Title

Advancing Climate-Smart Agriculture in San Diego: An Assessment of Regional Opportunities for Carbon Farming

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Advancing Climate-Smart Agriculture in San Diego: An Assessment of Regional Opportunities for Carbon Farming

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Executive Summary

San Diego is a region characterized by many unique attributes, including diverse urban development, conserved lands, coastal and terrestrial ecosystems, and agricultural lands. The region is known for its Mediterranean climate of seasonality and high temporal variability of rainfall. From coastal cliffs into expansive valleys and inland mountain regions, San Diego also encompasses a high degree of spatial variation of diverse microclimates. These distinct and diverse features present both challenges and opportunities in light of an increasingly changing climate. San Diego is already experiencing the many impacts of climate change. Projected increases in variability and intensity of temperature and precipitation extremes are exacerbating the region's water resource challenges. While San Diego faces vulnerability to these climatic stressors, recognition of these vulnerabilities have propelled the region forward to become a leader in innovative climate adaptation and resilience planning.

Agriculture plays a prominent role in San Diego, with many small farms, preserved lands, and valuable crops that hold economic, cultural, and historic value. The agricultural sector provides many ecosystem services that benefit the region's economy, ecosystems, watersheds, and communities. Agricultural lands have the ability to store carbon, reduce atmospheric greenhouse gases (GHGs), and sustain essential hydrologic benefits, making them an important part of the climate adaptation and resilience strategy. Recent studies have highlighted the potential of agricultural working lands to increase climate resilience through increasing carbon sequestration within soils. This suite of soil management practices, known as Carbon farming, can serve as an effective climate mitigation and adaptation strategy. This study helps illustrate the role that these active soil management strategies can have for buffering the impacts related to climate change. Specifically, these practices can alleviate the water-related challenges that San Diego farmers are especially vulnerable to.

As a region invested in both agriculture and sustainability, San Diego has the opportunity to further its role in climate resilience by expanding implementation of soil management practices throughout the county. While there are barriers that remain for on-the-ground implementation of carbon farming, recent advancements in climate modeling keep supportive economic policy make this an opportune time to make strides towards larger-scale implementation. With the growth of economic incentive programs, local, regional, and state agencies, and engaged citizen groups with the political will to take action, recently improved climate models need to be leveraged to inform more direct and effective efforts. San Diego can capitalize on these science-based decision support tools to understand the impacts of soil management for regional water resources and the opportunities to protect land for conservation of these agricultural opportunities. In doing so, the region can begin to scale out its carbon farming efforts, paving the way forward towards transforming the role of the agricultural sector as a major strategy in addressing the impacts of climate change.

Outline:

1.0 Introduction and Objectives

This report integrates regional climate modeling with agricultural and land use application to assess the water resource benefits that strategic soil management practices can have for San Diego's landscapes, the existing opportunities for implementation of practices, and the importance of preserving agricultural lands given future urban development plans. Analyses aim to address the barriers to implementation of climate-smart agriculture in San Diego, including (1) a lack of a comprehensive understanding of the region's agricultural landscape and (2) the areas where carbon farming practices can generate the greatest impacts for natural resources. Additionally, this report aims to quantify the potential benefits of soil management and the current opportunities for these practices. Analyses are designed to promote expanded implementation of carbon farming practices and to ultimately show the value of these lands and their ability to buffer climate change impacts, in light of (1) warming temperatures and (2) increased urbanization. Results highlight current opportunities for further implementation of sustainable agricultural practices and the potential benefits for water resources throughout San Diego. Additionally, analyses utilize planned land use projections to showcase (1) the vulnerability of agricultural lands to urban development and (2) the lost hydrologic benefit with the conversion of these lands.

2.1 Region and Landscape

San Diego's 4,530 square miles encompass a range of diverse human and natural landscapes, from iconic beaches, urban and suburban development, conserved lands, and major international seaports and airports (Kalansky et al., 2018). With 70 miles of exceptional coastline, culturally unique urban neighborhoods, and flourishing natural areas, it is no wonder that San Diego is home to a population of 3.3 million people and an abundance of natural resources. The region has 1.3 million acres of protected natural lands that buffer its growing population and conserve various ecosystems (Kalansky et al., 2018). These lands are home to some of the most ecologically and biologically diverse ecosystems in the world and support various habitats, plants, animals, and vegetation types (Jennings, et al. 2018). San Diego's landscape has historical and cultural importance, with more than 18 federally recognized tribes which is more Indian reservations than any other county in the United States ("Indian Reservations"). The combination of these natural open and agricultural lands, pristine coastal areas, diverse urban neighborhoods, and rich cultural history makes San Diego a vibrant and unique region that supports a variety of human communities and industries.

