January in Phoenix and, of course, it’s not cold. It is sixty-five degrees outside. I’m wearing short sleeves. I’m also wearing a scarf to assimilate better with my interview subjects when they bundle up to go outside into what in Flagstaff we would call balmy but in Phoenix they call winter. Either way, it is just the right temperature for a scarf and a shirt and there is just the right amount of security for an expensive building housing Level-3 biohazards. This place is clean. Stainless steel and glass, concrete floors and metal handrails, not a single uninvited microorganism in the place. Lots of invited ones though: *Enterobacter cloacae*, salmonella, and anthrax to name a few. The CDC, were the Biodesign Institute to stop photoscanning security passes, would pull its funding and all the work on anthrax would come to a complete stop.

But I’m not here to hear about anthrax. I want to hear good news. Tired of reading about Gulf Coast oil spilling, natural gas fracking, water polluting, and globes warming, I’m looking to hear about repair. Bruce Rittmann, Director of the Center for Biotechnology came to collect me. I hope that Bruce might be able to offer me something—a catalyst, a rescue rope, a stimulus package—to stop the cascade of bad news, but I don’t hold out a lot of hope. Still, Bruce promised to regale me with
stories about wastewater treatment plants, and if that didn’t sound like a story about saving the planet, I don’t know what would.

I have a hard time believing in heroes. To me, they are as unlikely and non-extant as aliens, unicorns, and the promises of Oil of Olay. But non-existent and nearly-invisible are not the same things. Things are visibly wrong. The air is thick with smog. The water, even when it runs clear, is riddled with man-made chemicals. Bruce would introduce me to organisms that are mostly invisible. Maybe, to be a good hero, you had to be mostly invisible.

A fixer is a kind of hero and, although I might not believe in heroes, I do believe in rehabilitation. Here, at the Biodesign Institute, I’m going to try to understand how these tiny beings remedy that dirty air and that toxic water. Remedy is a human metaphor. The water and the air don’t care what rides in their waves or on their winds. To them, they’re not broken. It’s from a user-based perspective that things have gone wrong. What Bruce shows me is that usefulness can be reoriented. To a microorganism, chemical-ridden water is as user-friendly as a vending machine.

The tiny lesson I will learn here: microorganisms can restore water to its original self, hero-like and non-metaphorically. The big, metaphorical lesson: perspective shift and adaptation can make almost anything user-friendly. If that vending machine neglects to unwind your Cheetos, you can finagle a tool to encourage the spindle, spend another
four quarters, shake the machine, call the manufacturer. You can adapt to this bad situation. And like you, microorganisms adapt to their surroundings and use them to survive, even thrive.

Bruce will take care of me, but I have to wait for the fix. Instead of wrapping me in the comforting story about things getting better, I first have to hear about things getting worse. Bruce chaperones me upstairs and hands me over to Rolf Halden, professor at the School of Sustainable Engineering and the Built Environment. Rolf, in the middle of preparing a talk to present to Congress, has been focusing on Superfund sites and cross-referencing them with hospital visits. Rolf takes me back downstairs toward bad news and lunch.

Arizona State University Organic Café

“So what do you want to talk about?” Rolf is obviously German. His accent as much as his first name make it obvious. But it’s his locution that I find particularly attractive. There’s such formality and precision in his voice but he’s smiling the whole time. He smiles even as he tells me that when he worked at Johns Hopkins he studied newborn babies, finding manmade chemicals already polluted their newborn bodies.

“One hundred chemicals found in the babies before they have even taken their first breath. One hundred man-made chemicals can be found in the breast milk of 99.9% of mothers.”
I think of Max, my son, and the breast milk I just weaned him from. I thought I had been doing him a big favor, nursing for a whole year. I thought I’d been promoting his good health, developing a stronger immune system, preventing allergies—all the things breastfeeding for one year is supposed to do. Instead, apparently I’d been dumping chemicals into him like he was the Cuyahoga River.

There are old wives’ tales about what not to eat while breastfeeding: onions, garlic, thyme, chocolate, tea, raspberries, and honey. And then there are the more American Medical Association-approved proscriptions against smoking and drinking. But no one had told me, because old wives never knew and doctors don’t track environmental contaminants, that I shouldn’t eat out of my non-stick pans, drink out of the carton, or smear organic butter because the chemicals that coat our pots, line our milk cartons, and cling to our vegetables don’t degrade. Chemicals stick around, persisting in our produce, our water, and, particularly, in our breast milk. Lipids, or fats, are great carriers of chemicals. If it’s in the water or in the butter then it’s in your boobs. If it weren’t so Frankensteinian sounding, it would be kind of cool to have breasts full of chemicals. Spider? Zap. Out shoots some DDT. Milk-and-insecticide-covered-dead spider. And yet, as far as I know, there are no cartoon superhero women who shoot venom out of their nipples, although perhaps I shouldn’t count out the Japanese on this one. Perhaps in American graphic art, expulsion from the nipple upsets the image of
the nurturing mother. But doesn’t too the image of the nurturing, nursing mother pouring contaminated lipids into her baby’s mouth?

“Rolf. I’ve been poisoning my baby.”

“No, no. It’s still the best thing you can do for your child. All that immunity. You’re protecting him from the environment he’d be introduced to anyway. And it’s not like the chemicals aren’t found in formula or cow’s milk. That’s what I mean by pervasive.” But pervasive isn’t the only problem. Finding the right tool to combat the myriad of pervasive contaminants in the water and soil is a lesson in making tiny decisions all the time. Microbiologists are as picky as farmers. One of the microorganisms used to clean toxic selenate out of water, Enterobacter cloacae, is also a notorious contaminant in infants and can kill babies born prematurely. Sometimes one microbe is a fixer. Sometimes a microbe is a killer. It’s entirely dependent on the application. Which is why, I guess, Rolf is picky about where we went for lunch.

Rolf wonders, as we walk, if we should try our luck at the Thai, Indian or American restaurants. He rolls his eyes at all three, saying, “They’re not that good. Cheap. Meant for college students. “Let’s see if the organic restaurant is open.”

We’re in luck. Even though the university is between semesters, the café is open.

“You like sushi?”

I nod. “Spicy tuna rolls.”
Rolf orders the sushi, a sandwich for me and one for him, a big salad for us to share. This is how Rolf is picky: he chooses everything and then takes a bite out of it to decide if in this particular application this sushi is good, this sandwich, this salad.

