From sewage sludge to biosolids: Building the case for waste

By Kristen Coyne

September 6, 2022

A Superfund site at a former mine in Leadville, CO, before it was treated with biosolids and lime. Photo by Chuck Henry.

Half a century ago, in response to burning rivers and other high-profile environmental disasters, the U.S. Congress passed the Clean Water Act (CWA) as a means to protect waterways from sea to shining sea. Commemorating that landmark legislation, the *Journal of Environmental Quality* this year has published a collection of papers celebrating the CWA. *CSA News* is highlighting some of that work through a three-part series.

Last month, we looked at recent research (**https://doi.org/10.1002/csan.20828**) on how constructed wetlands can decrease nutrient runoff on tile-drained agricultural fields. In this second installment, we examine how the CWA gave birth to and shaped the science around biosolids and present what scientists have learned about how this treated human waste can efficiently fertilize crops, rehabilitate contaminated mines, and boost soil health.

Research over the decades has drawn attention to biosolids' many benefits and improved their application. But while that work has laid many concerns about its safety and efficacy to rest, "forever chemicals" are raising new questions about its use.

When soil scientist **Sally Brown** first saw it, the area near the Upper Arkansas River outside Leadville, CO, was barren and lifeless. It was so littered with metalcontaminated tailings that the USEPA had named it a Superfund site. One could hardly call the stuff on the ground soil. When Brown tried to grow grass on it, it died. When she tried to populate it with earthworms in a lab, they perished.

As it has done at other Superfund sites, the USEPA could have paid a lot of money to haul the toxic tailings away. Instead, they allowed Brown and her colleagues back in 1998 to spread the area with about a foot of biosolids—specially treated sewage sludge—that had been trucked 100 miles from a Denver wastewater treatment plant and mixed with an equal amount of lime.

Just one year later, the place was transformed. As documented in a **2005 *Journal of Environmental Quality* (JEQ) study**, ryegrass carpeted the ground and tests showed decreases in biologically available lead, cadmium, and zinc in the amended soils as well as telltale signs of microbes. The voles and shrews that returned to the area had relatively low levels of cadmium and lead, and minnows exposed to the treated tailings fared far better than the ill-fated control exposed to untreated tailings. It was a veritable ecosystem Cinderella story with science supplanting the fairy godmother.

Photo by Mike Zimmerman, USEPA.

“You get to see something barren turn green very easily and simply,” recalled Brown, an SSSA Fellow and professor at the University of Washington who conducted similar research at Superfund sites in Missouri and Idaho. “There was no need to go back and reapply."

Brown is among a cadre of biosolids boosters who have devoted their careers to what is essentially recycled human poop. Over the decades, they have applied the stuff to crops, rangeland, fire-ravaged forests, contaminated sites, and urban areas and then studied its nutritional and restorative powers. They have worked to ensure its safe and effective use, advising the government on thresholds for trace metals, pathogens, and harmful chemicals. They have partnered with landowners, government agencies, and wastewater treatment facilities (WWTF) to inform best practices and educate anyone they could get to listen about a product most of us are primed to regard with disgust.

For decades, tailings from mining operations in Colorado were discharged into the Arkansas River, where they settled out in alluvial deposits. These alluvial tailings deposits near a former mine in Leadville, CO were highly acidic with elevated concentrations of cadmium, lead, and zinc. This area had been barren for over 50 years prior to the biosolids remediation. Photo by Mike Zimmerman, USEPA.

Recently, Colorado State University (CSU) soil scientist **Jim Ippolito** looked back at more than four decades of biosolids research (**https://doi.org/10.1002/jeq2.20376**) as part of a JEQ special issue commemorating the 50th anniversary of the Clean Water Act (CWA), which paved the way for widespread use of biosolids in the U.S. He and co-author **Ken Barbarick**, both Fellows of ASA and SSSA, viewed dozens of papers dating to the 1970s. Back then, it was still called sewage sludge in the literature, many farmers were afraid to use it, and lawmakers had yet to amend the CWA to include comprehensive regulations on how to treat and apply it. Ippolito follows the arc of that research through the present, as the focus shifted to soil health, evidence mounted on the many ecosystem services biosolids provide, and decades of data strengthened the case for their long-term benefits. Considering biosolids' potential for storing carbon and offsetting the planet's loss of **36 billion tons of soil a year**, this research is arguably more critical than ever.

