

# Measuring Societal Benefits of Soil Health: Biophysical Dynamics & Hydrological Ecosystem Services

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This discussion paper was developed by a national interdisciplinary team convened by the Wisconsin-based Michael Fields Agricultural Institute and the National Center for Appropriate Technology. The team, whose broad focus is measuring the societal benefits of soil health, chose to begin with the question, “How do different conservation/soil health-building practices reduce the amount and contamination of water leaving farm fields from storms of differing severity and timing?”

This paper focuses on the practices and conditions that increase soil’s infiltration and water holding capacity. A companion paper, *Measuring Societal Benefits of Soil Health: Cost Savings for Local Municipalities, Rural Communities, and States*, is available at [this link](#). While these papers are grounded in research and fact, they were written not as academic papers but rather to generate and inform discussion across disciplines, agencies, and kinds of stakeholders about practical solutions to challenging intersectional problems.

## Executive Summary

- Throughout most of the U.S., rains are becoming less frequent but more intense, leading to increased nuisance and large-scale floods.
- Especially in flood-prone areas with large agricultural zones upstream, soil health practices have the potential to mitigate flood risk, and at the same time reduce nutrient and sediment runoff and improve degraded soils.
- Healthy soil reduces flood risk because it increases soil’s infiltration and water holding capacity.
- This is dramatically evidenced by case studies throughout the U.S. in which farmers and ranchers use a suite of practices to improve soil health and greatly increase infiltration and water-holding capacity.
- Evidence from peer reviewed literature confirms this, although the literature shows more muted and scattered impact for two good reasons:
  - First, most studies intentionally isolate one practice change at a time, which limits the potential to recognize synergies and context-specific changes, both of which are essential to maximize benefits.
  - Second, case studies are chosen ex-post-facto, meaning practitioners with the most dramatic results garner the most attention.
- Logically, soil health at scale can have large impacts on reducing flood risks downstream, but there is scant research scaling soil health up to watershed scale impacts.

- **We recommend two concurrent lines of research:**
  - **First, improved hydrology models that better incorporate soil health as a parameter.**
  - **Second, watershed studies comparing either similar paired watersheds with differing soil health, or watersheds pre vs. post large-scale soil health changes**
- **Such research will help determine how and how much to invest in soil health to mitigate impacts on downstream infrastructure and communities.**

## Introduction

After rain falls on soil, it will either be infiltrated into that soil or remain on the surface to pond and then run off. Water that runs off soil carries sediment (displaced soil) and nutrients with it, simultaneously degrading the health of the soil and off-site environments. Runoff water can result in flooding, pollution of aquatic environments, and degraded quality of water for human consumption and recreation. The problems caused by runoff will increase with rainfall patterns that are projected under climate change – less frequent rainfall in greater volumes.<sup>1</sup> A chief solution to low infiltration rates that cause runoff is to improve the health of our soils, since healthy soils have greater amounts of soil carbon, better structure, and more pores to accept and store rainfall while also allowing it to drain. Much of our agricultural land has been degraded and left unhealthy, but reversing this can be done by adhering to soil health management principles. The principles of soil health management are to reduce disturbance as much as possible, diversify plants, keep living roots in the soil whenever possible, keep soil covered, and include grazing animals when possible.

Given that our agricultural soils have lost about half of their organic matter—the basic workforce and materials for healthy soils—there is much room for soils to be regenerated. Managing for soil health holds great promise for increasing the rate at which water infiltrates into soil, and the amount of water that soils can hold, thereby reducing off-site hazards such as flooding and water contamination. Although scientists and soil health practitioners have a solid grasp of the generalities surrounding the biophysical dynamics that relate changes in management to the off-site benefits that those managements convey, these relationships are far from simple. Some answers are found in scientific literature and others from the narratives of those who have implemented changes on their farms or ranches and witnessed the outcomes. The goal of this work is to illuminate what we do and don't know about the biophysical relationships between soil health and off-site water quantity and quality. While this work focuses on off-site water quantity, water quality is highly related. The quantity and speed of water leaving a site directly influence the nutrient and sediment runoff, so that the same mechanisms that reduce runoff quantity improve downstream water quality.