The server says hello to Rolf and pats him on the back like Rolf is an old friend. I gather, from the way the server brings us lemon for our drink and extra napkins without asking, that they are old friends, or at least that Rolf visited his local-organic-restaurant often. His kind of place, he thrives here. You can tell Rolf is a clean-living kind of guy. He works out. He doesn’t put toxic chemicals into his body, if he can help it. Which, according to him, no one can help. But he isn’t supercilious or sanctimonious. Perhaps Rolf has to be gregarious and open-minded if he’s going to immerse himself in the contaminants of the world and try to find the one right microbe to combat one of the contaminants. Rolf put himself out there, in the world, at Superfund sites, at the wastewater treatment plant, at the restaurant and opened his arms to say—come to me. And in so doing, he found the perfect microbe, a helpful server, and a delicious salad and sandwich, even if the sushi was only so-so.

**Brandywine Creek, Delaware**

All this eating. All this talking. As Rolf tells me about Teflon polluting in the water system, I think about the non-organic salad I ate yesterday. It pollutes: fifteen known contaminants in the lettuce,
the carrots, the beets. Rolf makes me feel like one big sponge. The body becomes a microcosm for everything that happens in the water, the food, the world out there. Bodies are places. Inside them, chemistry happens, DNA replicates, toxins reside. When I was nine, I put together a model of the Invisible Woman. I loved the bones the most, but I also loved the way the veins splintered and gathered and returned to arteries looked like a map of the rivers. I loved the idea of the Continental Divide casting rivers toward the east and rivers toward the west like a good heart organizing its oxygenated emissaries further and further toward the left and right hands of the coasts. I liked, then, the idea of everything being connected. Rivers are to veins as hearts are to watersheds. But in this version of the world, all that interconnectedness isn’t the relief, it’s the tension.

People put substances into places. The idea of “putting” something somewhere seems so intentional. If someone were to go out of their way to take, say, Teflon into a syringe and shoot it into a baby they would be arrested. Maybe go to jail. And yet the way Teflon rides through our consumer ecology mirrors the way Teflon rides on the water systems. Someone made it (culprit), but someone else wanted it (culprit), and someone else bought it (culprit), and some FDA official approved its nontoxicity (culprit). It’s easy to blame a man with his hand on the plunger of a syringe. It’s hard to blame the woman who wants to flip an omelet with one hand because she’s pregnant with one baby and holding
another baby on her hip. Even the chemist, who seems easily cast as the villain, is hard to blame directly. The chemist finds Teflon accidentally and now the woman flips omelets in her kitchen. The chemist shakes his beakers in a lab. The graphic designer draws pictures of beakers and kitchens in Adobe Illustrator in his office, three floors down from the marketing manager who will make a PowerPoint presentation to illustrate the new, cool kind of Teflon that can even withstand the nick of a metal utensil. These people never meet but their needs eddy and swirl, contribute to the river that becomes something like a necessity. Have you ever tried to scrub stuck-on scrambled eggs off a non non-stick pan? You might as well throw the pan away and what good would that do already-overflowing landfills?

In 1961, Marion Trozzolo, a chemist who had been using the substance on scientific utensils, came up with the advertising campaign for the new line of cookware, “The Happy Pan.” And if you think of the last nonstick pan you tried to scrub burnt eggs from, you too would call this the Happy Pan.

Of course, it is not all happy. When a substance leads to practical, making-life-easier products, it pervades the marketplace as surely as the residue from manufacture pervades the river system. Teflon flows from the confluence of the Christina River and Brandywine Creek in Wilmington, Delaware. The Teflon runs-off from the Dupont labs and follows the Christina River to the Delaware River into the Delaware Bay.
These are not hideous rivers turned sulfurous and soupy. The water looks clear. The rocks seem rocky, no noticeable damage pock-marking them, dissolving them, melting them. There are no rows of dead fish lining the banks. Like most water, it appears entirely clean. It’s see-through. Trees hover over the Brandywine. The leaves turn red in autumn but not chemically redder than the maples turning in Vermont. The water meanders toward the Delaware like it has for hundreds of thousands of years. The rocks move by millimeters. Turtles dig mud holes. Tadpoles swirl in eddies. This is a regular river that has regular water, at least in the sense that regular water now has Teflon flowing alongside it. Slippery rocks.

Teflon, applied to different products, is packaged up and carried out, where its residue finds its way into the water not by manufacture but by utility. Teflon flows on the backs of trucks and in the boxcars of trains, like a well-integrated, multi-directional river, west toward Oregon and southeast to Texas and due south to Oak Ridge, Tennessee. The Teflon goes on and on, across the sea to China where they now make the pans and then ship them back to Delaware where Walmart sells the T-FAL Basic Nonstick Easy Care 10” Covered Fry Pan for $16.97. T-FAL stands for Teflon. Teflon stands for Perfluorooctanoic Acid, for short, PFOA.

Substances slipping past places like rivers, even if they don’t stick there, do stick somewhere. Perhaps reside in is a better word choice. Reside means to make a home in. It suggests permanence. Coziness.
Safely ensconced in. A settlement. No one is relocating Teflon or PFOAs out of their newfound homes. PFOA settles in breast milk but it’s just one of many manmade chemicals that reside in bodies. Titanium oxide, used in toothpaste, is found in frogs. Triclosan, one of Rolf’s most current projects, persists in solid waste. Rolf tracks the PFOAs, the titanium oxide, the triclosan. Kris McNeill, a friend from college who is now a professor at the Swiss Federal Institute of Technology (ETH Zurich), published an article on how sunlight chemically converts Triclosan into dioxin in rivers. Ingesting dioxins is known to increase cancer risk. Warnings about eating fish from the dioxin-filled San Francisco Bay abound even though you love fish, especially when you’re in San Francisco.

Rolf spends a lot of time collecting samples from sewer systems across the US. The problem is, the FDA is interested in the cleanliness of water but Triclosan persists only in solid waste. Solid waste the FDA considers inert. Because it can be moved away from the community of wastewater-users, the FDA designates it fully resolved. But those biosolids from waste treatment plants are trucked somewhere to dry. In the US, we imagine that “over there” is safely distant from “over here.” But when the winds come, the chemicals from the solids are blown over crops or onto grazing land where cows nibble, digest, incorporate the Triclosan into their muscles. Their delicious muscles that humans go on to eat. The “over there” moves “over here” with the help of the planet’s big circular systems—wind and water. There is no over there.
Triclosan is one of the anti-microbacterial agents found in anti-bacterial soap. You can also find it on sports equipment and in deodorant, in carpet, rulers, and pens. My pencil sharpener claims to be anti-microbial. All those kids from my daughter’s school covered in germs. I can see the attraction.