“We have documented proof, not just in Colorado but all over the country, of the important role that biosolids play,” Ippolito says, “in terms of improving crop growth and plant growth and stabilizing soils and immobilizing heavy metals and trace metals in the environment, so they don't move into ground water.”

But new challenges have emerged that threaten biosolids' use. Chief among these are per- and polyfluoroalkyl substances, or PFAS, the “forever chemicals” **associated with a wide range of health problems**. Used in a wide array of products for decades, they are now found virtually worldwide in animals, water, soil, air, and, of course, our blood and poop. Their presence in biosolids has raised scientific and policy questions and prompted cost–benefit debates that have, in some communities, resulted in restrictions and outright bans.

Here we provide a broad overview of how biosolids research has evolved, highlighting work by some of the leaders in the field and noting the challenges that loom ahead. We'll start by traveling back in time to the birth of “biosolids.”

When Biosolids Became a Thing

Humans have recycled their solid waste as fertilizer for centuries. Still, before the U.S. Congress passed the CWA, there was little in the way of infrastructure or regulations supporting its use in the country. Essentially, explained Ohio State University (OSU) soil scientist and biosolids expert **Nick Basta**, “We didn't *have* any biosolids. We discharged everything into the rivers or into Lake Erie.”

When it became law in 1972, the CWA's priority was cleaning up the effluent being released into the nation's waterways, which required removing the solids. Billions of CWA dollars were spent to build and modernize WWTFs for this purpose. Other than prohibiting its disposal in or near water, the CWA had little to say about sewage sludge at the time.

Biosolids use varies by state. In Florida, more than half of all biosolids generated in the state are processed into the highest class of biosolids, like the product shown here fresh from the Thomas P. Smith Water Reclamation Facility in Tallahassee. Photo by Kristen Coyne.

That, of course, would change because the act led to a surge in sludge production, which **almost doubled between 1972 and 1993**. "That's what generated the biosolids," explains Basta, an ASA and SSSA Fellow. "Then it had to go somewhere, right? So, land became the place."

Some biosolids were shipped to the landfill or incinerated. But spreading it on land was a relatively cheap alternative that, as a bonus, could fertilize crops and condition soil. In those early days, the surfeit of sludge, imperfect understanding of its constituents, and lack of regulations led to what one researcher once called "the wild west" of biosolids use.

Soil scientist Jim Ippolito (right) has studied biosolids in Colorado for more than three decades. Here he is in 2019 with Liping Li of Henan University of Technology (left) and Travis Banet (center), now a Ph.D. student at the University of Kentucky. The three are at a former mining site that had been treated with biosolids and lime in Leadville, CO. Photo by Jim Ippolito.

"That's where research came in and said: 'Stop. You have to clean up the act,'" Basta says. "'Get the metals out of the sludge.... We've got to make a clean product.'"

In 1993 the USEPA, aided by **a group of land grant university experts in biosolids** supported by the USDA, issued **new regulations** on treating and applying biosolids, ushering in a new era of biosolids research and use. That year, about one-third of the 5.3 million dry metric tons of biosolids generated in the U.S. was used on land for beneficial use, mostly agriculture. Just five years later, the country was generating 6.9 million dry metric tons of the stuff, and 60% went to beneficial use.

The fate of biosolids varies considerably by state, according to 2018 numbers from the **National Biosolids Data Project** (NBDP). Connecticut incinerates the bulk of it, for example, while Kentucky sends most to the landfill. In **Colorado**, by contrast, 86% of biosolids go to beneficial use, most of it in agriculture.

While scientists have conducted important biosolids research in places like Maryland, Pennsylvania, and Ohio, forces combined to make Colorado a pioneer in the field.

The Colorado Sweet Spot

Not that biosolids research was universally embraced in the state. Ippolito recalls how, as a young researcher green as a soybean shoot, his arguments for biosolids left many farmers skeptical.