2.2 Agricultural Context

Agricultural rangelands and croplands are an important feature within San Diego's landscape, constituting 5.11% of the county's total land (Kalansky et al., 2018) with more than 250,000 acres and 5,000 farmers (San Diego Agriculture, 2018). These working lands are deeply rooted in the county's landscape, holding historic, economic, environmental, and social significance while providing a multitude of local benefits. Not only are these working lands important to the county for providing the public with local products and counteracting urban growth, they have significant economic value. Ranked 12th largest in the nation, San Diego agriculture has an estimated $2.88 billion annual value to the economy ("San Diego Agriculture", 2019). The region's agriculture encompasses rangeland, pastureland, and cropland, used for growing annual, perennial, nursery, and field crops (California Department of Food and Agriculture, 2015). Top crops include nursery products and crops, avocados, citrus, and miscellaneous vegetables ("San Diego Agriculture", 2019).

While the relatively moderate Mediterranean climate, in addition to a range of microclimates, makes San Diego an ideal place to grow agricultural crops and livestock products (San Diego Agriculture, 2018), there are many challenges associated with farming in the region. San Diego's current farmers face constraints on water-use efficiency and water availability that limits crop selection and efforts efforts to maximize production while also making a profit. From high irrigation demand, increasing water costs and land prices, to pervasive pest and plant diseases, San Diego farmers have no choice but to utilize innovative farming techniques and choose smart crop choices (Omsted, 2017).

Due to historic development patterns in San Diego, agriculture is often embedded within urban areas, with more small farms than any other county in the nation. Because of the average size of farms, the agricultural sector is spatially scattered throughout the unincorporated county, which can be difficult for identifying and monitoring existing agricultural land and practices. Nonetheless, San Diego's agricultural production remains more valuable than many other urbanized areas of California, including San Francisco, Orange County, and Los Angeles combined ("San Diego Agriculture", 2018). San Diego's agricultural landscape is composed of diverse lands, with varying terrain, vegetation, and agricultural use. These lands provide valuable and beneficial services for the region's food supply and ecosystems, including creation of wildlife, habitat, food for people and pollinators, and water filtration (Flint et al. 2018).

2.3 Climate

At a latitude of approximately 32 degrees North, San Diego is situated in the heart of the subtropical climate zone. The region encompasses a unique landscape, positioned between the coastal zone of the Pacific Ocean to the west and the foothills, interior mountains, valleys, and deserts to the east.

Like most areas in California, the region is known for its Mediterranean climate in which it experiences hot, dry summers, and mild winters (CNAP et al., 2015). San Diego's climate is characterized seasonally by latitudinal climate influences that cause this subtropical dryness in the summer and midlatitude storm-tracks in a concentrated wet season from October through April (Polade et al. 2017). Additionally, coastal low clouds and fog (CLCF) are a defining characteristic of San Diego's climate. CLCF typically persist throughout early summer months, helping moderate heating, buffer dryness and solar insolation, while also providing cooling and water for the region's coastal ecosystems (Kalansky et al., 2018).

The combination of complex topography, coastal effects, and wide altitudinal ranges coupled with subtropical and midlatitude influences results in a range of diverse microclimates throughout the region ("Climate of California"). In addition to impacting temperatures and humidity on the coast and further inland, the combination of these factors produce variability in monthly precipitation during the winter months (Bedsworth, 2018). With annual precipitation totals varying from as little as 50% to greater than 200% of long-term averages, California experiences the largest yearly variations in precipitation compared to any other region in the U.S (Dettinger, 2013). In particular, the year-to-year variability in southern California is higher than anywhere else in the U.S (Jennings et al. 2018). The average annual precipitation for San Diego is 10.34 inches (Murphy, 2014), however, historical averages reaching as low as 3.3 inches in 2002 and as high as 22.60

inches in 2005 ("Annual Rainfall Lindbergh") highlight the region's large inter-annual variability.

Variability in precipitation is primarily tied to the number of extreme precipitation events, known as Atmospheric Rivers (ARs). ARs contribute to 68% of extreme-rainfall accumulations in southern California (Lamjiri et al 2018). Figure 4 illustrates the correlation between the number of these top 5% of rainy days (approximating AR events) and precipitation variability. Given that the occurrence of a few AR events each year dictate floods, droughts (lack of ARs), and water availability (CNAP et al., 2015), understanding these extreme events are important for regional weather forecasting, infrastructure planning, and resource management.