“It seems like a good thing,” Rolf said, “no bacteria. But we’re beginning to suspect that it’s one of the causes of food allergies. It harms microorganisms in the gut biome. We don’t even know each of their names. But think, every time you wash your hands, you eventually put something that you touched into your mouth. The antibacterial soap reduces the microbacteria in your gut. Our immune systems. We’re weakening them every day.”

Our fear of the invisible, or the nearly invisible, coupled with our fear of contagion, and the heaped-on fear of anything that shows dirt, and you can see why the woman shopping for groceries has Pantene and Pinesol, Dial and Glad garbage bags, and a plastic cutting board in her cart. The germs are coming. She collects the arsenal that will protect her family.

I have my own germ phobias—when I’m not busy ignoring dog hair and piles of old laundry. I panicked fully during the swine flu epidemic. I vacillate between believing the studies that show the French are in better health because their immune systems are better balanced by the refusal to employ Lysol and my mother who says, even if her house...
is messy, that it’s “clean.” Clean meaning antiseptic. Clean meaning you can eat off the floor and not get sick, even if you don’t have the immune system of the French. I am a spectacle of contradiction. I keep sponges for weeks rotting in the sink but I also rub the handle of the shopping cart off with the Clorox wipes Safeway offers at the door. I will use my daughter’s toothbrush but if my toothbrush falls on the floor, I will dip it in Listerine before I brush. There is no restroom too gross for my wussy bladder but I squat to pee at bar bathrooms as well as in the forest.

But Rolf raises the question, what if the antibacterial soaps and antimicrobial pencil sharpeners do more harm than good? What if the arsenal the Lysol-loving mom sprays on every surface piles chemicals more dangerous than any well-lived-with germs? Hygiene is a good thing—running water and soap have transformed houses, restaurants and bathrooms from bastions of disease to bastions of sanitation. Perhaps the idea of “soap” has been taken too far. Celiac disease? Irritable Bowel Syndrome? Weakened immune system? Are these diseases that you might have avoided if you’d been a better host to those internal microorganisms? If you recognized that your body is a wastewater management system, then you would know that healthy systems are made with the help, not the obliteration, of microorganisms.
Rolf pointed to the dessert he bought—some sort of coffee ice cream frozen into a tiny creamer and some ginger-crusted profiterole. He motioned for me to take a bite. I felt secure there, surrounded by organic food, a sustainable building and Rolf’s insistence that we can figure out how to make this work, like it wouldn’t kill me to enjoy myself a little—stop thinking about polluted breast milk and eat a little dessert. I could tell Rolf had a sense of balance. He could bring the bad news but then still eat a smorgasbord. Maybe he was just trying to stimulate his gut biome.

“Do you have a degree in chemistry?”
“No, biology and engineering.”
“And yet you spend so much time with chemicals.”
“Well, that’s why I’m trying to make them green. My biology and engineering degree conspire to make me make sure things turn out good.”

The idea of Green Chemistry isn’t new. Paul Anastas, a one-time employee of the EPA, and John Warner developed the principals of Green Chemistry—a chemist’s version of the medical doctor’s “First do no harm.” The argument for green/sustainable chemistry is similar to the argument for all kinds of sustainability: Use as little energy as possible. Clean up after yourself. Make sure that you use all parts. Don’t use corrosive agents. Use renewable feedstock. It’s a lot like the model of
whole animal eating: kill the pig quickly and cleanly and humanely. Eat the ears.

As Rolf tracks Triclosan and studies its effects and works with Congress, he goes forward with the mission to persuade drug companies to embrace Green Chemistry, by which he means follow your chemical to its end state, make sure that when it’s done doing what it should do that it doesn’t bind with other molecules and disguise itself as clean or eddy around in rivers or isn’t stockpiled in biosludge where it’s shipped off to the desert or the outlying agricultural lands where it becomes part of the soil and the soil becomes part of the plant and the plant becomes part of the cow and the cow becomes muscle we eat and the PFOAs and the Tricolsan and the hundreds of other chemicals become a part of us. Like wind and rivers, he argues chemists should make sure the circularity of chemical systems ends in equanimity.

Although Rolf doesn’t study one place, he does think about the consequences of chemistry in terms of place. He thinks about the consequences of all “progress” in terms of place. “If we lived like humans once did, in small villages where everyone could see what everyone else was doing, there would be no Concentrated Animal Feed Operations, no nuclear power plants, no landfill, no sewage system. Our neighbors would not like those industries to be their neighbors. We could see what goes down, what effluent flows into the rivers. We could smell the landfill, the sewer, the CAFO.” We’d also have very little beef in our diets,
less electricity for our laptops and a lot fewer of the bad microbes living in our garbage and our sewage, because we could smell it before we could see it. NIMBYism is one of the most destructive human sentiments. Because we can ship our shit far beyond our backyards, we don’t think about what is in the shit. If we had to live with our garbage, we’d make sure it didn’t smell bad. The poet Diane Ackerman wrote, “Our cerebral hemispheres were originally buds from the olfactory stalks. We think because we smelled.” Perhaps if we smelled more often, we’d think more often about what made that smell stink.

Change the sensory input from olfactory to visual: If you expand the lens and zoom out, the water that flows from the landfill is the same water you drink. The water that feeds the cows becomes embedded in whatever meat you eat. There is no new water. All the water is the same water that’s been always here. It’s getting older and heavier and more laden with toxins and it flows from east to west, rains from west to east, it cycles and spools like a gigantic wastewater treatment system.

Wind and water make everyone and everything, including your waste, your backyard.

But the problem with everything and everywhere—it becomes nothing in your mind. It’s too big and too pervasive. It’s like trying to talk about language without using words, just hand signals. That water is inside you as much as it “in nature.” You can look outside on your
human-planted trees and believe that this is nature. And it is natural. It was natural for you to want plants. It’s natural for plants to grow, with enough imported water and nutrients, where you plant them. It’s natural to look outside and sigh contentedly that you don’t live next to a landfill, a coal plant, a silicon chip factory, a gypsum, gold, or copper mine, an oil refinery, a nuclear waste dump, a concentrated animal feeding operation or its attendant slaughterhouse.

