ammunition and explosives were buried underground in a chemical depot. Partnering with Jack Istok, a professor in water resources engineering, they are using a combination of strategies to clean up the aquifer.

• Wastewater treatment plants spend more than 60 percent of their total operating costs on pumping oxygen through water in order to remove excessive amounts of ammonia from wastewater. Tyler Radniecki, an assistant professor in environmental engineering, is looking at cost-effective ways to clean up wastewater systems by integrating complex microbial processes with constructed wetlands.

As we continue building a strong culture of inclusivity, diversity, and cross-disciplinary collaboration at Oregon State, we strengthen faculty and graduate research. And through providing more rigorous and hands-on experiences working on critical global challenges, we ensure our graduates are equipped and ready to find sustainable clean water solutions.

Go Beavs!

Scott A. Ashford, Ph.D., P.E. (California)
Kearney Professor and Dean
Oregon State University
College of Engineering
Lewis Semprini is working to build strong, healthy communities that thrive on toxic waste.

The communities in this case are made up of a special type of anaerobic bacteria that “breathe” chlorinated organic solvents, similar to the way humans breathe oxygen. Semprini, a distinguished professor of environmental engineering at Oregon State, has spent the past 30 years working on bioremediation strategies using these and other types of microorganisms to help clean up contaminated groundwater.

Chlorinated organic solvents, such as trichloroethylene (TCE), are widely used in industry. For much of the 20th century, massive quantities of these highly toxic substances were casually dumped without a second thought. Over the years, these chemicals have migrated from the soil into groundwater sources, where they persist indefinitely as environmental contaminants. Tens of thousands of contaminated sites have been identified throughout the United States.

For a class of microorganisms called organohalide-respiring bacteria, however, cleaning up these solvents comes as naturally as breathing. “These species can perform a complete detoxification,” Semprini said. “They take in a toxic, heavily chlorinated molecule like TCE and transform it into a much more benign, completely nonchlorinated molecule, ethene.”

Semprini’s lab recently concluded a major study in collaboration with Stanford University and funded by the National Science Foundation that examined the community structure of an organohalide-respiring species called Dehalococcoides mccartyi.

As it turns out, D. mccartyi bacteria are not all built exactly the same. Due to slight, difficult-to-detect genetic variations, different strains produce enzymes required at certain stages of the dehalogenation process but lack the ability to produce enzymes required at other stages, so the cleaning efficiency of bacterial cultures varies. The particular culture used in this study, known as the Evanite culture, is a home-grown variant. It comes from the site of what used to be known as
the Evanite Fiber Company, located on the Willamette River near Oregon State’s main campus in Corvallis. Cleanup of TCE-contaminated soil has been going on at the site for more than 25 years.

Genetic variation is where community structure becomes an important concept. In a well-structured community, each strain does its job and the conversion from TCE to ethene is complete. If conditions are not optimal, however, toxic accumulations of intermediate chlorinated compounds — dichloroethane and vinyl chloride — can build up, and the dehalogenation process will stall.

“The question for us was, how do we tease out and actually enumerate the different variants of this microorganism?” Semprini said.

To answer that question, Semprini’s lab maintained for seven years a culture of *D. mccartyi* in a chemostat under varying substrate conditions. A chemostat consists of a continuously stirred tank in which effluent is siphoned off at the same rate as fresh culture medium is supplied. The goal is to maintain a constant volume with a stable bacterial population. But keeping a culture alive in a chemostat in the long term can be a tricky proposition, especially when dealing with anaerobic bacteria, because even the slightest exposure to oxygen can be deadly.

The Stanford collaborators provided the advanced molecular techniques required for the study. Semprini credits Research Associate Mohammad Azizian, a key collaborator for the past 20 years, with developing the systems and techniques necessary for its success.

“If the Guinness Book of World Records had an entry for the longest-running chemostat, we would certainly be in contention for the title,” Semprini said. “This study represents the longest anyone has kept this microorganism alive in a chemostat on a continuous-feeding basis.”

The study, published in *Environmental Science & Technology*, demonstrated that the viability of different strains within a bacterial community can vary.