“I just remember a lot of people going, ‘Well, that’s interesting, but I’m not gonna put that on *my* land,’” Ippolito recalls.

But eventually scientists found partners in the state’s more progressive pockets, where a reverence for the land bred an open mind for recycling waste, Ippolito says. This included places like Fort Collins, Steamboat Springs, and the Littleton/Englewood area south of Denver where the USEPA funded a new, CWA-compliant WWTF dubbed **South Platte Renew**. For decades, CSU researchers have studied and informed the plant’s application of biosolids to some 10,500 acres of farmland it owns.

“Partnering with CSU increases the transparency,” says Blair Corning, deputy director of environmental programs at the plant. “When you go show the city councils or your governing supervisory committee a picture of crops fertilized with biosolids next to crops fertilized with commercial fertilizer, and you can see the difference in the one side versus the other, it really sends a message that, ‘Look: Ph.D.’s are looking at this, and it’s verified that it’s beneficial.’”

The diversity of terrain in Colorado provided researchers with a variety of testbeds.

“In Colorado, we have everything,” Ippolito says. “I mean, we grow corn. We actually grow soybeans in Colorado, but we have prairies. We have short-grass and we have mixed-grass prairies. We have agroecosystems, we have rangelands, pasturelands, disturbed lands, mined lands … which just makes this state kind of the sweet spot, if you will, for land application of biosolids.”

In the early 1990s, CSU began partnering with Fort Collins to study biosolids on city-owned rangeland. Years of overgrazing had opened the door for barrel cactus and prickly pear to usurp the short-grass steppe ecosystem. Barbarick, Ippolito, and others wanted to hone in on the optimum application rate.

After experimenting with a range from zero to 15 dry tons per acre, the researchers found that a sweet spot of 5 dry tons per acre produced the best bang for the buck for plant productivity. Underground, the chemistry was also encouraging. The biosolids provided plants a healthy dose of nitrogen and phosphorus, no significant increase in trace metals, and boosted soil carbon and microbial activity. The team did a second application in 2002 (reapplying about every seven years seems to work well there, Ippolito says) and continue to monitor the impressive results.

“What we’ve done is kick-started this system from a baseline of cactus, basically, to something that’s palatable to an animal,” Ippolito says. “And when you have proper managed grazing, which they do at this site, you can maintain this ecosystem at least for 30 years.” The city now applies all its biosolids, about 580 semi-truck loads per year, in rotation across its 26,000 acres of rangeland.

Generally, Ippolito said he’s wary of describing his biosolids results as “resilient” or “sustainable”: He finds the words can be used too casually. But he feels confident applying them to this study. “This is the beauty of having long-term research,” he says.

Apparently, the cows concur. “The cattle actually prefer the areas that have had biosolids applied,” Ippolito says. “I’m guessing it’s likely due to improvements in plant growth that we’ve documented.”

Of course, different sites and conditions call for different practices. Use near water and on steep slopes remains off limits while lower application rates are used on crops. In a long-term study published in JEQ in 2017 (**https://doi.org/10.2134/jeq2016.12.0470**), Ippolito and his co-authors looked at the effects of biosolids on no-till winter wheat in Colorado over 20 years, applying an average of just a few dry tons per acre, depending on that year's nitrogen needs. Ippolito was surprised to see benefits in the soil as deep as 15 cm even though the biosolids were surface-applied. He was even more pleased to see that, in soils typically zinc deficient, the biosolids boosted the wheat's zinc concentrations. With **more than a billion people worldwide** suffering from zinc deficiency, that's an important bonus. Other research showed biosolids boosted protein in winter wheat better than inorganic fertilizer, making the crop more valuable.

Delivering biosolids for land application to a family farm in Virginia. Photo courtesy of Virginia Biosolids Council.

"So here we are," Ippolito says, "sprinkling biosolids out in small doses across the landscape over long periods of time. And we're seeing benefits."