The bad news is you do live next to all these toxin-emanating, resource-processing, industrialized plants. They’re bringing their effluvia to a neighborhood near you.

When I was fourteen, sitting by the swing set at Sugar House Park, watching my boyfriend smoke, I pulled the grass up gently so I didn’t break the root. Pulling each blade between my teeth, I drew a little milky cellulose like I was drinking from a straw. It felt industrious, getting something useful out of ornamental lawn. My mom, if she ever caught me, would have yelled at me not to do that. It was disgusting. Not just the goose poop but the pesticides. The park’s pond sat at the bottom of Emigration Canyon, where the Mormons had first entered Salt Lake Valley, where now septic systems lined the banks, where silver ore had once been mined, where oil now seeps into the river, closing the canyon, forcing the city government to close Sugar House Park where the river flowed into man-made ponds.
Now, when I eat my Swiss chard, I think about the ground the
chard was grown in or the reservoir that watered it. Sometimes, the Swiss
chard tastes saltier than other times. Sometimes it even tastes metallic.
Compared to the Swiss chard I eat from farms that grow their vegetables
near Superfund Sites, the grass I ate at that park had been purer. I miss
that milkiness now.

Your Stomach, USA

To understand microorganisms not generally but specifically is
to understand how each one works and how each one works in unique
environments.

This is why oil-eating microbes undid some of the damage done by
the BP Gulf Oil Spill. This is why the same microorganism that creates
a dangerous biofilm build-up on the interior of a pipe in a wastewater
treatment plant might turn superhero when it reduces a particular
astringent man-made chemical pooling up anew in the Cuyahoga River.
Take an antibiotic, kill the microflora in your gut. It takes years to rebuild
that microflora. In the meantime, you wonder why you’re suffering from
hemorrhoids, why you just can’t eat spicy foods like you used to, why you
get stomach cramps when running. There’s even some evidence that an
upset balance of microflora in your stomach can lead to colon, stomach,
and prostate cancers.
After lunch, Rolf takes me to meet Rosy, officially, Dr. Rosa Krajmalnik-Brown. She and her graduate students are attempting to catalog the thousands of microorganisms that abound in your stomach. Dr. Rosy has found correlations between gut flora and autism. Rosy’s team compared kids with autism to kids without and noticed that the gut flora of autistic kids was very different to the flora of normal kids. “We know there’s a link between the GI and autistic behavior, and when the microbiology is handled a little bit, they are still autistic but their behavior improves significantly,” she tells me.

Microbe maladjustment in the gut might not only be a contributing factor in the behavior of autistic kids but also in the cause of autism itself. Scientists link auto-immune disease, celiac disease, and rheumatoid arthritis to inflammation in the cell walls of pregnant mothers. This inflammation inhibits and interferes with the placenta’s ability to communicate soothing hormones to a growing fetus. In an August 25, 2012 New York Times article that links inflammation, microbes, pregnancy, and autism, Moises Valaquez-Manoff writes, “And really, if you spend enough time wading through the science...an ecosystem restoration project [of the womb]...not only fails to seem outrageous, but also seems inevitable.”

Dr. Rosy’s team also looked at groups of obese patients, patients who had gone under gastric bypass surgery, and patients who had always been thin. “The bacteria that is present in obese patients, together with
other microorganisms, form teams that are more efficient at getting all the energy out of the things that come into the intestine.” The teams of microorganisms in the obese patients don’t let any food go to waste—they store it as fat, whereas a thinner person’s microorganisms let some of the calories from the food go—an argument against efficiency. The inefficient body lets more calories pass through the system unused—possibly because the microorganisms are in better balance with each other. Less stressed, they don’t see every instance of food as a sign of future scarcity. “I’d better store up, just in case,” says the stressed out, lonely microbe. The happy microbes are like, “Dude, there will be more where that came from. Let’s hang out and dance around instead.” These are very relaxed microbes.

My friend, Gabe Brandt, who works as a chemist and microbiologist at Johns Hopkins wrote me again to say, “There’s an Armenian guy at Caltech who has some nice stuff on how the composition of bacteria in your gut correlate strongly with Crohn’s disease— he makes some nice points about how there are ten times as many bacterial cells in your body than there are human cells. Also, the number of bacterial genes in your corpus relative to your own is like a thousand-fold higher. And there are numbers of species of bacteria whose sole habitat in the universe is inside the guts of mammals.” We are more bacteria than our own genetic material. When Whitman claimed he contained multitudes, he understood the gut biome.
We don’t tend to think about the stomach as a place. It doesn’t seem that nice of a place to live. Microorganisms are much more flexible in their habitat. They enjoy the vicissitudes of the stomach. Their scenery changes every day. The canopy of broccoli florets, a sea of blueberries, geysers of Sprite, waves of wine, dune of pretzel, the lush partnership of yogurt. The gut flora make their home in a highly acidic, ever-shifting landscape. They have learned to adapt to you. You have adapted to them. In fact, you both grew and adapted together. A partnership of environments that lets you eat raw meat and somehow to continue to sit at the dinner table while the microorganisms do the hard work of calming e. coli, and making friends with salmonella. As you get up to stretch, your internal planet stretches with you. You respire and all the little beings are rewarded with new oxygen. They continue their good work.

The same microorganisms that rot meat are the same ones that age prime rib. Cheese, nicely sealed in its rind, relies on microorganisms to give it taste. Once that same cheese is exposed to air, it begins to turn to mold. Microorganisms in your soil can give you tetanus but other microorganisms in your soil allow the seed you planted to germinate.

I feel about microorganisms like I once did about maggots. I used to think that maggots were generally disgusting and worth exterminating until I saw them applied to a wound where they proceeded to eat all the necrotic flesh.
Biofilm is another word for slime. Microorganisms accumulate on the edges of wet lips—of pipes, faucets, bathroom corners, the creases behind stoves. Organisms pile up on these lips, living off the other slimy things that grow there like chemicals or other bacteria. This thin film of slime is slippery. It’s the stuff of germs and sludge. It is the stuff you usually want to eradicate and eliminate. Do stuff to it with long “a” sounds. “Take.” “Away.” “Hate.” You want to get rid of the slime. The gunk. Slime forces long “ew” sounds: Lubricant. Lewd. Drool. Rude. Stool. Pool. Booger. Accumulate.