“This process is already being used to clean up groundwater,” Semprini said. “So there are important questions about the types of conditions needed to support the right microbial community. What we’ve shown is the importance of substrate addition, having enough available to achieve complete dehalogenation, and also that we can track these different strains using advanced molecular techniques.”

**BY KEITH HAUTALA**

Using advanced strains of microorganisms, Lewis Semprini and Mohammad Azizian develop systems capable of cleaning contaminated ground water.
From forests to faucets: improving watershed health
WATER—THE MOST PRECIOUS RESOURCE ON THE PLANET

We can survive just fine without gold, or diamonds, or platinum.

But water? Not so much.

For thousands of years, water has slowly flowed through watersheds via vast capillary-like networks of wetlands, creeks, and lakes that naturally purify it along the way. Not long ago, we freely drank pure water from rivers and streams without fear of the health risks.

“Although we value water, we spend more money on phone bills than water bills,” said Meghna Babbar-Sebens, an associate professor in water resources engineering at Oregon State. “It’s interesting how backward our thinking is about the value of water.”

People are altering natural environments to make way for infrastructure and agriculture — removing vegetation, filling in wetlands, straightening river channels, and constructing dams. As populations grow, people are pushing further into watersheds and engaging in activities that impact water quality.

Today, water is tainted by a wide-range of contaminants, including agricultural fertilizers, flushed pharmaceuticals, industrial pollutants, roadway runoff, and human waste. Increased contaminants flowing through diminished watersheds make it challenging for nature’s water purification system to be effective.

To obtain potable drinking water, we now rely on highly engineered, centralized water treatment plants in municipalities that filter and treat the contaminated water before it is distributed for human consumption.
“Nature is very efficient at capturing contaminants, so why not make sure the water arriving at the water treatment plant has a chance to be treated by nature before it gets there?” Babbar-Sebens said. “We want to develop effective strategies that minimize upstream contamination and add natural features to watersheds so that it’s less expensive and more efficient to clean water downstream.”

Babbar-Sebens’ research identifies locations in watersheds where “green infrastructures” can be created to help biosystems naturally purify waterways. These infrastructures may include ecological systems such as wetlands, filter strips, grassed waterways, bioswales, and even agricultural management practices such as cover crops and no-till farming.

THE TOOL THAT LEARNS, AND TEACHES

Babbar-Sebens has developed a web-based, participatory tool called Watershed Restoration Using Spatio-Temporal Optimization of Resources (WRESTORE), and she hopes to partner with watershed stakeholders willing to test drive the new tool.

“Information technology, simulation models, and machine algorithms analyze the landscape and other large data sets about a watershed and suggest the best strategy for installing natural features that improve the environment’s capacity to clean water,” Babbar-Sebens said.

The web-based system allows people to try various solutions in a simulated version of their watershed landscape. The interactive framework takes user feedback and employs an iterative search-and-learning method to find better potential solutions that address the user’s feedback. Users can then identify alternatives that best fit their particular needs. The tool not only learns from users about their needs, but users also learn about how their watershed can respond to various actions or changes on their particular piece of land.

“The science is very clear about which watershed improvements and natural features could be installed to achieve the highest impact,” Babbar-Sebens said, “but implementation takes the support and help of the people who live in the watershed areas — and that can complicate things,” she said.

THE HUMAN FACTOR

Computer simulations have a limited ability to incorporate subjective or unquantified criteria such as personal values, interests, biases, historical knowledge, and the preferences of the stakeholders living in the watershed areas.

A farmer, for example, might be less enthusiastic about giving up acreage currently used for row crops in order to convert it to a wetland. Or, a homeowner living near a river might balk at the suggestion of planting vegetation that obstructs a view or seems aesthetically unpleasant. Likewise, outdoor enthusiasts may not want to curtail activities in some areas.

“By engaging people in upstream solutions, my ultimate goal is to create new, integrated, and collaborative approaches to managing clean water — starting from the moment the rain falls from the sky to when water comes out your faucet,” Babbar-Sebens said. “Issues like clean water and climate change will not be solved with just science or algorithms. We must engage humans — along with machines — to ensure we discover the best possible solutions.”

