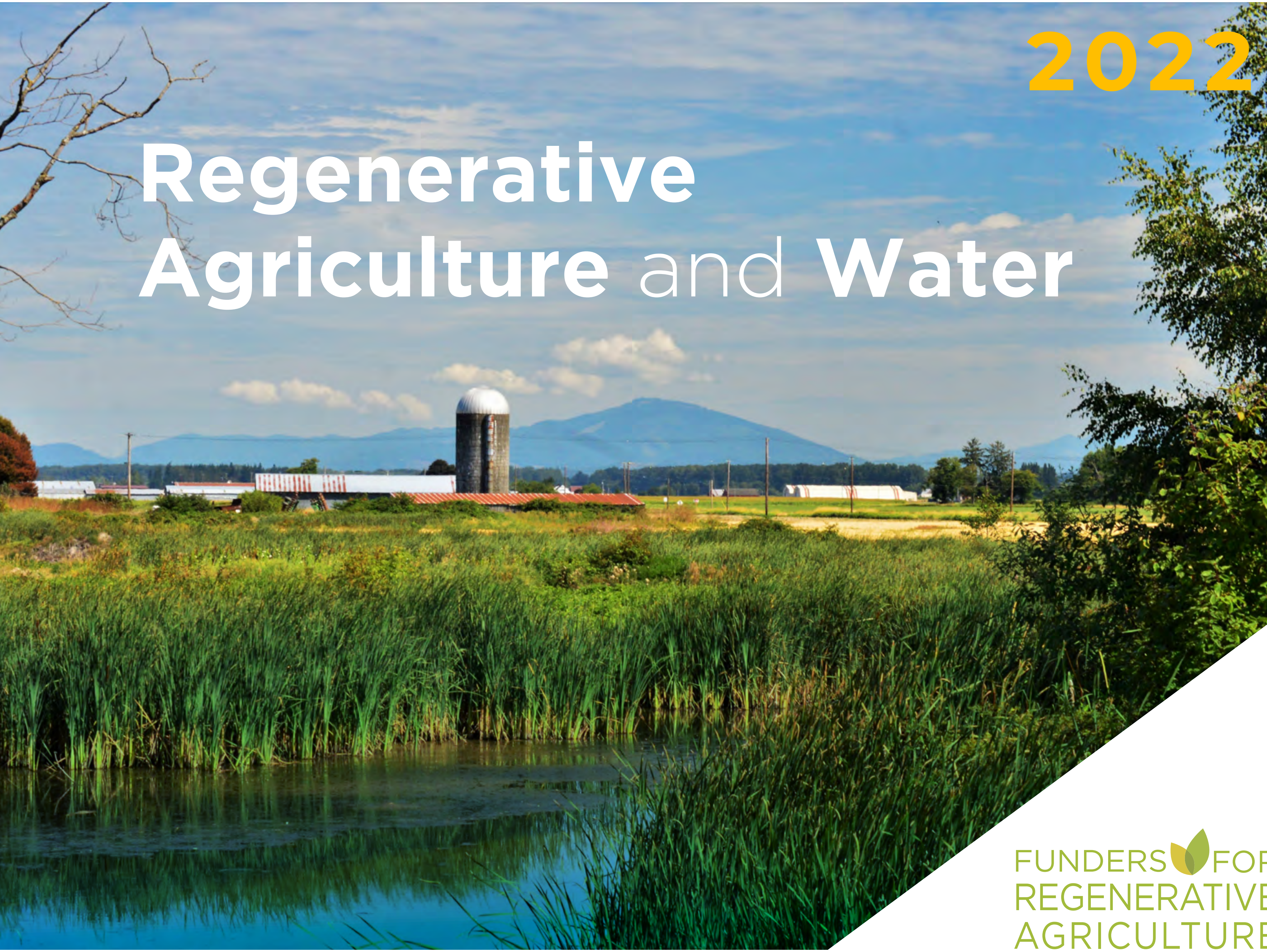
2022

Regenerative Agriculture and Water



FUNDERS FOR REGENERATIVE AGRICULTURE

CONTENTS

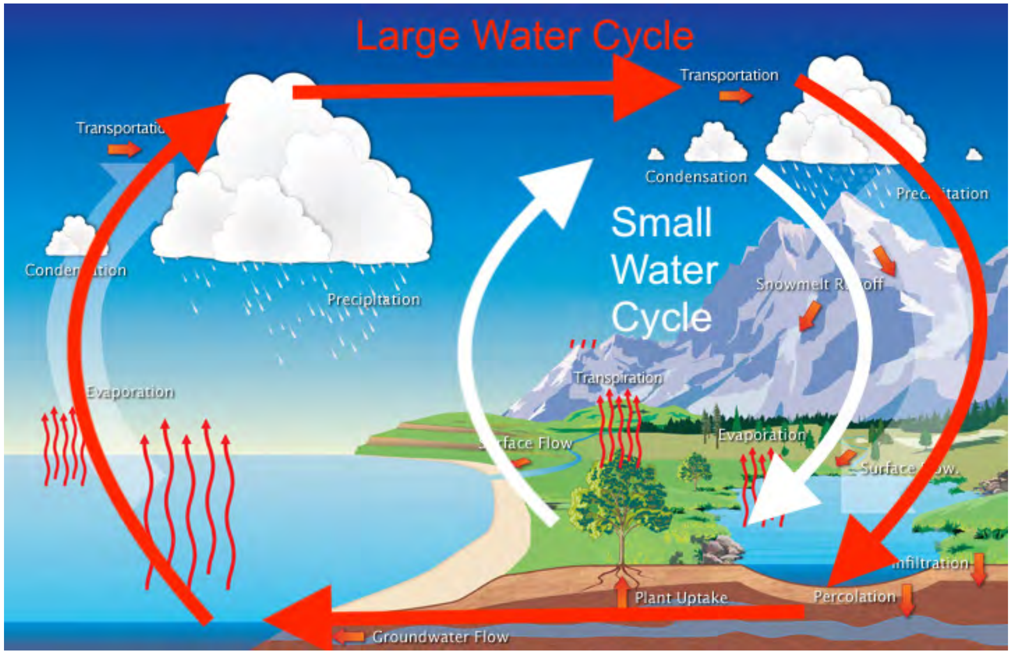
Cover photo: Organic Farm, Credit: Bryan Hanson on Unsplash

OVERVIEW

Regenerative agriculture is key to restoring and maintaining the water cycle, an essential element of life on earth. Regenerative agriculture uses water efficiently, conserving it for future needs, and can keep water cleaner than conventional farming. Its emphasis on nature-based practices helps build resilience, to withstand extreme weather events like floods and droughts. This is especially important in water-based farming systems, such as rice cultivation and aquaculture, which depend on a healthy and abundant water cycle.

The flow of moisture in nature is usually portrayed as a great circle: clouds raining or snowing over land; water flowing down the rivers to the sea; water vapor rising from the ocean surface to the atmosphere where it condenses into clouds that drift over land to precipitate again. This flux between land and sea is the *large water cycle*. However, only 40 to 60 percent of precipitation that falls over land comes from oceans. The remainder originates over land itself.[1] This is the *small water cycle*. Moisture evaporates from lakes, plants, trees, and the soil, making clouds overhead. Often, this moisture falls back to the ground over the area it originated from. If the land is covered with green plants and the soil is a carbon-rich sponge, rain and snow will be absorbed.