## Assessing Soil Health

Above, we listed soil health in terms of management principles. These principles are manifested when farmers and ranchers adopt systems of practices that reflect an understanding of those overarching principles. Examples of soil health practices are reducing tillage, cover crops, and implementing managed grazing. Over time, farmers use these practices to change the dynamic properties of soil. Such changes to soil can be measured using indicators of soil health. Accepted soil health indicators of hydrologic properties are infiltration rate (preferably at saturation to standardize results), water retention (such as plant-available water holding capacity), soil aggregate stability, and soil bulk density (related to whether soils are compacted). While each of these indicators represents our conceptualization of a soil process, the holistic nature of soil systems dictates that all are interrelated to some degree. While not a direct measure of soil hydraulic functioning, soil carbon often indicates soil structural changes that accompany water-related changes, and hence it too is a (less direct) indicator. These indicators of hydraulic soil health do not depend only on management, but also on the inherent properties of different soils: for example texture (the underlying ratio of sand, silt and clay in the mineral portion), slope, and depth to bedrock. Soils, like humans, have innate capabilities. The goal then, is not to obtain a particular measured indicator value across all soils, but rather to manage each soil to be as healthy as it can, given its inherent properties.

While indices like changes over time in infiltration rates and aggregate stability are the go-to for scientifically documented changes in response to soil health management practices, soil health practitioners use their own observations to track changes on the land they steward, though some farmers and ranchers also use the above-listed indicators as well. Soil health practitioners observe management effects when they assess their fields, and note, for example, the health of their crops and the insect and animal diversity on their operations. Specifically related to hydrology, they note whether and how long water ponds on their fields after rainfall, how green their crops are and for how long, how much soil erodes from their fields, and the clarity and quantity of water leaving their fields. Although practitioner observations may have disadvantages (lack of repeatability and often lack of a control scenario), they have several distinct advantages also. Practitioner observations are made under the scenario that is our ultimate goal, that is, farmers and ranchers implementing practices at scale in the real world; for example, managing for net profitability rather than just repeatability. They also integrate the dynamics of the whole farm (such as changes in soil type and local changes in terrain and hydrology) and seek out synergies.



Most research trials draw conclusions at a smaller scale and much shorter timeline, isolate the impacts of a single factor, and optimize for this single factor. They also often have resources available (funding, tools for measurement, etc.) that would be unlikely on a farm scale. Regenerative managers on the other hand, tend to consider a multitude of factors and often prioritize those actions that may appear second-best from an each-parts-based perspective, but which, together, create a more dynamic and functional whole. For example, practitioners implement changes that make sense within the time and resources they are able to commit, for long- and short-term benefits, for ecology and profitability. Taken together, and understanding their limitations, our team uses learnings from peer-reviewed literature as well as observations made by soil health practitioners to evaluate the effectiveness of soil health management systems in achieving off-site water-related benefits.

## Soil Health Benefits From Practitioner Observations

**We have compiled learnings from soil health practitioners related to soil hydraulic function. We organize these learnings under themes. It is important to remember that, because practitioners observe outcomes of soil health on different soil types and in different geographies and climates, their findings are not necessarily transferable to new contexts. However, they provide us with a constellation of outcomes that we can use to advance our understanding of what is possible.**

### Changes in organic matter and infiltration

Many practitioners have made observations that speak to the magnitude of the change in soil health that can be made. Dave Brandt <sup>2</sup> notes that because of the transition to no-till and cover crops on his Ohio farm, where he grows corn, soybeans and wheat, he has increased soil organic matter substantially (as much as a quarter of a percent per year) while also reducing erosion to less than 100 lbs. per acre per year. Compared to what those soil loss rates were previously, about 4 tons per acre per year, this has huge implications for off-site water quality. Allen Williams reports even higher changes in soil organic matter on his Alabama cattle ranch <sup>3</sup>, increasing as much as half a percent per year. Williams also reports improvements in infiltration, noting, for example, that the 1st half-inch of water in one trial infiltrated in 4 seconds. Other producers who report better infiltration rates include Gabe Brown of North Dakota, whose nature-based farming philosophy for row crops and animal integration has dramatically increased the soil infiltration rates to as high as 15 inches per hour, <sup>4</sup> and Jimmy Emmons of Oklahoma, whose nature-based farming principles have increased soil infiltration rates to over 6 inches per hour from the 1/2 inch per hour <sup>5</sup> he was getting before they started implementing the soil health principles. Jimmy grows row-crops and grazes livestock, and his results were also achieved while dramatically reducing or eliminating imported off-farm resources like fertilizers and pesticides.