Bruce, even though his name has the “ew” sound in it, isn’t himself slimy. But he does attend to slime. Bruce is balding. His hair fluffs over his ears, making a ring toward the back, but the top of his head is shiny and reflective. He reminds me of my dad, maybe because his name was also Bruce, but perhaps it’s because all semi-bald men remind me of my dad. It’s one of my flaws—an inability to make distinctions. If I met a microorganism on the side of the road, I would not know whether to kill it or not. I wouldn’t even know how to begin to distinguish between “good” microorganisms and bad, slimy ones. Scientists are good at making distinctions. Writers are good at making generalizations. We metaphor-makers write about a fat, thick tree, green needles, and plump pinecones and hope the reader extrapolates our meaning to be healthy forest. A scientist takes samples from that tree and then the next one and
then the next one. The scientist doesn’t get to “healthy forest” until she’s counted all the trees, diagnosed the dirt, measured the girth, palpated the roots. Microorganisms, tend, it turns out, to be more like writers. They’ll extrapolate anything, grow anywhere, make a meal out of metaphors of food.

Bruce Rittmann studies microorganisms and how they can do for us what we could do but don’t do for ourselves. As chemists and biologists working for Dow Chemical, Dupont, Johnson & Johnson, Merck, the FDA, the USDA, and Monsanto develop new chemicals, Bruce and his team of graduate students and post-docs work to figure out what to do with those chemicals once they’ve done their job and have been flushed down the drain.

When you think of microorganisms, the idea of them cleaning water seems counter-intuitive. Aren’t the people who buy anti-bacterial everything trying to get rid of microorganisms? Aren’t microorganisms in the water the thing you’re trying to avoid?

It’s important, Bruce notes, “that you understand that the environment under which some microorganisms are helpful and the environment under which some microorganisms do damage. It changes everything. Same is true of pollutants, of course. Some microbes, in some instances, are dangerous. Different microbes, in the same place, do good.”
Bruce studies place as much as he studies slime. There are so many microorganisms that most of them aren’t even named. But, Bruce clarifies, we don’t necessarily need to know each one, individually. We’re trying to get to know the microorganisms discretely enough that we can know in what instances some microorganisms can do. We’re creating the opportunity for the microorganisms, whoever they are, to do some good work by giving them a place and a circumstance in which to do it.

Bruce says, “The basic science is to create an environment for the useful microorganisms to thrive.” He tells his students to “Grab the low hanging fruit” or even better, to keep their eyes open for “falling off the log technology,” which means looking for opportunities to find obvious solutions, looking for no-brainer moments. “Not fighting nature but working with nature—follow the pattern of nature, work with natural tendencies and ecosystems.” Although scientists rely on singularity in the labs, in this case, a little artistic generalization happens when they apply the science to the scene.

Convincing microorganisms to help humans out is old science. The idea of aerating wastewater for some microbes to “reduce” and oxidize contaminants1 is as ancient as the Romans. It is also old science to then cap the waste and let the anaerobic microbes take over. Aerobic and then anaerobic microbes. The Romans didn’t quite know that there were tiny creatures making dirty water clean again but they knew that exposing sewage-rife water to oxygen for a given amount of time and
next, shutting off all oxygen to the sewage, transformed their water back into something potable and not-bad-microorganism-ridden.

All water on earth is treated to a similar process—naturally filtered by sands, through evaporation, in the stomach juices of an oyster. There’s only one water. We are all, in effect, drinking dinosaur pee. But what Bruce does takes cleaning this water aerobically and anaerobically to the next level. Those things like nitrates and the Superfund site contaminants like rocket fuel and dry cleaning fluids? Bruce has found microbes that can reduce these contaminants.

Bruce’s process is simple. He follows the principle, what does nature do in nature? And then he extends the metaphor. The first question he asks is what is a particular microorganism’s physiology and metabolism?

“To get a bit anthropomorphic—what motivates a microbe? All organisms work the same. Humans, at the high end of the food chain, need to eat a lot of highly caloric, high-energy food to make the complex systems work. To get the max energy out of them. Microorganisms are at the low end—they can exploit the tiniest bit of energy. Methane for instance. A microorganism just needs a little to be encouraged to respire, eat, reproduce.” The microorganism methylbakter tundripaludum uses methane to build new cell material and to produce energy and has been used to oxidize methane in landfills and soil. There’s hope though that as the climate warms, the bacteria will help compensate by growing and consuming more methane. But it needs oxygen to work and, if global
warming persists and permafrost melts, the bacteria might drown. Then the work they do to reduce global warming will be, thanks to global warming, put to an end.

I asked about microorganisms reducing the oil plume in the gulf. What were they doing before all that oil burst forth from BP’s pipeline? He explains that oil has always been seeping from the ocean floor. Now there was just more of it. To the microbes on the ocean floor, oil is regular food. (The food metaphor seeps in—even with Bruce. Scientists like metaphors too). But when more of it poured out, when the pipeline cut loose from the ocean floor. It was like they were being served doughnuts. Too many oil-eating microbes may be bad for the ecosystem just like too many doughnuts may be bad for the human digestive system. Bruce says the protozoa will eat the microbes and so on and so on. Changing the ecology but not necessarily ruining it. Hopefully. It could go bad. They microorganisms, as they multiply, could denude the ocean of oxygen, or make it overly acidic, or affect the protozoa, then the protozoa-eating fish, then the fish-eating fish, then the bird-eating birds, then the bird-eating alligators with oil-eating microbes which may or may not be a good diet for the fish, birds, or alligators. Like butter or chocolate or bacon, even good things can be too much of a good thing.

A senior advisor at the White House called Bruce during the Gulf Oil spill for some science advice. People were trying to sell the government microorganisms to pour into the ocean. He told the advisor
it was probably a bad idea for two reasons—one, you’d need so many and
two, that by the time whoever was selling could grow them, they will
have naturally grown themselves. He thought it looked like a good way
for microorganism-researchers to make a quick government buck.

“It’s important to remember that some microbes naturally do this
work,” Bruce said. Some microorganisms abound or lay low depending
on the circumstances, for instance, a BP refinery explosion that, in turn,
makes their population explode. Finding the right microorganism, Bruce
said, isn’t usually that hard. There’s usually more than one that will do the
trick. That’s why they don’t have to name each of the individually.