Every living thing on the planet relies on water for its existence, from the smallest microbe to the largest whale. Water makes up 70 percent of every cell inside every creature. It is essential to every stage of life. Without direct access to water, an organism will quickly die. Water composes roughly 60 percent of a human's body weight and is essential to maintain healthy organs, reduce body temperature, and process waste. An adult human needs to consume the equivalent of 12 to 16 cups of water every day to stay hydrated. All creatures indirectly need water, as well, from the web of life that supports and feeds us, to the small and large cycles of water on the planet that bring nourishing rain and snow to ecosystems and the communities that depend on them.



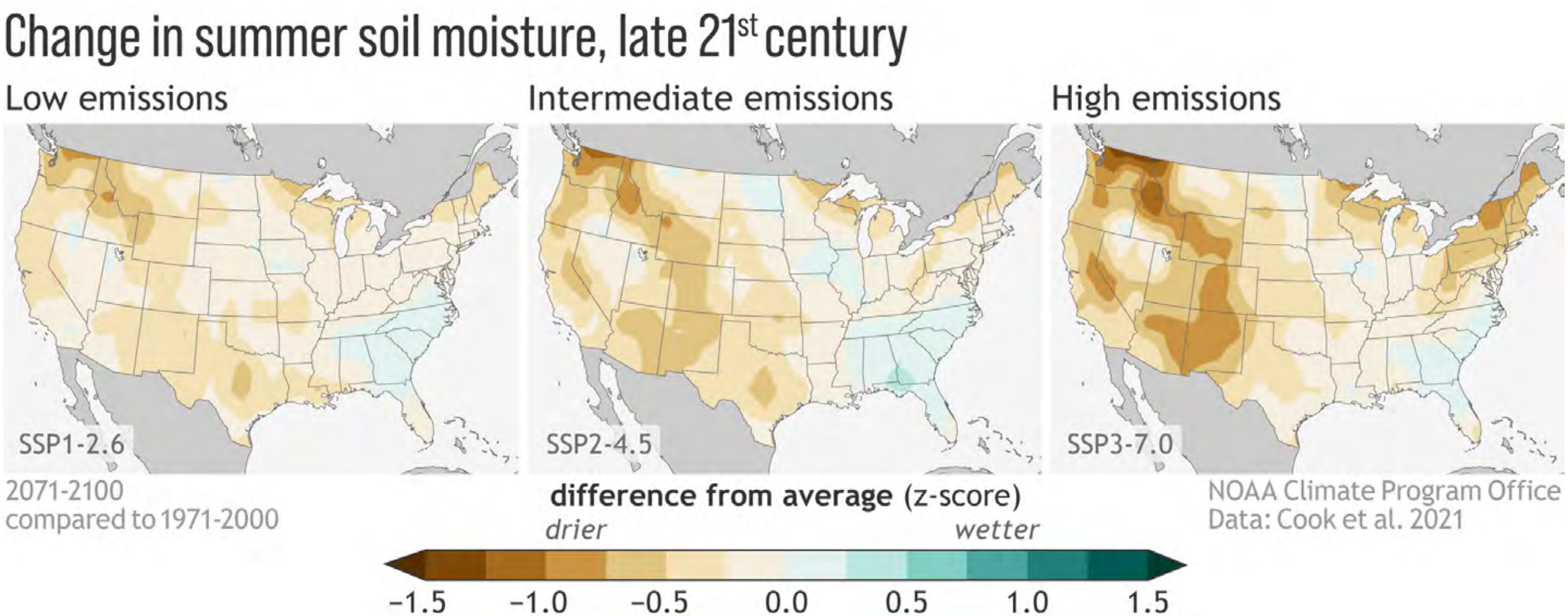
Water Cycle, Credit: NOAA Weather Service

Water, however, is in trouble. Only three percent of all water on the planet is freshwater and two-thirds of that is locked up in ice sheets and glaciers. The remaining one percent is being severely strained by increased demand, prolonged drought, and widespread pollution by agricultural chemicals, antibiotics, pathogens, plastics, and sediments. Over 40 percent of domestic and public drinking water in the US is contaminated with at least one human-sourced agricultural chemical.[2] According to the US Environmental Protection Agency (EPA), sediment eroding from farm fields is the most prevalent source of agricultural water pollution.[3] At the same time, water scarcity affects over 700 million people globally, a number that's growing according to the UN.[4] Nearly one million people die each year from water, sanitation and hygiene-related diseases.[5]

WATER SHORTAGES AND CLIMATE CHANGE

A NASA study identified nineteen hotspots, on every continent, that are experiencing dramatic water declines.[6] These shortages were found to be significantly impacted by industrial agriculture practices, including pumping water from aquifers for irrigation, which, when depleted, compact soil and compromise the viability of these long-term important reserves. The state of California, as a notable example, produces one-third of US vegetable production and 20 percent of the country's milk and dairy output, and is experiencing extended periods of severe and historic drought. Half its aquifers are dangerously depleted, necessitating stringent curtailing of water withdrawals in some instances.[7 8 9 10]

Under climate change, droughts will become longer and more intense, negatively affecting the availability of water in many ways. For example, a projected decline in soil moisture as a result of hotter and drier conditions under climate change in the Southwest will adversely affect crop yields and natural habitat. Soil moisture is essential to plant health and growth. Its decline and loss over time will amplify drought conditions as plants wither and soil succumbs to wind erosion, causing desertification to spread.



Change in summer soil moisture. Credit: NOAA,

PRESSURES ON WATER FROM AGRICULTURAL POLLUTION AND CHEMICALS

Water-related calamities are happening in real time: intensifying storms that destroy property and threaten food security bring floods that cause erosion and increase soil salinity.[11] In some regions, increased heat and aridity are causing crop failures and upticks in pests, diseases and noxious weeds.[12] Many waterways are clogged with plastics whose microparticles have infiltrated a myriad of ocean and freshwater species and our drinking water supply, with risks to health not yet fully assessed.[13]

Globally, about 70 percent of all fresh water, including groundwater, is used as irrigation for agriculture.[14] Irrigation carries chemicals used in industrial farming across the fields. Rain events move the chemicals into streams. A US Geological Survey report found the popular weed killer glyphosate (also known as Roundup) to be in 66 of 70 streams in the US[15] Atrazine, another weedkiller widely used in row crop agriculture, contaminates the drinking water of 7.6 million people living in the US[16] Groundwater recharges lakes, rivers, and wetlands and supplies critical moisture to the roots of trees, and is pumped for humans to use in the form of drinking water.[17] The USDA estimates that 50 million people use groundwater that is potentially contaminated by agricultural chemicals.[18] Approximately 40 percent of domestic and public drinking water is contaminated with at least one agricultural chemical, such as metolachlor, dacthal, acetochlor, simazine, and alachlor. [19] Chlorpyrifos, an insecticide used in row-crop farming operations, has been found in soils, sediments, and groundwater. Antibiotics used to treat and prevent livestock diseases, as well as pesticides used to rid certain fruit and nut trees of pest-borne diseases, contaminate drinking water and poison wildlife species. They also create reservoirs of antibiotic resistance in the bacteria that can sicken humans.[20]