Much of the early work on biosolids focused on getting the recipe right for the plants. "We never ever thought of soil health directly," Ippolito says. "We never said in 1991 that, 'The soil health of this system is going to improve,' as the term 'soil health' wasn't widespread back then."

But biosolids weren't just making healthier, happier plants and cows. Those visible results came from healthier soil, and researchers began to pay more attention to things like physical changes to that soil. The more holistic view has been helping scientists paint a more accurate and compelling case for biosolids.

Sustenance for Soil … and Soul

Ohio State's Basta has studied biosolids at a variety of sites over his career, including cities. At a steel mill-turned-Superfund site outside Chicago, he led a 2016 JEQ study (https://doi.org/10.2134/jeq2015.01.0009) in which researchers applied varying amounts and blends of biosolids and compost to degraded soils. All the treatments improved the soil, supporting native prairie subsequently planted there, but the biosolids outperformed the compost in soil quality, vegetation, and earthworm survivability, according to the study.

Biosolids' benefits to cities stretch far beyond the ground as Basta has been demonstrating through a partnership in Columbus, OH. There city officials are trying to meet sustainability goals by growing more trees, producing more food, controlling stormwater runoff, storing carbon, attracting pollinators, and improving water quality. By applying biosolids to vacant lots, Basta and his students are showing they can contribute to all those goals, he says.

"If you're talking about the Clean Water Act, biosolids here are improving the water quality and reducing the stormwater runoff," he says. "It's stopping erosion. It's increasing infiltration. And we need to document this."

Basta is so passionate about documentation that he designed an entire **class** at OSU around it. While students learn how to use tools like the Soil Management Assessment Framework (SMAF) to evaluate biological, chemical, and physical changes in soils, they also learn to quantify how biosolids help ecosystems meet our human needs. This is a critical step toward convincing stakeholders to support biosolids, Basta argued.

“We know it makes improvements, but we need the measurements,” he says. “Metrics matter.”

In Colorado, Ippolito and his colleagues have embraced SMAF in their biosolids research. For example, in one **2021 study** he and his coauthors drew on more than two decades of data to compare how biosolids and inorganic nitrogen fertilizer impacted soil health on dryland wheat. They found that biosolids significantly improved soil biological health while the synthetic fertilizer had little effect. Currently Ippolito is investigating the same question through a new, six-year study. So far, the data show significantly better soil health for the biosolids-applied lands.

“You start seeing improvements in carbon. You start seeing improvements in microbial activity. You start seeing improvements in nutrient availability. And the list sort of goes on and on,” Ippolito says. “And it’s really interesting because we’re not really doing too much to this agroecosystem. We are hardly putting any biosolids down. But if you add it up over time, it’s causing a really interesting benefit in terms of soil health.”

In addition to advancing the science, metrics help communicate the case that biosolids’ advantages outweigh potential risks. This is especially critical, says Basta, because of one particular risk on everyone’s minds these days: PFAS.

PFAS in Perspective

The practice of applying biosolids to land faces numerous pressures, from urbanization and suburbanization to odor complaints to the USDA’s prohibition on its use for organic crops. While the percentage of U.S. biosolids used for agriculture and other beneficial purposes continued to inch up **between 2004 and 2018**, it remains at about half of all biosolids, well below what the USEPA had once foreseen. And that was before the PFAS alarm bells reached their fevered pitch.

South Platte Renew treats 20 million gallons of wastewater daily and partners with Colorado State University scientists on biosolids research. Photo courtesy of South Platte Renew.

While hardly the first problematic chemicals to end up in the sewer, PFAS pose the greatest threat to the industry to date, according to SSSA member Ned Beecher, former longtime director of the **Northeast Biosolids and Residuals Association**.

"PFAS is the set of chemicals of concern that have created the greatest challenge to biosolids management ever—and by far," says Beecher, now an independent consultant in the field. "I don't ever see anything reaching the same level of concern."

Those concerns have led some communities to restrict and even ban their use as **the state of Maine did** earlier this year. Further muddying matters, the **USEPA has been at odds with its own inspector general on the issue**. The USDA-affiliated experts group, which includes Ippolito, Brown, and Basta, **has defended the USEPA's work and called some of the inspector general's assertions "alarmist**."