## Profitability

Another strong theme among farmer case studies is that using soil health principles is good for farm profitability and yield. Russel Hedrick, the dryland division state winner in the 2016 North Carolina Corn Yield Contest, [6](#) credits cover crops as a key part of his increased yield. Through soil health, he reports that he has reduced fertilizer costs by more than \$70 per acre. A similar story is told by Scotty Herriman, [7](#) who has placed first in Oklahoma in the National Corn Growers Association Corn Yield Contest four times since adopting no-till. In a Soil Health Institute study of 100 farmers [8](#) across Iowa, Nebraska, Tennessee, Illinois, Indiana, South Dakota, Minnesota, Ohio, and Michigan, net farm income was increased by \$52 per acre on average for corn crops and \$45 an acre for soybean when farmers used soil health management systems. A “banking on soil health” case study conducted by the USDA found that farmers who focused on soil health documented a 12% increase in yield and a 176% return on their soil health investments. [9](#) The USDA study also documented increased infiltration and better water quality outcomes.

## Synergies and co-benefits

Many practitioners describe their soil health journey as a whole-system transition. While they may test individual practices or introduce new elements in a staged way, the eventual goal is transitioning to soil health-focused decision making. This requires a total reassessment of all farming practices. Soil health-focused decision making is important because outcomes often don't flow from soil health practices in a simple additive way - rather, it is synergies between practices adopted in a coherent management approach that provide needed results. Kristine and Thorsten Arnold have observed just how important such synergy is as they developed their bio-intensive market garden. [10](#) They have had to rethink management aspects including seeding dates, a shift from seeding to transplanting, changes in water management and drainage, labor management, and marketing. But these strategic changes allow them independence from tractors, earlier planting with transplants, extended harvests, and new markets.

Recognizing synergies is critical when transitioning to regenerative agriculture and also of utmost importance when thinking about co-benefits. Practitioners see that they are managing soil and water dynamics for increased resilience to extreme weather incidents, improved biodiversity, and abundance of rare animals in the field. Examples of keeping synergies front-and-center include the Ramos Ranch (formerly the Ranney Ranch) in New Mexico, where Nancy Ranney has established grassland and soil stewardship that is yielding increased biodiversity, including an Audubon certification for Bird Friendly Land. [11](#) In Georgia, White Oak Pasture's grass-fed beef farm has been shown to store more C in soil than it emits. [12](#) They accomplish this by acquiring degraded pastures and managing them holistically for both profits and soil health. As well, the documentary series *Carbon Cowboys*, a collaboration of Arizona State University and the World Bank, chronicles how ranchers have refocused on soil health to develop profitable and regenerative systems. [13](#)

## Corroboration in the Peer-Reviewed Literature

The practices that lead to healthy soils also lead to improved water dynamics because the characteristics of healthy soil are the same characteristics that increase infiltration and decrease runoff. Because of the deep link between healthy soil and water infiltration and runoff, there are two ways to demonstrate agricultural practice's influence on water infiltration and runoff. First, by directly measuring a practice's impact on infiltration or runoff, and second, by measuring a practice's impact on soil health, and then demonstrating the link between soil health and infiltration and runoff.

### 1. Connecting agricultural practices directly with increased infiltration

In a comprehensive meta-analysis of 89 studies from around the world, Basche and DeLonge (2019)<sup>14</sup> estimated the average impact on infiltration of various practices generally associated with soil health. The two statistically significant practices they found were switching to perennials (59% increase in infiltration) and introducing cover crops (35% increase in infiltration). While not statistically significant, they also found a positive impact on infiltration from introducing crop rotations and no-till, and a negative impact on infiltration from introducing grazing to a crop system. It should be noted that these numbers are averages, and each practice showed a wide variety of impact, further demonstrating that context and how a particular practice is applied highly determines its effectiveness. In another meta-analysis of 37 studies, Basche and DeLonge (2018)<sup>15</sup> found that infiltration rates significantly increased in grazing operations by increasing plot rest periods (68% increase in infiltration), reducing stocking rates (42% increase in infiltration), and adding grazing complexity, such as through rotational grazing or adaptive management (34% increase in infiltration).