Today, pesticide production is a multibillion dollar industry, with the global market worth more than $60 billion in 2020 and is projected to increase to $82 billion by 2028.[21] The chemical industry is supported by public policies that subsidize industrial corn and soybean production in the US (and many other nations), policies that are wreaking havoc on waterways all the way down to the Gulf of Mexico. According to the EPA, agriculture is the likely cause for more than 145,000 miles of rivers and streams, one million acres of lakes and reservoirs, and 3,000 square miles of bays and estuaries being too polluted for swimming, fishing, and drinking.[22]

Sediment from farm fields is one of the most prevalent sources of agricultural water pollution, according to the EPA.[23] Sediment is on the rise in our drinking water, threatening human health.[24] But it also has adverse effects on plants and animals that inhabit various water-bound ecosystems. Sedimented water makes it hard for animals to find food; prevents the growth of natural and necessary vegetation; clogs fish gills and inhibits egg and larvae development; activates harmful algae; and generally, negatively affects the food chain and threatens biodiversity.[25] Synthetic fertilizers can trigger large quantities of algal blooming, which significantly reduce the amount of dissolved oxygen in the water. As a result, marine life are unable to survive, leaving “dead zones” and further ecological imbalance.[26]

MISCONCEPTIONS

There are stand-alone solutions to water quality issues.

No one single practice will clean up the problems associated with our industrial agricultural system.[27] Riparian buffers, for example, which are popular on many farms, are not sufficient by themselves. Buffers have many beneficial effects on water quality, wildlife and fish habitat, overall ecosystem function, and landscape aesthetics. They trap sediments, recharge ground water, and immobilize contaminants that originate upland. Riparian vegetation stabilizes banks and reduces water temperatures that may contribute to eutrophication in nutrient-stressed waters. For these reasons and others, riparian buffers have become the focus of many conservation efforts on farms and ranches. However, they are not a substitute for employing regenerative practices and cannot solely alleviate the damage caused by industrial agriculture.

Water — and water contamination — is self-contained.

There's no such thing as an isolated body of water. Water moves, and so do the contaminants within it. Rainwater, for example, seeps into soil and then into groundwater; groundwater, in turn, can flow into streams and lakes. In consideration of the interconnectedness of all this, and after years of contending with polluted drinking and other waters due to the activities of massive confined animal feeding operations (CAFOs), the Maryland Department of the Environment, as an example, now requires poultry farms to make note of its watershed, that watershed's water quality status, and other resource concerns when applying for operating permits.[28]

UNMANAGED INDUSTRIAL LIVESTOCK PRODUCTION AND WATER

Overgrazing. Credit: Los Padres Forestwatch,

77 percent of all agricultural land globally is connected to livestock production, including meat and dairy operations, grazing lands and arable fields used for animal feed production, all of which affect natural water cycles when livestock are mismanaged.[29] While many grassland ecosystems evolved with native herbivores, overgrazing and unmanaged livestock can lead to the denuding of vegetative cover, soil erosion, and downcutting.[30 31] Trampling or continuous grazing can destroy topsoil and interfere with nutrient cycling, biomass production, soil stability and water infiltration, according to the US Fish and Wildlife Service. Continuous grazing can also cause soil compaction, which can damage plant roots and cause them to grow close to the surface rather than penetrating deeply. Overgrazing can stress desirable plants and leave an opening for invasive species to take over, reducing biodiversity and optimal ecosystem functioning.

CAFO Manure Lagoon. Credit: Jeff Vanugam, USDA

One of the main agricultural contributors to water pollution are CAFOs.[32 33] A single CAFO can house as many as 1000 cattle or swine in cramped, unhygienic conditions. Large amounts of manure are generated by CAFOS and are stored for long periods of time in tanks, man-made pools, or lagoons that can leak into the ground, contaminating the groundwater on the farm as well as further downstream.

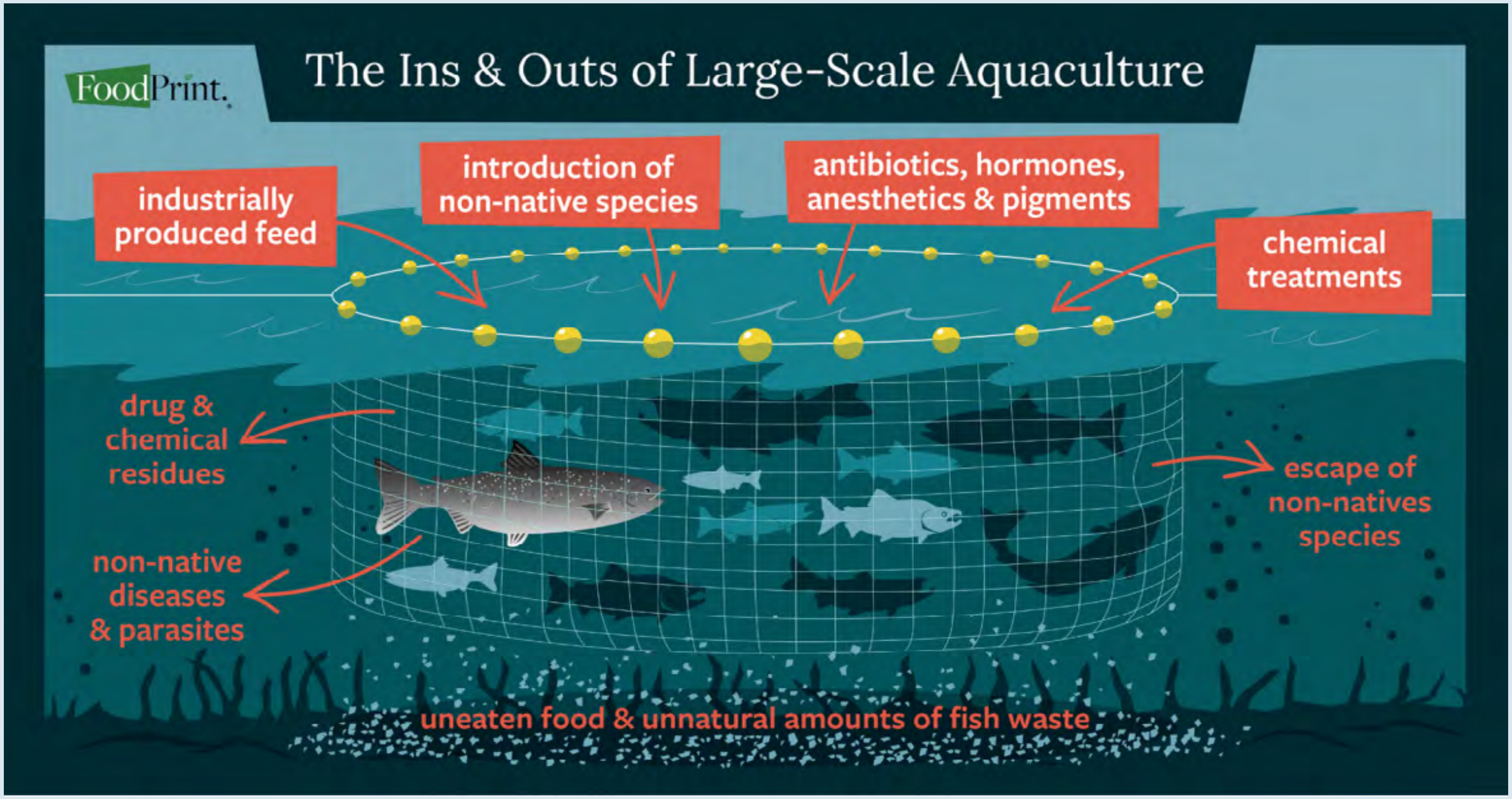
Animals in industrial livestock confinement systems are treated daily with antibiotics and other drugs, passing these substances into manure and water sources ultimately. As a result, these operations create conditions conducive to the proliferation and antibiotic resistance of pathogens. Industrial swine operations have been implicated in high levels of antibiotic-resistant *E. coli* in surface and ground water.[34]