Associate Professor Meghna Babbar-Sebens and Ph.D. student Amir Javaheri discuss how computer models of green infrastructure can be used to engage decision makers in designing solutions that are efficient in treating stormwater.
Advancing access to safe drinking water

Taking time and air pollutants out of the equation
Twice a day, at an all-girls high school dormitory in Eastern Uganda, a cook boils water for safe drinking over a smoky, open fire. Each 80-liter pot takes roughly an hour and multiple logs to boil. Around the world, a similar story plays out as people spend hours collecting firewood and disinfecting water in this dangerous, highly-polluted environment.

Despite the technological advances of the last century, more than one in 10 people worldwide lack access to clean drinking water, according to the World Health Organization. Without proper treatment, water can carry pathogens that lead to diseases such as cholera, typhoid, and bacillary dysentery. Consequently, contaminated drinking water is responsible for the death of an estimated 1.5 million children every year.

Population growth, climate change, and population displacement are amplifying the need for better and safer large-scale water purification systems. To tackle the issue, a team of researchers at Oregon State University, led by Nordica MacCarty, an assistant professor of mechanical engineering, is partnering with InStove, a nonprofit organization based in Cottage Grove, Oregon. The group received the Impact Invention Award in 2017 from the Lemelson Foundation for their work.

The team has developed and tested a novel water purification product and is investigating ways to support its deployment. The InStove Water Purifier can produce 4,500 liters of safe drinking water per day — enough for 1,000 people — at a minimal cost to users and the environment. Although the water purifier can be used with any heat source, when paired with an InStove cookstove, the fuel savings are substantial: one liter of potable water can be produced for a pencil’s weight of wood fuel. It’s the first solid fuel powered pasteurization system of its type.

“The key to a sustainable solution is finding out what works for the communities in the long term…”

“I have traveled to Africa many times, including 18 trips to refugee camps, observing firsthand the desperate need for affordable, clean water technology,” said Fred Colgan, InStove’s founder. “We have been working on this program for years, and, with the help of Oregon State, we are about ready to deliver this innovative technology to the world.”

In August 2017, Oregon State researchers partnered with MAPLE Microdevelopment to test the water purifier at a high school dormitory.
in Mbale, Uganda. They evaluated its technical performance, user preferences, and appeal. Users found the product easy to use and it saved them time and money. The reduced emissions also meant less smoke in the users’ eyes and lungs. When the pilot program ended, the school manager was sorry to see it go and plans to purchase the system once it is commercialized.

With some initial support from Venturewell (and a student entrepreneurial team), the next step is working with InStove and MAPLE Microdevelopment to build a sustainable business strategy. “The system design includes maintenance,” MacCarty said. “The key to a sustainable solution is finding out what works for the communities in the long term and then helping local partners and entrepreneurs implement it successfully.”

In 2018, continued evaluation and implementation of the water purifier will be led by Grace Burleson, a dual master’s student in mechanical engineering and applied anthropology. “The InStove Water Purifier must be evaluated both technically and socially. We’re working with engineering, anthropology, and business faculty to look at the project holistically,” Burleson said.

Nick Moses, a graduate student and lead engineer for InStove, will head technology development and manufacturing for both water and clean cooking technologies.

The project is part of the Humanitarian Engineering program at Oregon State, which works to cultivate science and engineering-based solutions that fulfill basic human needs, enhance life quality, and advance the level of resilience in the local and global community.

“We do that through an interdisciplinary approach, which we like to think of as engineering in context, where we look at technological solutions in light of surrounding social, economic, and environmental factors,” MacCarty said. “This type of research really teaches students about the broader impact of their work and provides opportunities to develop many of the multidisciplinary, entrepreneurial, and social and cultural competencies needed to be a successful engineer in the 21st century.”

BY OWEN PERRY

Graduate student Grace Burleson records measurements from an InStove Water Purifier in Uganda.
Clean water for a thirsty region

Researchers employ microorganisms to consume groundwater contaminants

Water is the foundation of life, and in a semi-arid climate where water is scarce, groundwater contamination is a critical problem. To tackle this issue, Oregon State researchers are partnering with the U.S. Army to produce groundbreaking applied research that will ensure clean water for a region that needs it and ultimately contribute to cleaner water throughout the nation and the world.