"Our industry does not use or produce these chemicals," Beecher notes. "But the wastewater profession and the biosolids profession are trying to deal with it."

As they did with heavy metals in the early days of biosolids, scientists today are applying their expertise to the PFAS problem. And the industry recognizes communication and education on the issue is a top priority, Beecher says. While there are a few cases (including in Maine) of heavily industrially contaminated biosolids causing excessive levels on several farms, according to Beecher, the vast majority of biosolids land-applied across the continent are not significantly impacting farm and garden product quality and water bodies.

“When it comes to beneficially using [biosolids],” Beecher says, “the amount of research, the amount of experience, the decades of work on it, have really demonstrated [their] effectiveness. The measurable benefits overwhelm potential negative impacts, and many, many farmers really benefit and are very happy with biosolids use. … We have to continue to communicate that all the time.”

Sally Brown agrees. The University of Washington professor is dedicating more of her time these days to educating the public about the value of biosolids and other **exogenous organic matter**—“getting people to embrace their waste,” as she put it. This involves highlighting the connections among recycling waste, green urban spaces, environmental justice, quality of life, and the health of the planet. It all starts, she says, with getting your hands dirty.

During a vermiculture project at a prison, for example, Brown was struck by how inmates responded to making soil out of their food scraps. “To witness that transformation,” she observed, “that leads to enhanced knowledge and decreased fear and an understanding that you are part of the process.”

Brown lives in a corner of the country that is particularly open to that message: **Washington has the most robust, long-term support for biosolids recycling in North America**, according to the NBDP. The state applies 77% of its biosolids for beneficial use; almost a quarter of all its biosolids are Class A, most of it "exceptional quality" (EQ), which meets the USEPA's most stringent metals standards. While Class B biosolids target agricultural lands and require a site permit in most states, Class A biosolids undergo additional treatment that makes them safe to use even in home gardens.

South Platte Renew operator Matthew Tafoya takes a biosolid sample to test nutrients and percent solids before sending it to farms for land application. Photo by Faustino Salazar.

Some communities, including Tacoma, WA, **sell these products directly to the public**. The rise in the production and use of Class A/EQ biosolids is up nationwide; **Florida** tops the list with more than half of its product meeting those specifications. At a challenging moment for biosolids, the bump in Class A/EQ use is an encouraging trend. And new findings **on their carbon sequestration benefits** could add big points to the "for" column of the biosolids tally sheet.

"Soil is the foundation of life," Brown says. "But this is *the* tool to make soil healthier."

Dig deeper

Persephone Ma, Aaron Rendahl, Daniel Kaiser, Carl Rosen, Changes in soil test phosphorus and soil cations following application of sewage sludge ash and other recycled phosphorus fertilizers, Soil Science Society of America Journal, 10.1002/saj2.70048, **89**, 2, (2025).

View the *Journal of Environmental Quality* papers referenced in this article:

- “The Clean Water Act and Biosolids: A 45-Year Chronological Review of Biosolids Land Application Research in Colorado”: **https://doi.org/10.1002/jeq2.20376**
- “Meta-Analyses of Biosolids Effect in Dryland Wheat Agroecosystems” **https://doi.org/10.2134/jeq2016.12.0470**
- “Restoring Ecosystem Function in Degraded Urban Soil Using Biosolids, Biosolids Blend, and Compost” **https://doi.org/10.2134/jeq2015.01.0009**
- “Ecosystem Function in Alluvial Tailings after Biosolids and Lime Addition”: **https://acsess.onlinelibrary.wiley.com/doi/10.2134/jeq2005.0139a**

Check out two new episodes of the *Field*, *Lab*, *Earth* podcast to celebrate the Clean Water Act's 50th anniversary: In the first episode, Dr. Alex Chow discusses how we can take a proactive approach to lithium pollution. In the second episode, Dr. Jim Ippolito discusses 45 years of biosolids research in Colorado. Find us at **https://fieldlabearth.libsyn.com** or through your favorite podcast provider. Subscribe for free to never miss an episode. CEUs available.

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