The UN Food & Agriculture Organization (FAO) calls the flow of these drugs, chemicals and pathogens into our water supply what it indisputably is: a *crisis*.[35] In 2006, a multistate outbreak of pathogenic *E.coli* in spinach was tracked to a farm in California that was using irrigation water downstream from a livestock farm where the pathogen was later confirmed to have originated.[36 37] There are multiple risks to water quality from livestock operations and the manure-based waste they generate, with nitrogen a pollutant of widespread concern.[38 39] In addition, these facilities are frequently erected in proximity to low-income minority residents, furthering the environmental injustices for these communities and putting them at greater health risk.

AQUACULTURE

Similar to industrial agriculture on land, intensive aquaculture or fish farming have the same issues with chemical and drug intensive application practices that contaminate water and waste effluent directly.[40] In addition, the waste in these systems contains excessive nutrients in the form of nitrogen compounds that, like chemical fertilizer, pesticides, and antibiotics runoff, can cause toxicity to the environment and to human health. In cases like shrimp, entire farms have been known to collapse from pathogen overload due to difficulties in maintaining healthy and hygienic conditions. Raising fish in open net pens in the ocean, such as most farmed salmon, has detrimental effects on the ocean and sea life. The drugs, chemicals, and concentrated feed are literally flushed into the oceans, as are the diseases that occur in intensive ocean fish farming.[41] In the case of salmon farming, for example, sea lice infestation and disease from the net pens infect and, in most cases, have decimated proximal wild salmon populations.

By contrast, there are better designed aquaculture and seafood systems that are more sustainable and regenerative, and support water conservation, water quality, environmental quality, wild fish stocks and healthier food.[42 43]



Large-scale aquaculture. Credit: FoodPrint.org

AQUACULTURE AND SEAFOOD SYSTEMS: A COMPARISON OF INTERSECTIONAL ISSUES[44]

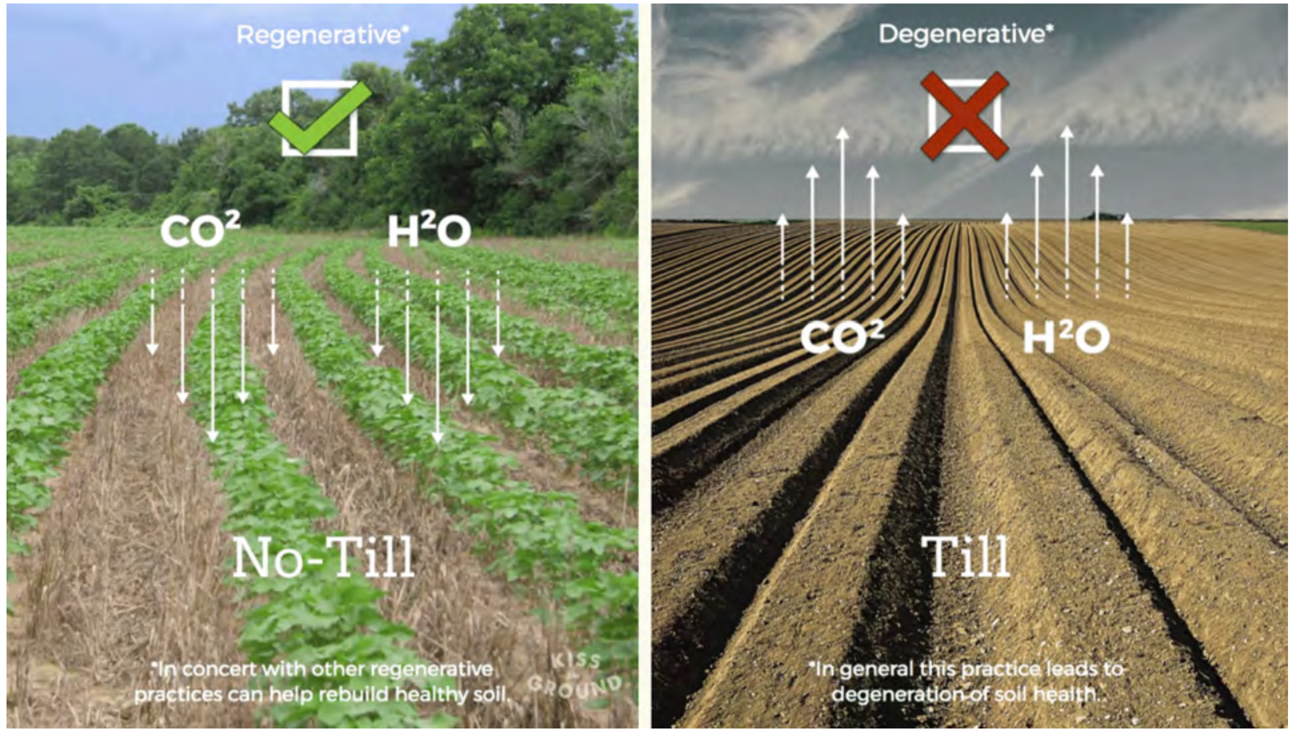
	Restorative Wild Fishing in the Ocean	Regenerative Bivalve and Kelp Ocean Farming	Well-designed Recirculating Farm Systems (land)
FEED FOR FISH	No	These are filtering organisms that feed on the nature's nutrients, so no external feed is required	Protein in feed does not exceed percent protein produced Seek more natural forms of feed (e.g., worms, algae) Reduce reliance on wild fish meal
DRUG USE	Not used	None	Minimized
CHEMICALS	Not used	None	Minimized
DISEASE MANAGEMENT	Managed by nature (Damaged by intensive offshore aquaculture)	Managed by nature	Water filtration and stocking densities help reduce rates of disease
FISH ESCAPE	Not necessary	N/A	Closed loop system prevents any escape
FISH WASTE / EXCESS NUTRIENT EFFLUENT POLLUTION	Not necessary	N/A	Water is filtered and reused while nutrients can be collected as fertilizer for crops. In aquaponic systems, water can be captured from crop effluent and used for aquaculture.
FISH STOCK DENSITIES	Stock of fish and seafood are not overharvested and bycatch is minimized	N/A	Manage density of fish to be able to manage recycling of nutrients, good water quality and fish health

REGENERATIVE AGRICULTURE CAN HELP RESTORE NATURAL WATER CYCLE BALANCE

Regenerative agricultural practices can restore natural water cycles, reduce excess evaporation, increase water holding capacity of soil, and improve water quality, principally by increasing the amount of soil organic matter (SOM). Cover crops, for example, planted in soils with high organic matter, can reduce runoff in flood years by nearly one-fifth and cut flood frequency by the same amount, while also making as much as 16 percent more water available for crops to use during droughts. Regenerative practices, used in combination, can reduce nutrient and sediment loss, suppress weeds, and keep up to 2 percent of phosphorous and 89 percent of nitrogen out of waterways.