Maggie’s Farm, Farmville, USA

Microorganisms reduce nitrates found in crop fertilizer. Bruce has
found several microbes that, if introduced to a nitrate-rich environment,
will begin to exchange that nitrate for food, reducing the nitrate in the
drinking water.

Nitrate, NO₃ comes from fertilizer. Fertilizer runs off agricultural
fields into the neighboring ground water, into the neighboring rivers. By
the time the fertilizer makes it back downtown to the water treatment
plant, the water, in the form of run-off, in the form of rivers, in the
form of sewers, in the form of storm drain, has carried past home and
home and home. Now that the suburbs have become exurbs, farmland
and homestead are neighbors once again like they were in the idyllic
agricultural past when houses and farms abutted, although now in a much more Costco-sized manner. Big houses. Big, agricultural fields. Big fertilizers.

Fertilizer isn’t any newer than the home-farm connection. Humans have been using organic compounds to feed their plants since the beginning of gardening. If you have a choice between planting a seed in black, rich, manure-rich humus or in sandy, gray, flat, dirt, the black soil is the obvious choice. What’s not so natural are synthetic fertilizers. These are made from a combination of ammonia and urea which provide all kinds of macronutrients—primarily, nitrogen, phosphorus and potassium, and secondarily, calcium, sulfur and magnesium—and some micronutrients—in this case, the trace minerals boron, chlorine, manganese, iron, zinc, copper, molybdenum, and selenium.

Without the inorganic and synthetic fertilizers developed in the past 150 years, the population would probably be half what it is today. Population explosion, awesome or awful, is nevertheless filled with awe. Thanks to the development of nitrates produced on an industrial scale, nitrate-fertilized crops support half the world’s population through its extreme chemical maneuvers. Sprinkle it on lettuce, tomatoes, cabbage and watch your vegetables grow and grow and grow.

That big, booming carrot in your vegetable crisper would be a tiny little thing without artificial nitrates. It also probably took a barrel of oil to grow that carrot as big as it is. Organic carrots are spindly
and curvy and not as bright orange. Chemical manipulation helps to sculpt wayward-growing carrots into perfect, Bugs Bunny-seducing, supermarket carrots. Once, I took a carrot from the farmer’s market to my grandmother when she was living in an assisted-living apartment, with its one-bedroom attempt to look like it wasn’t adjacent a nursing home, but with the nursing home smell percolating over the transom and under the door. (Please note the gas-guzzling I myself did, driving to the farmer’s market, driving back to my mother’s. The farmer’s drove their trucks from their farms to the square. It is not an entirely guilt-free carrot.) The dirt from the bunch of carrots put a dent in that smell. And although her hips were no longer her own, her teeth were. She bit that carrot like she wasn’t going to die within the month. She bit that carrot like she remembered pulling them from her backyard garden. She said she hadn’t tasted a carrot like that since my dad was a kid.

But no one lives by carrots alone, even big, bulky, synthetically fertilized carrots. The crops that are propping up the global populace are wheat and corn and rice. And when you’ve got so many crops to feed and such a record population to grow, you don’t skimp on the good stuff. The farmers use enough nitrates to grow an extra planet. And the nitrogen that the Bugs Bunny-worthy carrot, or wheat, or corn, can’t absorb is left behind on the fields.

In the west, nitrate stays behind on the fields in dry form, at least until the monsoons. When the rains come, the nitrate that has been
sitting on top of the soil, on top of the neighboring crops, on top of the crops that have yet to be harvested, is flushed. Flushing implies a cleansing but like all cleansings, the water has to go somewhere. The rain takes the nitrates into the streams that contribute to the rivers that flow to the Colorado, that, on good years, flow into the Pacific Ocean. Some of the nitrates, on their way down the Rocky Mountains and under and across the deserts are left behind, changing the cornflowers, the sage, and the chaparral in the coastal forests. The animals eat the nitrates too in high altitude lakes in Estes Park Rocky Mountain National Park, in Lake Tahoe, in Mirror Lake in the Uintahs in Utah. The deer drink from those pristine-looking lakes. The fish swim in them. Owls dive-bomb the fish. The nitrates, like the PFOAs, persist in the most tucked-in folds of the wilderness.

Along the way to the ocean, the nitrates seep into ground water. They end up in wastewater treatment plants. They end up back in the drinking water—you might taste them, if you’re highly sensitive to the flavor of ammonia. You might gravitate toward them if you like a clean tongue and hope to one day adapt toward photosynthetic capabilities.

Nitrogen balance is tricky. Nitrogen in soil is good but too much is bad. Nitrates in your food may be unhealthy. Too much nitrate in your blood is bad, especially for babies. If they get too much nitrate in their system, the nitrate is converted to nitrite in the infant’s gut, a place where it inhibits the baby’s growth. Some research has suggested that
when the nitrite combines with hemoglobin, it forms methemoglobin, limiting bloods ability to carry oxygen. They call it blue baby syndrome. Most babies need as much oxygen as their blood can get them, especially prematurely born infants who are prone to other cyanotic diseases like respiratory distress syndrome. In fact, too much nitrate in the water can make a regular-term baby act like a premature one, requiring doctors to keep the baby in the hospital and deliver oxygen nasally. Sometimes these babies require transfusions. Methemoglobinemia can easily be treated with supplemental oxygen. But, if you’re living in the world of too many nitrates in the water, treating the symptoms isn’t really a cure.

*North Dakota by Fall*

It’s not that the farmer wants your baby to turn blue. The farmer doesn’t even know where his carrots are at the moment. Or his wheat. Or his corn. He no longer stands on the porch of his farmhouse and look over his crops. He no longer digs his hand into the dirt or breaks his knuckles on rock to see if this is the exact right consistency for fertility. His grandfather could weigh the amount of nitrate and phosphate and potassium by the heaviness of the dirt in his hand, in the way a granule turned upside down reveals its mineral content. By smelling it, he knew if there was a good amount of copper, selenium, iron and zinc. It’s not that his senses equaled the precision of a mass spectrometer. It’s more
that he knew what the ground was supposed to feel and smell like. He put some in his mouth to taste its balance.