Starting in the early 1960s, the Umatilla Chemical Depot in Eastern Oregon housed a large supply of ammunition and explosives. Before the risks of dumping wastewater into the ground were fully understood, munitions were washed into a lagoon, which inadvertently created a plume of contaminated groundwater.

“This site is in an arid region where water is precious. So, having a large volume of unusable water is an issue,” said Jack Istok, a professor of water resources engineering at Oregon State.

After the Army identified the contamination, a pump-and-treat process was used to clean up the contaminated aquifer. The process involved extracting the groundwater and filtering it using activated carbon, then re-injecting the clean water through a series of large, horizontal pipes below the ground (called an infiltration gallery).

Unfortunately, the pump-and-treat process is quite slow, so after a few years of pumping and treating, the Army was looking for a more efficient approach. Mandy Michalsen ('07 Ph.D., Civil Engineering), a research engineer at the U.S. Army Engineer Research and Development Center Environmental Lab, partnered with Istok, her former doctoral advisor at Oregon State, to test a more efficient cleanup technology. The
researchers used bioremediation, in which microorganisms break down contaminants.

To begin, Istok and Michalsen employed Istok’s single-well, push-pull method, which consists of injecting a prepared test solution into a well and extracting a combined sample of the test solution and groundwater. Within the aquifer, contaminants in the test solution are broken down by a combination of physical, chemical, and microbiological reactions. By measuring the concentrations of the solutes during the extraction phase, the mass of reactant consumed, and the product produced, the research team is able to calculate the reaction rates.

“The plume map has changed significantly, and for the better.”

During their push-pull test, Istok and Michalsen amended the solution with fructose, which allowed the microbes to consume electron acceptors, such as oxygen and nitrate, until the environment became anaerobic.

“Under those anaerobic conditions, the contaminants degrade relatively quickly,” Michalsen said. Istok added: “Results of the small-scale, single-well push-pull tests showed that the fructose addition worked and allowed us to predict how fast it would happen. That gave everyone confidence that we could scale up the process.”

To decontaminate more of the area, Michalsen and a team from the U.S. Army Corps of Engineers (Seattle District) and the U.S. Army Engineer Research and Development Center introduced large quantities of fructose-amended groundwater throughout the aquifer by using the existing infiltration gallery that covered the original lagoon.

“It’s been remarkably successful,” Michalsen said. “The extent of the groundwater above the cleanup level is much smaller now. The plume map has changed significantly, and for the better.”

But that’s not where the story ends, she pointed out.

Although the new process removes contaminants, anaerobic bioremediation has drawbacks, including an unpleasant odor in treated groundwater. To improve their process, Istok and Michalsen teamed with a group of researchers to demonstrate how adding bacteria to the groundwater, a method known as bioaugmentation, could avoid some of the water quality impacts associated with anaerobic treatment.

“The special bacteria added can use the contaminants as a nitrogen source for growth under aerobic conditions, using 95 percent less fructose,” said Michalsen.

Now that Michalsen and her team have produced positive lab and field results using the bioaugmentation process and published their results, they are working on additional publications to share their lessons learned and support implementation at other sites.

“Top scientists and engineers worked with stakeholders, including state and federal regulators who offered valuable technical input, to solve problems and clean up a significant portion of the aquifer,” Michalsen said. “I feel really good about the work we did — it was carefully executed, well documented, and wildly productive.”

BY JOHANNA CARSON
contains excessive ammonia or nitrite (and therefore nitrogen) when it’s released, the potent nutrient overstimulates algae growth in rivers and streams, threatening fish and other aquatic life.

“The conventional way to remove nitrogen from wastewater is to bubble air through it continuously so bacteria can turn ammonia into nitrate,” Radniecki explained. “Adding a carbon source, like methanol, enables bacteria to convert nitrate into nitrogen gas.”

That aeration process is expensive, accounting for about 60 percent of a treatment facility’s energy costs. And methanol can cost millions of dollars each year. Anammox reduces the need for aeration and eliminates methanol from the equation.