According to USDA's Sustainable Agriculture and Research Education, cover crops increase infiltration of rainfall more than sixfold in some systems.[45] Reduced chemical inputs make waterways less polluted. Well-managed grazing yields deeper, faster-growing plant roots for better drought tolerance.[46] Riparian buffers act as sediment, phosphorous and nitrogen filters. Improved soil organic matter from regenerative farming practices, decreases the amount of water that crops need, better conserving this critical resource. Overall, it is estimated that cropland in the US could store an amount of water equivalent to what flows over Niagara Falls every 150 days by increasing SOM by 1 percent.[47]

With less clean freshwater at our disposal, carbon, and SOM become increasingly critical to water conservation. Tilling and other conventional farm practices, such as leaving the ground bare after harvest exacerbate these challenges.[48] They release carbon, decrease SOM, break up the aggregates that "glue" soil together and introduce temporary plants with short roots into growing systems. The FAO found that these practices compact soil and inhibit its ability to absorb and retain water on the one hand (a conservation issue) and on the other, increase and then prevent the buffering of chemicals from our waters (a cleanliness and water quality issue).



Regen ag can help restore water balance. Credit: Kiss the Ground,

In contrast, regenerative agriculture employs a host of practices that minimize soil erosion, increase soil organic matter and improve nutrient cycling. It relies on roots of plants and pasture to play a critical role in ground water retention. It uses animals to help accelerate root growth while providing important microbiology, nutrients, and carbon to the soil — accelerating the ability of the land to retain water (**see Soil Brief**).

REGENERATIVE SOIL AND LAND MANAGEMENT PROMOTES SOIL WATER RETENTION

No-till practices used in conjunction with cover crops are a potent combination for improving soil health, which in turn improves water retention. Low-impact and no-till eschews conventional blading of land to prepare it for planting, to leave fungi, earthworms and arthropods, bacteria and blocks of decaying organic matter intact. Regenerative agriculture limits chemical inputs, to keep these organisms alive. Together, these three practices promote soil biology, fertility and nutrient uptake by plants.[49] The interactions between these organisms and organic materials also help create macro- and micro-pores in soil, which increase its capacity to hold water.[50] Crop residues, which decompose into soil and eventually add to its structure — its humus — help this process along. Additionally, research from the UN's FAO found that some types of SOM could hold up to 20 times their weight in water.[51]

Photo by Markus Spiske on Unsplash

ORGANIC FARMING AND WATER

The EPA defines 'organic' as any food grown or processed without the use of synthetic fertilizers or pesticides. These chemicals kill soil biology, including beneficial microbes, fungi, and earthworms. By eliminating these chemicals, organic farming reduces water pollution. To determine the impact organic farming practices have on water quality, USDA initiated a long-term study in 2011. For three years, data was collected to compare nitrate pollution from plots with organic and conventional crop rotations as well as organic pastureland. Researchers found that nitrate loss via water in the conventional cropping systems was twice as high as nitrate loss from the organic cropping system, and that the organic pasture system lost the least amount of nitrate. Results of this study suggest that "organic farming practices such as the application of composted animal manure and the use of forage legumes and green manures with extended cropping rotations, can significantly improve water quality in Midwestern subsurface-drained landscapes."[52]

According to USDA's Sustainable Agriculture and Research Education (SARE), cover crops such as cereal rye, barley, and clover can increase infiltration of rainfall more than sixfold in some systems, which means significantly decreased runoff.[53] Cover crops also prevent evaporation of water from soil, making more moisture available to plants, both immediately and in the long term.[54] And with only 15.4 million out of 267 million US cropland acres planted with cover crops per a 2017 statistic, that means there's ample opportunity for water conservation improvement based on this one practice alone.[55]

Planting diverse plants — either as crops, pasture, or cover crops in both rangelands and croplands — also has an important role to play in water retention. The complex interactions of plant roots with each other, as well as with soil microorganisms, help to build up soil carbon and increase soil's ability to hold water.[56] Moreover, plant species richness (diversity) has also been shown to increase soil microbial communities which, in some grassland systems, also strongly increases soil moisture.[57] Cover crop diversity was also found to contribute to greater moisture retention than a single crop cover species.[58] Diversity in pastures and grasslands composition increases water retention and can play an important role in restoring degraded lands and surrounding ecosystems.[59]

Regenerative practices prevent erosion by keeping the ground covered and stable with deep roots; they therefore have the potential to reduce nitrogen and other excessive nutrient loads from run-off entering waterways. Cover crops in particular reduce nitrogen losses into waterways — by an average of 48 percent and as much as 89 percent in one SARE study — in part because they have the ability to scavenge leftover nitrogen from deep in the ground, holding it in place and converting it to enzymes, hormones, and amino acids that can be taken up by plants.[60] Research shows that regenerative practices might also reduce phosphorous loads from between 15 percent to 92 percent — although SARE reports that further study is required.

Critically, however, regenerative farming practices improve SOM, which works to decrease the amount of water crops need to begin with — particularly impactful in regions experiencing aridity.[61] High SOM levels give soil its structure and porosity, and in turn improves the amount of water that can infiltrate and be held by soil. Research published in the *Journal of Soil and Water Conservation* found that when SOM was increased from one-half percent to three percent, this more than doubled the soil's water holding capacity regardless of what kind of soil it was.[62] Water-holding capacity of soil is directly related to the amount of organic matter it contains. This is an important piece in the water conservation puzzle: when the amount of SOM increases so does the capacity of the soil to hold water, which reduces the need to irrigate crops. The regular use of organic amendments such as manure from grazing or compost are a simple and effective way to increase soil organic matter and with regular use, can also increase microbial biomass soil fertility and carbon sequestration significantly.[63]

In an agricultural system in which crop residues are allowed to remain on fields — as opposed to burning them, which is common in industrial agriculture — those residues provide a myriad of critical functions: keeping soil covered and cool, helping to hold and filter contaminants from water, and also improving the small water cycle. In a rainfed maize system studied between 1997 and 2009 in the Mexican highlands, a combination of no-till and residue management buffered against periods of drought — resulting in higher yields than industrial management systems that used tilling and residue removal.[64] In another study, the combination of crop residues and conservation tillage was shown to increase pore size in soil, and to create greater water capacity.[65] And a study of canola in a semi-arid region of northern Iraq found that minimal till combined with residue management led to high soil water content, improved soil quality and increased productivity.[66]

REGENERATIVE GRAZING SYSTEMS AND WATER RETENTION

Well-managed livestock grazing is also an important component of water and climate conservation. According to the Union of Concerned Scientists, by transitioning corn-for-cattle monocrop or industrial all-beef-production systems — the latter of which can use 29 gallons of water to produce a single ounce of meat — into systems that integrate diverse crops and livestock, water resource demands are reduced.[67] These integrated practices improve both water holding capacity and infiltration by building up SOM, which reduces the need for irrigation. Carefully managed mixed-use systems can yield deeper and fast growing crop roots which improve drought tolerance and provide an overall more stable farm environment.[68] In a 2017 study, if a farmer converted one-third of a 1,000-acre conventional corn-soy farm to a well-managed, grass-based grazing system integrated with diverse crops, each year they could potentially save $28,000 in fertilizer costs and $1,500 in fuel costs; reduce climate emissions from fertilizer, fuel, and soils by more than 400tCO2e; reduce the farm water footprint by 280 million gallons; and generate $98,000 in profit.