To grow crops plentiful enough to feed not the hundreds but the billions, you would need millions of farmers to go into the fields and taste the dirt. There are not that many farmers. No one has walked on the fields where they grow these things in a long time. A company of threshers starts the harvest in mid-May and works its way up by tractor to North Dakota by fall. The semis drive their tractors from large farm to large farm. The men climb from truck to thresher. The threshers spin across the fields, in mile-wide formations, cutting across fields as easily as a man shaves across his cheek. The only difference the tractor-drivers note is that their coffee at Dunkin Donuts tastes sweeter below the Mason-Dixon line, that there are more Starbucks on the coast, that Tim Horton coffee rules the north and northeast.

The nitrates mostly come and go through our bodies with no absolute effect on our health—cancer predictions haven’t been substantiated—but they don’t just reside in our bodies. Like everything else, they’re flushed back into the world, down the drain, into the sewer, to the wastewater treatment center where they go back into the rivers, into the ground water, toward the ocean where they do more effective harm to fish than they do to people. And then the people eat the fish and the oceans rain the rain and the story abounds and resounds and
accumulates and accumulates in the soil, in the water, in your baby, in your fish, in your flesh.

The air wants its nitrogen back.

Dr. Bruce Rittmann honors the air’s request. His metaphor of grabbing-the-low-hanging-fruit, of falling-off-the-log logic, of just follow nature’s true course pays off. It’s not, usually, a matter of finding the one right microorganism—there are many good ones and they’re hard, even for his discerning genius, to tell apart. It’s when he introduces microorganisms from one environment into another that the magic happens. A wide-variety of microorganisms are able to transform nitrate. They just happened to live somewhere else and ate whatever conveniently surrounded them. The microorganisms didn’t even know they liked nitrate. But Dr. Rittman, by giving them an opportunity to try it, finds out they do. With little effort on their part, they turn nitrate to nitrogen gas. Microorganisms are low-overhead. Bruce contrasts them to humans. “People like nice wine. Some of them will buy a three-hundred-dollar bottle because they like it. They think it tastes good. They think it’s worth it. But microorganisms don’t care. They’ll drink your three-hundred-dollar bottle but, just as easily, they’ll drink boxed wine. They’ll drink malt liquor. They are not too particular as long as you give them something to eat.” Microbiologists and writers seem to share a love of metaphor. And wine.
Just like those oil-eating microbes used the oil as sustenance and converted it to something less toxic so did these microbes reduce, in the chemical sense of give electrons to as well as to reduce the contamination itself, the nitrate in the soil. These just needed to be persuaded to the deliciousness that is nitrate. They not only like the taste, they need it. Even if you’ve grown to like nitrate-tasting carrots, your body can’t do anything with that extra nitrate. The microorganisms can.

**At the Cleaners**

Dry cleaners used to clean clothes using trichloroethylene (TCE). Although TCEs were phased out in the fifties, they were an amazing solvent, dissolving grass stains and blood stains and all kinds of slime stains away. But TCEs contaminated soil, so that when it rained, much like the nitrate, TCE leached into ground water. A good percentage of it resolved in the air, meaning it rained down again. But even though TCEs were replaced by PCE, tetrachloroethylene, the bad news is abundant. One highlight, from the EPA website, reads, “Effects resulting from acute, inhalation exposure of humans to tetrachloroethylene vapors include irritation of the upper respiratory tract and eyes, kidney dysfunction, and at lower concentrations, neurological effects, such as reversible mood and behavioral changes, impairment of coordination, dizziness, headache, sleepiness, and unconsciousness.”
This is acute, meaning direct, contact. But studies have also shown that there are severe reproductive and developmental effects that include spontaneous abortion, menstrual disorders, altered sperm structure, birth defects and fetal resorption of tetrachloroethylene with casual contact.

A woman I know married a man who ran a drycleaner. After her seventh miscarriage—each in the fourth month—just at the time when she was getting used to the pregnancy, just when she was almost convinced that fetus might stick around this time, just when she started wondering, is this body growing on its own? She gave up trying to stay pregnant. Whatever forces were conspiring for the fetus to grow met head-on with forces that prescribed the ways of water. Gravity happens. Gravity, with a little added PCE, is a force she had to learn to live with. Once upon a time, maybe, her body, its inertia, its biological drive toward new life, could have resisted gravity. But now, gravity colluded with more target-specific forces.

There’s no certain way to blame the PCEs for her miscarriages. For all we know it could have been PCEs in the water or any string of chemical compounds, or, of course, nothing chemically induced at all. Although scientists working with Bruce are currently compiling the database to correlate Superfund neighborhoods with numbers of hospital visits, correlation isn’t the same as cause and effect. There are enough unnatural entities in the water to blame the water generally, not the PCEs or TCEs
specifically. There are enough unnatural entities in the air to blame the air. When you’re so pregnant-tender that you can’t even wear a tight shirt for the pressure it exerts against your breasts, it feels natural. When you are eating a saltine cracker as you lie in bed too nauseated to get up, that feels natural. When you fall asleep, head on the kitchen table, right after lunch, waking up with sandwich bread stuck to your forehead, that feels natural.

What feels unnatural is the unraveling of your belly button, the tug of an ovary, the stitch in your side that you weren’t supposed to feel again for nine months. It’s easy to blame unnatural forces for miscarriages. Spiteful, naked, you sit on the bare dirt, bleed into it, and give back to the earth the bad dirt it gave to you. Maybe it was the dry-cleaning detergent. Maybe it was the rocket fuel. Maybe it was a natural unwinding to an inevitable unwound ending. But, if you get pregnant next time, you filter your water. You hope there are some of those TCE-oxidizing microorganisms thriving naturally in the ground water outside your house. You hope they find a PCE-adapting microorganism. You adapt a little yourself. You make your dry-cleaning husband wash his clothes in regular laundry detergent before he comes to bed. It’s more of a superstition than a remedy, but you would like to pretend you have a little control over the territory of your body.
Rocket fuel and semi-conductor production have left perchlorates all over the southwest like an invasive species. At Superfund sites, Bruce and his teams of graduate students have released several key microorganisms to reduce the level of contamination. These microorganisms do the hard work the forest rangers do, but on a chemical, rather than physical level. The ranger pulls at an invasive Tamarisk tree. The roots have locked themselves deeply into the southwestern rivers banks. The ranger’s hands are raw, her arms ache, but she is ebullient, effervescent with her accomplishment. Tamarisk produce a million seeds a year. They steal the water from the indigenous plants. They crowd out the natural flora, thereby killing the native flora. Tamarisk are a macro problem. It’s easy to be ecstatic when stuffing one into the coffin of a plastic bag. The microorganisms know that ebullience if not that ecstasy. They throw their electrons off onto those invasive perchlorates. They dig their ecological mission, if only because it makes them light and airy and bubbly as club soda.