### 2. Connecting agricultural practices with infiltration and decreased runoff through soil health

A key characteristic of healthy soil is high soil organic carbon (SOC). A wealth of studies exist measuring the correlation between practices and SOC, and it is increasingly well known that certain practices tend to increase SOC. For brevity, here we choose one illustrative and comprehensive study. Franzluebbers, Langdale, and Schomberg (2010)<sup>16</sup> conducted a meta-analysis of studies throughout the southeastern United States, studying the impact relative to conventionally tilled cropland of two conservation practices: implementing conservation tillage and transitioning to perennial pasture. They found a highly significant increase in SOC in response to both practices, and a further increase in SOC from adding cover crops in conservation tillage plots. Note that the term “conservation tillage” can hold a multitude of meanings today. The NRCS uses a commonly cited definition based on minimizing soil disturbance,<sup>17</sup> while many other related definitions exist as well.<sup>18</sup>

A wealth of studies in turn demonstrate that SOC is highly correlated with other key measures of soil health, increased infiltration, and decreased runoff. For example, studies consistently find that SOC is highly correlated with: decreasing soil bulk density,<sup>19,20</sup> increasing available water capacity,<sup>21</sup> increasing soil aggregate stability,<sup>22,23</sup> and decreasing water and nutrient runoff.<sup>24,25</sup>

## Gaps and Next Steps

The examples given here demonstrate that the same soil health-promoting practices that store soil carbon and increase productivity for farmers and ranchers also benefit water quality and quantity leaving farms. This can be of great benefit to communities and stakeholders who depend on hydrologic ecosystem services. In addition to case studies, several peer-reviewed studies demonstrate the effects of soil health management practices on off-site water-related ecosystem services, such as reducing nutrient load in downstream aquatic systems, reducing sediment load impacting downstream infrastructure, and reducing flooding downstream after heavy rainfalls. [26,27,28,29](#) Most of the work addressing these connections is done via modeling.

Specific examples include a 2008 paper in which the modeled magnitude of the change in baseflow and stormflow was amplified by changes in agricultural land management, [30,31](#) or a more recent modeling study that found that cover crops reduced flood peak discharges in four Iowa watersheds.[32](#) We have an understanding of how changes in soil health benefit off-site hydrologic services, but our certainty in predicting the magnitude of such changes using models is low.[33](#) The challenges associated with these predictions are that 1) we can't reliably extrapolate findings of one study to other locations and watersheds, practices, climates, or soils; [34](#) 2) our models don't capture dynamic properties like soil biology or soil structure that soil health management systems actually influence; [35,36,37](#) and 3) there is difficulty in scaling our knowledge to the landscape and catchment scale because spatial and temporal variability can overshadow management effects.[38](#) A staggering example of the limits of our predictive ability is that there is no coherent physical theory linking the movement of water through macropores to the movement of water through the rest of soil.[39](#) These challenges are both exacerbated and made increasingly important by climate change. [40,41,42](#) It has also been noted that software implementations of the leading agricultural models hasn't changed much in the last decade and that a focused effort on agricultural modeling software and process is needed.[43](#)

A multifaceted approach is needed to better understand how soil health affects off-site ecosystem services—or more specifically, to better understand the value of, and extent to which, soil health can reduce flooding and nutrient and sediment runoff, impacting downstream communities and infrastructure services like flood mitigation and water quality. Progress is needed towards a better representation of the effects of soil structure and soil biology in water quality and quantity models. We also need to manage risk within the context of uncertainty, since our ability to predict the future is limited by the complexity of soil/water dynamics.[44](#) This enhanced system knowledge and risk management would inform policy and stakeholder choices regarding the right agronomic systems to achieve goals related to on farm profitability as well as off-site hydrology.

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