Managed grazing has other positive impacts on water. Manure in managed grazing systems acts as a natural fertilizer and compost, building up SOM, which helps soil to retain water. A lack of available water in soil reduces plant root growth, which, besides causing plant death, can increase the incidence of soil compaction and decrease the amount of soil organic matter. Similarly, research published in the *Journal of Soil and Water Conservation* found that the permanent ground cover that comes along with the forage plants required by well-managed grazing systems helps to elevate soil organic carbon — an important step in building SOM and ultimately, conserving water.[69]

REGENERATIVE GRAZING IMPROVES SOIL NUTRIENT MANAGEMENT AND WATER QUALITY

Managed grazing, pasture based animal systems are much better alternatives to industrial CAFOs, which have massive negative effects on our water supply. In regenerative livestock systems, the number of animals is factored into determining how much the land (soil and plants) can support. Regenerative livestock systems do not hold massive amounts of manure in one place as the grazing animals are always moving and directly depositing manure and urine into soil. This process provides natural and balanced nutrition and biological support to soil as manure and urine naturally disperse and decompose, preventing excessive nutrient runoff into water. Relatedly, as research published in Global Change Biology found, livestock manure amendments from managed grazing operations increased soil carbon stocks by an average of 19 tons per hectare, and also found a link between perennial (as opposed to annual) grasses to this positive impact, which also helps to prevent erosion.[70]

Since few drugs are administered to regeneratively raised livestock, manure from managed grazing is by its nature “cleaner.” This promotes a healthy soil biome. It promotes better human health as well: when there are no antibiotics administered to livestock, there are no antibiotics in water — and that water, once transported downstream and into taps, is cleaner and healthier.

REGENERATIVE AGRICULTURE IMPROVES RESILIENCE TO WITHSTAND CLIMATE EXTREMES

In a comprehensive look at how regenerative farming practices could lead to improved drought and flood outcomes — including by reducing sedimentation runoff that pollutes waterways in which the water filtration and holding capacity of soil plays a large part — the Union of Concerned Scientists evaluated no-till, cover crops, alternative grazing, combined crop/grazing systems and perennial cropping. They found that, "70 percent of experiments showed an increase in water infiltration when any of these practices was used." Perennial crops, though, "were the clear winner at managing heavy rains...increase[ing] infiltration enough to absorb a heavy rain event of one inch per hour." Diverse cropping, too, "increased resilience to both flooding and drought," while cover crops linked with perennials had the power to change the structure of soil by increasing porosity by an average of 8 percent.

IN SUMMARY

Discussions about water are often couched in terms of scarcity — there's not enough water to go around, its limited supplies are dwindling, or its quality is in jeopardy. The conversation, however, changes dramatically when the discussion about water is couched in terms of *abundance*. The natural world is filled with abundance, not scarcity. Sunlight, for example, provides energy for photosynthesis in plants and is the key to their growth and health. It is also extraordinarily abundant and available globally. Soil is abundant too, as are the trillions and trillions of microscopic creatures found in a shovelful of healthy soil. The relationships found in living landscapes are abundant, as well, from bacteria to elephants. At every level, Nature tries to increase abundance and expand richness, which we call *regeneration*. Water is key to life and thus regeneration. There's plenty of it to go around if we change our thinking — and our practices — to foster the conditions that improve both the large and the small water cycles. Sunlight, soil, plants, animals, microbes — these elements exist in abundance.

Clean water can too.

ENDNOTE

1 Van der Ent, Rudi J., et al. "Origin and Fate of Atmospheric Moisture Over Continents." *Water Resources Research,* vol. 46, no. 9, 2010, https://doi.org/10.1029/2010WR009127.

2 Bexfield, Laura M., et al, "Pesticides and Pesticide Degradates in Groundwater Used for Public Supply across the United States: Occurrence and Human Health Context," *Environmental Science & Technology,* vol. 55, no. 1, 2021, https://pubs.acs.org/doi/10.1021/acs.est.0c05793.

3 "Protecting Water Quality from Agricultural Runoff." *United States Environmental Protection Agency,* 2005, https://www.epa.gov/sites/production/files/2015-09/documents/ag_runoff_fact_sheet.pdf.

4 "Water for Life Decade." *United Nations Department of Economic and Social Affairs* web site, n.d., https://www.un.org/waterforlifedecade/scarcity.shtml#.

5 Rijsberman, Frank R. "Water Scarcity: Fact or Fiction?" *Agricultural Water Management*, vol. 80, no. 1-3, 2006, pp. 5–22., https://doi.org/10.1016/j.agwat.2005.07.001.

6 Cole, Steve. "NASA Satellites Reveal Major Shifts in Global Freshwater." *NASA*, May 16, 2018, https://www.nasa.gov/press-release/nasa-satellites-reveal-major-shifts-in-global-freshwater.

7 "California Agricultural Production Statistics." *California Department of Food and Ag*, 2019. Accessed 28 April, 2021, from https://www.cdfa.ca.gov/Statistics/#.

8 Matthews, William and Sumner, Daniel. "Contributions of the California Dairy Industry to the California Economy in 2018." *University of California, Agricultural Issues Center*, A Report for the *California Milk Advisory Board*, 2019, https://aic.ucdavis.edu/wp-content/uploads/2019/07/CMAB-Economic-Impact-Report_final.pdf.

9 "Drought." *California Department of Water Resources*, n.d., https://water.ca.gov/Water-Basics/Drought.

10 Stokstad, Erik. "Droughts Exposed California's Thirst for Groundwater. Now, the State Hopes to Refill its Aquifers." *Science,* April 16, 2020, https://www.sciencemag.org/news/2020/04/droughts-exposed-california-s-thirst-groundwater-now-state-hopes-refill-its-aquifers.

11 Borisova, Tatiana, et al. "Economic Impacts of Climate Change on Florida: Estimates from Two Studies." *University of Florida,* Food and Resource Economics, March 25, 2018, https://edis.ifas.ufl.edu/publication/fe787.

12 Rosenzweig, Cynthia, et al. "Climate Change and Extreme Weather Events: Implications for Food Production, Plant Diseases, and Pests." *Global Change and Human Health,* vol. 2, no. 2, 2001, pp. 90–104., https://doi.org/10.1023/a:1015086831467.

13 "Microplastics in Drinking-water." *World Health Organization,* 2019, https://apps.who.int/iris/bitstream/handle/10665/326499/9789241516198-eng.pdf.