Finding microorganisms that love living in the places where perchlorates and nitrates flourished was relatively easy for Bruce. Microorganisms exist in all kinds of places: in ponds, in the dirt, on the edges of pine needles, on your eyelashes, at the bottom of the ocean, in the extremely briny water of the Great Salt Lake where they’re called extremophiles. Microorganisms from all over the place, so many different species of microbes, love the taste of nitrate and perchlorates.
But tetrachlorethylene, the dry-cleaning solvent, has no natural microbial partners. When Bruce says, “follow nature’s path, do what nature does,” that works well for nitrates since there are so many microbes able to help out. But perchlorate is different—only one or two strains within the species were able to do the work. Bruce needed to physically supply the contaminated area with the microbes instead of, as he had done with nitrates, creating a more ideal environment for the organisms.

Is there anything these microorganisms won’t do? Answer: yes. See triclosan. Also PFOAs. Also titanium oxide—the teeth whitening agent in your toothpaste. But Bruce is working on finding good microbial partners for them. Until then, I throw out my non-stick pan. I let my scrambled egg pan soak. My teeth. They’re a little yellow but my husband doesn’t notice. I don’t need titanium oxide. I want my gut biome to keep me from getting Crohn’s disease but every soap I find has triclosan. So I just stop using soap.

**Oasisamerica**

Microorganisms: work, reduce, mitigate, eat, resolve, transfer, chemically react, come to the rescue, at least in certain circumstances. Bruce points out, “They do the same things we do.” They eat. They excrete. They convert food into a different kind of energy. In the right place, at the right time, they do good work. They also, from the human perspective, do plenty of bad work: cholera and botulism, just to name a
few human-destroying microorganisms. The concept of good and bad is, of course, a human one. The microorganisms are just doing their thing, eating, reproducing, respiring.

Between the 7th and 14th centuries, the Hohokam built a system of canals between the lower Salt River and the middle Gila River to irrigate what is now known as the Phoenix basin. This irrigation system rivaled in complexity those built in ancient China, Egypt, and the near East. People have been organizing and reforming water for centuries, for better or for worse. Now, one additional problem we have, toxins in our water, has a potential, if partial, solution. The microorganism, borrowed from another scene, returns that perc-ridden water to Hohokam-fresh water.

This is a good thing for the microorganisms to do for humans. It is a natural thing for microorganisms. The ideas of good or bad don’t trouble the microbe. It is bad thing when botulism bacteria colonize digestive tract, causing first, the eyelids to droop and flicker, then making it hard for the baby to move his arms, then, in severe cases, making the exchange of carbon dioxide into oxygen in the blood difficult, then impossible. The botulism doesn’t think this is a bad idea. Its colonization of the digestive tract is the same as its colonization of fields of nitrate. In fact, even in a field of nitrates, the microorganisms might run amok, over-reproducing and over-colonializing, causing their own kind of damage, like algae blooms that choke the oxygen from reaching plants or fish. But, in a different environment, a little botulinum toxin produced by
*Clostridum botulinum* can reduce the wrinkles around the eyes. Pressed. Skin. Managed microbes.

The concern of course is that we keep pretending humans have foresight. This microbe helps now. Will it help later? Miles of pens of salmon rattling against Chile’s coast, radiation seeping from the Fukushima Daiichi nuclear plant, dumping toxins into well-water, into streams, into oceans, cutting down forests to make paper, to grow cattle for meat, idling our cars in the drive-thru and leaving the lights on all night, making the atmosphere hotter, thawing ice caps, making the polar bears swim.

Microorganisms eating perchlorate are as self-serving as humans cutting down pollution filtering forests to grow cows for meat. Microorganisms do what they do and we do what we do. Microorganisms are happy eating and respiring whether inside a dented tin can or a seep of perchlorate. We enjoy our carrots fat whether we’re next to the farm or in the North Pole.

We are, as far as the planet is concerned, microorganisms—we harm the planet, we fix the planet, we do and undo. Microorganisms, like people, are persuadable. Microorganisms are adapters, fixers, heroes, destroyers, builders, recyclers, breathers, eaters, reproducers. They adapt to the environment. They adapt the environment to suit them. They have the capacity to change the chemical make-up of the planet.
But the metaphor between humans and microorganisms breaks down when you think about place. When the microorganism runs out of food, it stops adapting, it stops respiring, reducing toxins or reproducing selves—it slows down. It eats less. It self corrects. There are limits to its ability to create its own environment. Microbes can’t get in a car and move to the next delicious Superfund site or to the next dented tin can. Someone, be it a human, an animal, a waterway, or a microbe-transporting breeze, has to take it there.

Humans, self-propelling, if not self-correcting, take themselves everywhere—they bring the carrots, fat and pointed, with them. They plant the carrot seeds in whatever soil they choose. They pump the nitrates into the soil. They hope they discover a microbe that turns their water back into unadulterated toxin-free water.

Notes

1. I would like to call what they do “eat” but no one likes to think of things eating sewage, not even microorganisms. In chemistry, “to reduce” means to add electrons. This is one reason it’s hard to translate chemistry. Eat is a metaphor and it’s not exactly right although the scientists seem to use “to eat” as shorthand for what the microbes chemically do. Reducing adds electrons, which chemically changes the pollutant from noxious to null. To reduce by adding is counterintuitive but then so is sending slimy things in to
fight even grosser things. As my chemist friend, Gabe, clarifies in a micro-
essay of his own, “When I apply the word ‘eat’ to bacteria, I’m tending to
think of the process of extracting energy from food, but of course a broader
perspective would appreciate that we’re breaking up the food (usually a
process during which the food molecules ultimately get oxidized) but
then we’re building new pieces of ourselves (often a chemical reduction).
If your use of the term ‘eat’ encompasses both, then it’ll have to involve
both oxidation and reduction. If you rather separate the two ideas, then eat
means I burn the food I eat for energy (almost non-metaphorically true,
as the chemistry of burning sugar and metabolizing sugar give identical
products).