Appendix 7: Soil Health and Resilience

Healthy soils have clear benefits to water supply and water quality. However, understanding whether or not a soil is “healthy” is not as simple as checking off a list of binaries. Rather, healthy soils are able to sustain ecosystems thanks to a combination of context-dependent physical, chemical, and biological factors (Cardoso et al., 2013). Despite the overall complexity of soil health, many of its physical indicators are fairly straightforward to identify and have clear implications for hydrological processes such as erosion, aeration, runoff, infiltration rates, and water holding capacity (Schoenholtz et al., 2000). Soil structure—and characteristics such as porosity, aeration, and water retention—is a physical soil attribute largely influenced by the accumulation of organic matter (Cardoso et al., 2013). Organic matter enables the binding together of silt, sand, and clay particles into secondary units called soil aggregates (Unger and McCalla, 1980). A well-aggregated soil has a mix of small and large pore spaces that enable it to act like a sponge. Pores improve infiltration rates by allowing water to pass into soil at higher speeds during rain events (Groh, 2020), and increase water holding capacity by binding water tightly enough to maintain soil moisture, yet loosely enough to allow for plant uptake (Cates, 2020). In simple terms, the complex structure of healthy soil helps it absorb, retain, and infiltrate water, all of which are important qualities for climate resilience and ecosystem health. By improving infiltration, a system will experience a reduction in ponding, runoff, erosion, sediment export to streams, and an increase in water supply to plants; a higher water holding capacity will enable soil to store water during dry periods, increasing resilience to drought and decreasing the risk of stream eutrophication (Bryant, 2015; Cates, 2020). When soil is compacted, many of these benefits are negated by the elimination of pore spaces. Furthermore, differences in soil structure and surface roughness amplify these impacts depending on land cover type.

After a 4-inch rainfall event, for example, the amount of runoff per acre of land is expected to be 13,600 gallons for forested land, 21,700 gallons for turf, 54,300 gallons for an agricultural field with corn or soy, and 105,900 gallons for impervious surfaces (Frankenberger, 2020). While soil can be lost quickly through erosion when soil aggregates are broken down, soil formation is extremely slow. Depending on the system, it can take between 100 and 10,000 years to form an inch of topsoil (Idowu et al., 2019).

Supporting practices that build soil organic matter and enable the development of a healthy soil structure is critical for mitigating these system impacts. Understanding the benefits of soil aggregates helps underscore why soil organic carbon (SOC) is one of the few universally agreed-upon indicators of soil health. For every 1 percent increase in soil organic matter (which is roughly 57% carbon on a dry-weight basis), soil can hold as much as 20,000 gallons more water per acre (Bryant, 2015). In other terms, a silt loam with 4 percent soil organic matter has more than twice the water-holding capacity of silt loam with 1 percent of soil organic matter (Hudson, 1994). This increased water holding capacity means that groundwater recharge can be bolstered, system runoff can be reduced, and the export of sediment and pollutants to waterways can be prevented (Frankenberger, 2020). This also exemplifies how best management practices (BMPs) for growing SOC stocks often do double-duty for protecting water quality, improving resilience to both drought and heavy rain events, protecting critical ecosystem services and vice versa.

The relationship between SOC, soil health, and water quality holds true across land cover types. In areas dominated by impervious land cover, not only does tree planting enhance SOC, but it also has watershed benefits, even when adopted at small scales. In urban and suburban areas, a single deciduous street tree can prevent between 500 and 760 gallons of stormwater per year from becoming runoff; a mature evergreen street tree can intercept more than 4,000 gallons over the same time period (Cotrone, 2015). In agricultural systems, the interconnectedness of SOC and water quality can be seen in the forest buffers typically adopted to filter agricultural runoff. Studies in Maryland have seen nitrate reductions of up to 88 percent when agricultural runoff passes through a forest buffer (Cotrone, 2015). This BMP also has the ability to increase above and belowground carbon sequestration. In wetland restoration, reinstating natural hydrology is a BMP that both builds SOC and improves the self-sufficiency of the ecosystem. Across land cover types, soil carbon, soil health, water quality, and hydrology are inextricably linked. While soil health and water security are often shelved as two distinct policy areas, it is important to acknowledge the ways in which they are one and the same. In Massachusetts, supporting BMPs that build SOC and promote soil health can have broad benefits for water quality, water availability, agricultural productivity, and ecosystem resilience. Managing for healthy soil is a critical step in preserving water quality and supporting ecosystem services across the state." -- (From HSAP pg 21-22)

By analyzing the land use history of a site, the likelihood and intensity of soil degradation can be estimated. In Apple Country, an analysis of historic land use data spanning 1971 to 2016 shows there are 45 distinct categories of land use history (see land use history map in appendix). Forests on steep slopes and large wetlands are least likely to have been subject to degrading land uses, and are estimated to have the highest concentrations of SOC. As noted in appendix 8, wetland soil, due to its anaerobic condition, stores even more carbon than upland soil.

Each of these categories was assigned a score ranging from 1-10 for both the intensity and probability of SOC degradation, soil contamination, and degradation of the soil profile. For a full description of the methodology and associated data see appendix 8.

In addition to SOC losses, many common land uses can result in soil contamination with persistent heavy metals and other chemicals, and significant changes to the soil profile like the removal of topsoil during construction. Combined, these forces can result in soil impairments that last from decades to millennia. The properties of these degraded soils determine what activities can take place in these locations, and drive the intrinsic functions and the contributions a soil unit can make to ecosystem health.