14 "Irrigation Water Use." *US Geological Service*, 2018, https://www.usgs.gov/special-topics/water-science-school/science/irrigation-water-use.

15 "Glyphosate – Widely Used, Widely Detected." *U.S. Geological Service* Water Resources, 2020, https://www.usgs.gov/news/herbicide-glyphosate-prevalent-us-streams-and-rivers.

16 Naidenko, Olga and Lunder, Sonya. "Atrazine: A Harmful Weedkiller Taints Tap Water for Millions in U.S." *Environmental Working Group*, August 29, 2017, https://www.ewg.org/news-insights/news/atrazine-harmful-weedkiller-taints-tap-water-millions-us#.

17 Barbeta, Adrià and Peñuelas, Josep. "Relative Contribution of Groundwater to Plant Transpiration Estimated with Stable Isotopes." *Scientific Reports*, vol. 7, 2017, https://www.ncbi.nlm.nih.gov/pmc/articles/PMC5585407/.

18 Nielsen, Elizabeth G. and Lee, Linda K. "The Magnitude and Costs of Groundwater Contamination From Agricultural Chemicals." *USDA Economic Research Services,* Agricultural Economic Report Number 576, October 1987, https://naldc.nal.usda.gov/download/CAT88907300/PDF.

19 Bexfield, Laura M., et al. "Pesticides and Pesticide Degradates in Groundwater Used for Public Supply across the United States: Occurrence and Human Health Context." *Environmental Science & Technology,* vol. 55, no. 1, 2021, https://pubs.acs.org/doi/10.1021/acs.est.0c05793.

20 Landers, Timothy, et al. "A Review of Antibiotic Use in Food Animals: Perspective, Policy, and Potential." *US National Library of Medicine National Institutes of Health*, Public Health Reports, vol. 127, no. 1, 2012, https://www.ncbi.nlm.nih.gov/pmc/articles/PMC3234384/.

21 "Crop Protection Chemical Market Size, Share, and COVID-impact Analysis, 2021-2028." *Fortune Business Insights*, https://www.fortunebusinessinsights.com/industry-reports/crop-protection-chemicals-market-100080.

22 Rumpler, John. "Corporate Agribusiness and the Fouling of America's Waterways." Environment America Research and Policy Center, 2016, https://environmentnorthcarolina.org/sites/environment/files/reports/NCE%20Farms%20Report%20Jun16.pdf.

23 "Protecting Water Quality from Agricultural Runoff." *United States Environmental Protection Agency,* 2005, https://www.epa.gov/sites/production/files/2015-09/documents/ag_runoff_fact_sheet.pdf.

24 McDonald, Robert, et al. "Estimating watershed degradation over the last century and its impact on water-treatment costs for the world's large cities." *Proceedings of the National Academy of Sciences of the United States of America,* August 9, 2016, https://www.pnas.org/content/113/32/9117.

25 "What is a Water Shed?" *Mid-American Regional Council,* n.d., https://cfpub.epa.gov/npstbx/files/ksmo_sediment.pdf.

26 Chakraborty, Subhendu, et al. "Effects of Fertilizers Used in Agricultural Fields on Algal Blooms." *The European Physical Journal Special Topics*, vol. 226, no. 9, 2017, https://link.springer.com/article/10.1140/epjst/e2017-70031-7.

27 Johnson, Craig W. and Buffler, Susan. "Riparian Buffer Design Guidelines." *United States Department of Agriculture*, January 2008. Accessed 28 April, 2021, from https://www.fs.fed.us/rm/pubs/rmrs_gtr203.pdf.

28 "Animal Feeding Operations (AFOs)." *Maryland Department of the Environment*, n.d. Accessed 28 April, 2021, from https://mde.maryland.gov/programs/LAND/RecyclingandOperationsprogram/Pages/AFOInfo.aspx.

29 Centeri, Csaba. "Grazing Effects on Water Erosion, Compaction, and Infiltration on Grasslands." *Hydrology*, vol. 9, no. 2, 2022, https://doi.org/10.3390/hydrology9020034.

30 Al-Kaisi, Mahdi, et al. "Managing Your Pasture to Reduce Soil Erosion." *Iowa State University, Extension sand Outreach, C-490*, 2003, https://crops.extension.iastate.edu/encyclopedia/managing-your-pasture-reduce-soil-erosion.

31 "Farming Our Way Out of the Climate Crisis." *Project Drawdown*, 2020. https://drawdown.org/sites/default/files/pdfs/DrawdownPrimer_FoodAgLandUse_Dec2020_01c.pdf.

32 Berg, Mary, et al. "Environmental Implications of Excess Fertilizer and Manure on Water Quality." *North Dakota State University,* Environmental and Natural Resources, 2017, https://www.ndsu.edu/agriculture/sites/default/files/2022-06/nm1281.pdf.

33 "The Sources and Solutions: Agriculture." *United States Environmental Protection Agency,* Nutrient Pollution, n.d., https://www.epa.gov/nutrientpollution/sources-and-solutions-agriculture.

34 Sapkota, Amy, et al. "Antibiotic-Resistant Enterococci and Fecal Indicators in Surface Water and Groundwater Impacted by a Concentrated Swine Feeding Operation." *Environmental Health Perspective,* vol. 115, no. 7, 2007, https://pubmed.ncbi.nlm.nih.gov/17637920/.

35 Mateo-Sagasta, Javier, et al. "Water Pollution From Agriculture: a Global Review." *Food and Agriculture Organization of the United Nations*, 2017, http://www.fao.org/3/i7754e/i7754e.pdf.

36 "Irrigation Water and Spinach E. coli Outbreak." *Center for Disease Control and Prevention*, Environmental Health Services, n.d., https://www.cdc.gov/nceh/ehs/water/irrigation-water-ecoli-spinach.html.

37 Gelting, Richard, et al. "Irrigation Water Issues Potentially Related to the 2006 Multistate *E. coli* O157:H7 Outbreak Associated with Spinach." *Agricultural Water Management*, vol. 98, no. 9, 2011, https://www.sciencedirect.com/science/article/abs/pii/S037837741100093X.

38 Burkholder, JoAnn, et al. "Impacts of Waste from Concentrated Animal Feeding Operations on Water Quality." *Environmental Health Perspectives*, vol. 115, no. 2, 2007, https://ehp.niehs.nih.gov/doi/10.1289/ehp.8839.

39 Mallin, Michael and McIver, Matthew. "Season Matters When Sampling Streams for Swine CAFO Waste Pollution Impacts." *Journal of Water and Health*, vol. 16, no. 1, 2018, https://iwaponline.com/jwh/article/16/1/78/37985/Season-matters-when-sampling-streams-for-swine.

40 Martinez-Porchas, Marcel and Martinez-Cordova, Luis. "World Aquaculture: Environmental Impacts and Troubleshooting Alternatives." Scientific World Journal, April 29, 2012, https://doi.org/10.1100/2012/389623.

41 Pulkkinen, K., et al. "Intensive Fish Farming and the Evolution of Pathogen Virulence." Proceedings of the Royal Society B, October 28, 2009, https://royalsocietypublishing.org/doi/abs/10.1098/rspb.2009.1659.