Energy-efficient solutions for wastewater treatment

We humans manage to foul up our planet’s vital water supply in countless ways. Although we have found some reliable strategies to clean up the abundant mess, a few among us are determined to find better answers to a serious and growing problem. Tyler Radniecki, an assistant professor of environmental engineering, is one of those individuals. He’s spent his entire career cleaning up dirty water.

“The overall quality of water in our country is deteriorating,” Radniecki said. “Is it in crisis mode? I don’t know, but it’s getting worse, and we need practical, affordable solutions.”

Radniecki has explored how titanium dioxide nanoparticles interact with sunlight and generate a reactive form of oxygen, creating molecular cannonballs that destroy waterborne toxins. He’s studied the effects of using a giant magnifying lens to supercharge sunlight and beam it through water brimming with dangerous pollutants, thereby intensifying the photocatalyst’s power to decontaminate water previously untreatable using titanium dioxide nanotechnology. Now, he’s researching a pair of promising wastewater treatment systems that rely on complex microbial processes.

The anammox (anaerobic ammonium oxidation) process enlists special bacteria that combine the ammonia and nitrite already present in wastewater to form harmless nitrogen gas. If treated wastewater still
It works best when ammonia concentrations are high, but not so well in more dilute wastewater that typifies municipal sewage. Anammox also demands a lot of technical expertise and continuous monitoring, making it financially nonviable for many smaller communities.

Radniecki sees a possible solution: integrate anammox with constructed wetlands and let the chemistry kick in and run on cruise control. In partnership with Clean Water Services, a water resources management utility in Hillsboro, Oregon, he’s testing the idea in his lab. If everything falls into place, he envisions a full-scale anammox wetland going up one day.

“It’s a passive system. To work, it has to pretty much run on its own,” Radniecki said. “It requires a strong understanding of how an anammox wetland responds to a wide variety of complex and real-world conditions to ensure that it won’t be overwhelmed. The system I want to create will be affordable and make sense for smaller communities that have abundant land but not a lot of money or technical expertise.”

FOG (fats, oils, grease) co-digestion is another promising development. It starts with the anaerobic digester, a sealed silo used by many wastewater treatment plants to process sludge, the solid constituents in the waste stream. Inside, bacteria gobble up pathogens and neutralize organic contaminants to produce nutrient-rich solids (that can be used as fertilizer) and methane gas, which is usually flared off.

Adding FOG sources to the digester (such as restaurant fryer grease and other high-energy byproducts of the food industry) can boost methane output so dramatically that the excess biogas becomes an economically viable source of renewable energy. The Gresham Wastewater Treatment Plant (GWTP) in Gresham, Oregon, began using the process in 2012. By 2015, it achieved energy self-sufficiency, saving the town a half million dollars in electricity costs annually.

Curious about how the plant determines the amount of FOG to feed into the digester, Radniecki asked the plant’s chief engineer to explain it. His answer was surprisingly arbitrary: “He said, ‘well, we add a little, which seems to work;’ but they’re wary of overdoing it and upsetting the chemical balance,” Radniecki said. “Adding too much FOG could harm the digester and possibly cause millions of dollars in damage.”

Radniecki saw an opportunity to help the GWTP solve the problem and offered to build a model digester in his lab to analyze the impact of various FOG sources and quantities on methane production.

“Anaerobic digesters are picky eaters, and there’s a lot we don’t know about how FOG affects their microbial ecologies,” he explained. “If you shift the microbial environment too quickly, methane production can decline rapidly. Also, different FOG sources result in higher methane production than others, though the reasons remain unclear. This leads to a trial and error approach to FOG co-digestion.”

Radniecki posits that a thorough understanding of how the anaerobic digester’s resident bacteria interact with FOG will lead to a framework by which engineers can accurately control the reactions and enhance methane production. There’s even some evidence that FOG co-digestion can be used to produce alternative by-products, such as hydrogen gas and bioplastic precursors.

“Methane production is the low-hanging fruit,” Radniecki said, “but I see other applications, and to get there, we need a much better understanding of what’s happening within these complex biochemical communities.”

Assistant Professor Tyler Radniecki and Ph.D. candidate Richard Hilliard inspect an immobilized anammox bioreator.