42 "What Is a Recirculating Farm?" Recirculating Farms Coalition web site, https://www.recirculatingfarms.org/what-is-a-recirculating-farm/.

43 Greenwave web site, https://www.greenwave.org/.

44 "The FoodPrint of Farmed Seafood." FoodPrint and the Northwest Atlantic Marine Alliance, 2020, https://foodprint.org/wp-content/uploads/2020/10/2020_09_29_FP_Aquaculture_Report_FINAL-1.pdf.

45 "Cover Crops Improve Soil Conditions and Prevent Pollution." *Sustainable Agriculture Research and Education*, July 2017, https://sare.org/wp-content/uploads/Cover-Crops-Improve-Soil-Conditions-and-Prevent-Pollution.pdf.

46 "Managing Grazing to Improve Climate Resilience." USDA Northeast Climate Hub, https://www.climatehubs.usda.gov/hubs/northeast/topic/managing-grazing-improve-climate-resilience.

47 Nichols, Ron. "A Hedge Against Drought: Why Healthy Soil is 'Water in the Bank'." *United States Department of Agriculture*, February 21, 2017, https://www.usda.gov/media/blog/2015/05/12/hedge-against-drought-why-healthy-soil-water-bank.

48 Ibid.

49 Schmidt, Radomir, et al. "Cover cropping and no-till increase diversity and symbiotroph:saprotroph ratios of soil fungal communities." *Soil Biology and Biochemistry*, vol. 129, no. 99-109 (2019). Accessed 28 April, 2021.

50 Nichols, Ron. "A Hedge against Drought: Why Healthy Soil is 'Water in the Bank'." *United States Department of Agriculture*, February 21, 2017. Accessed 28 April, 2021, from https://www.usda.gov/media/blog/2015/05/12/hedge-against-drought-why-healthy-soil-water-bank.

51 Bot, Alexandra and Benites, José. "The importance of soil organic matter." *Food and Agriculture Organization*, FAO Soils Bulletin vol. 80, 2005. Accessed 28 April, 2021, from http://www.fao.org/3/a0100e/a0100e.pdf.

52 Cambardella, Cynthia, et al. "Water Quality in Organic Systems." Sustainable Agriculture Research, vol. 4, no. 3, 2015, https://www.ccsenet.org/journal/index.php/sar/article/view/50106/26958.

53 Myers, Rob and Tellatin, Sami. "Cover Crops Improve Soil Conditions and Prevent Pollution." *Sustainable Agriculture Research and Education,* Cover Crop Resource Series, July 2017, https://sare.org/wp-content/uploads/Cover-Crops-Improve-Soil-Conditions-and-Prevent-Pollution.pdf.

54 Rijsberman, Frank R. "Water scarcity: Fact or fiction?" *Agricultural Water Management*, vol. 80, no. 1-3, pp. 5-22, August 2005. Accessed 28 April, 2021, from https://www.sciencedirect.com/science/article/abs/pii/S0378377405002854.

55 Dreibus, Tony. "Ag Census: Cover Crop Acres Surge from 2012 to 2017." *Successful Farming,* April 19, 2019, https://www.agriculture.com/news/crops/ag-census-cover-crop-acres-surge-from-2012-to-2017.

56 "Regenerative Agriculture Is About Direction Over Perfection." *Noble Research Institute*, February 26, 2020, https://www.noble.org/news/publications/ag-news-and-views/2020/march/regenerative-agriculture-is-about-direction-over-perfection/.

57 Lange, Markus, et al. "Biotic and Abiotic Properties Mediating Plant Diversity Effects on Soil Microbial Communities in an Experimental Grassland." *PloSOne*, vol. 9, no. 5, 2014, https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4015938/.

58 Chu, Mingwei, et al. "Effect of Multispecies Cover Crop Mixture on Soil Properties and Crop Yield." *Agricultural & Environmental Letters*, vol. 2, no. 1, 2017, p. 170030., https://doi.org/10.2134/ael2017.09.0030.

59 Fischer, Christine, et al. "Plant Species Richness and Functional Groups Have Different Effects on Soil Water Content in a Decade-Long Grassland Experiment." *Journal of Ecology*, vol. 107, no. 1, 2018, pp. 127–141., https://doi.org/10.1111/1365-2745.13046.

60 Clark, Andy. "Cover Crops Improve Soil Conditions and Prevent Pollution." *Sustainable Agriculture Research and Education*, 2015, https://www.sare.org/publications/cover-crops/ecosystem-services/cover-crops-improve-soil-conditions-and-prevent-pollution/.

61 Bot, Alexandra and Benites, José. "The Importance of Soil Organic Matter." *Food and Agriculture Organization*, Soils Bulletin, vol. 80, 2005, http://www.fao.org/3/a0100e/a0100e.pdf.

62 Hudson, Berman D. "Soil Organic Matter and Available Water Capacity." *Journal of Soil and Water Conservation*, vol. 49, no. 2, 1994, https://www.jswconline.org/content/49/2/189.abstract.

63 Diacono, Mariangela and Montemurro, Frencesco. "Long-term Effects of Organic Amendments on Soil Fertility: a Review." *Agronomy for Sustainable Development*, vol. 30, 2010, https://link.springer.com/article/10.1051/agro/2009040.

64 Velhurst, Nele, et al. "Soil Water Content, Maize Yield and Its Stability as Affected by Tillage and Crop Residue Management in Rainfed Semi-arid Highlands." *Plant and Soil*, vol. 344, no. 1-2, 2011, https://link.springer.com/article/10.1007/s11104-011-0728-8.

65 Bescana, P. et al. "Soil water retention as affected by tillage and residue management in semiarid Spain." *ScienceDirect*, Soil & Tillage Research, vol. 87, no. 19-27, 2006. Accessed 28 April, 2021.

66 Abdullah, Araz Sedqi. "Minimum Tillage and Residue Management Increase Soil Water Content, Soil Organic Matter and Canola Seed Yield and Seed Oil Content in the Semiarid Areas of Northern Iraq." *Soil & Tillage Research*, vol. 144, 2014, https://www.sciencedirect.com/science/article/pii/S0167198714001548.

67 DeLonge, Marcia. "Reintegrating Land and Livestock." *Union of Concerned Scientists*, 2017, https://ucsusa.org/sites/default/files/attach/2017/11/reintegrating-land-and-livestock-ucs-2017.pdf.

68 Eubanks, Emily. "Grazing Cover Crops Improves Water Quality." *IFAS*, University of Florida, n.d., https://blogs.ifas.ufl.edu/clue/2020/04/27/grazing-cover-crops-improves-water-quality/.

69 Teague, W. R., et al. "The Role of Ruminants in Reducing Agriculture's Carbon Footprint in North America." *Journal of Soil and Water Conservation*, vol. 71, no. 2, 2016, https://www.jswconline.org/content/71/2/156.

70 Owen, Justine, et al. "Long-term Impacts of Manure Amendments on Carbon and Greenhouse Gas Dynamics of Rangelands." *Global Change Biology*, July 16, 2015, https://onlinelibrary.wiley.com/doi/abs/10.1111/gcb.13044.

CONTACT

staff@forainitiative.org

forainitiative.org