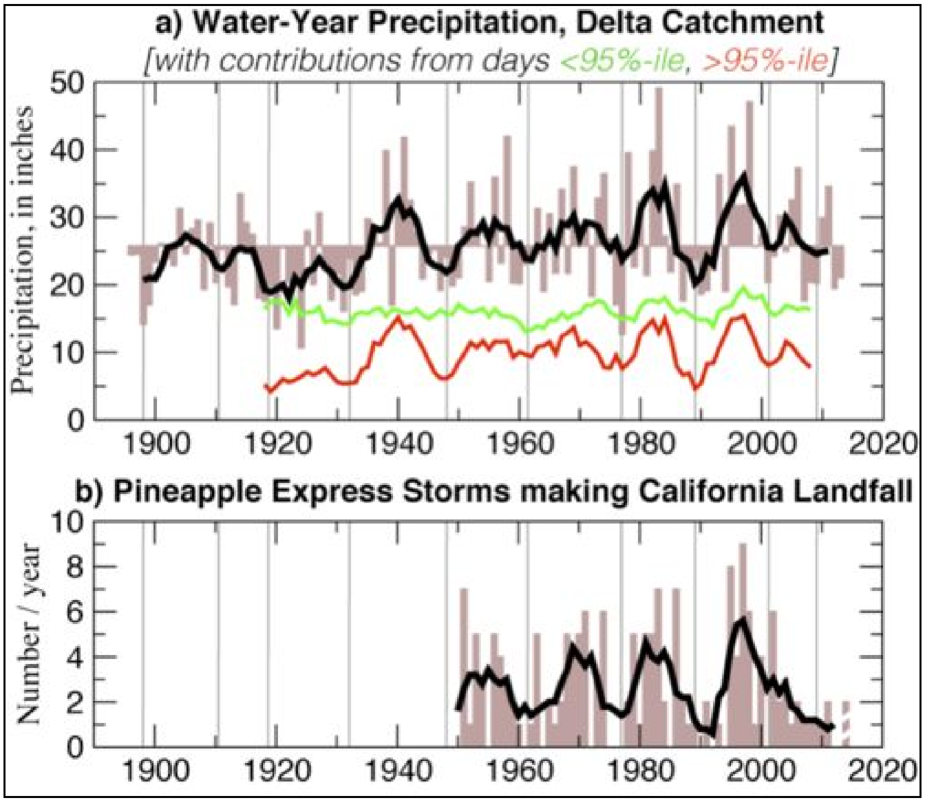


FIGURE 4: Water-year precipitation and associated contributions from the top 5% of wet days versus the other 95% and association with pineapple express or atmospheric river storms.

2.4 Water Resources and Agriculture Water Use

The San Diego County Water Authority (SDCWA) has served as the wholesale supplier for San Diego since its creation in 1944, working to secure reliable water supply for the region. SDCWA's water supply sources have changed throughout San Diego's unique historical periods. Despite these changes, SDCWA has consistently relied on imported water in some capacity ("History"). Currently, San Diego County imports around 80% of its water supply, using both local and imported sources ("Where does San Diego's", 2011). In the past, San Diego relied heavily on a single supplier of water, the Metropolitan Water District of Southern California (MWD), which includes water from Northern California and the Colorado Basin. Since the enactment of the Colorado River Compact in 1922, allowing for the diversion of water from the river to surrounding states, Colorado has been a major supplier for San Diego ("Where does San Diego's", 2011). In 1991, the MWD constituted 95% of San Diego's water supply ("Expanding a Diversified"). In the last two decades, after an extensive drought that caused MWD to reduce water delivery to San Diego, SDCWA has developed several strategies and long-term plans to diversify the region's water supply portfolio. These strategies aim to improve the region's water infrastructure, promote water-use efficiency, and ultimately secure reliability of supply ("Water Supplies"). In 2017, supply from MWD had significantly declined to 40%, allowing for inclusion of other sources. Agreements made with the Imperial Irrigation District, and the Coachella and All-American canals, which source water from the Colorado Basin, contributes another 40% of imported water to San Diego's current supply portfolio. Local sources contribute the remainder of supply, including groundwater, recycled water, and desalination ("Water Supplies").

Agriculture is one of the many sectors that is greatly dependent on these water resources. With water pricing escalating since the early 1990's, water costs have been the primary water concern for San Diego farmers ("Water", 2016). As drought conditions increasingly threaten the region's imported water sources, farmers have shifted their focus towards water availability as well ("Water", 2016). While SDCWA has worked to ensure reliable and diversified water sources over the last few decades, new water sources have proven to be expensive ("San Diego Farmers Need", 2018). In the last 12 years, the price of water has tripled, while the revenue from farm products are generally consistent, creating challenges for farmers across the region. Water alone constitutes the largest monthly expense for many farmers ("San Diego Farmers Need", 2018). Thus, farmers are eager to adopt strategies that maximize water-use efficiency, minimize use and overall costs, and increase financial returns. For farmers who choose to participate in SDCWA's special agricultural water pricing, water charges are priced at discounted rates. Nonetheless, costs per acre foot remain high, and much of the sector, specifically nursery, flower, fruit, and livestock farmers, do not participate (Simon, 2017). Not all of San Diego receives the imported water supplied by MWD and geographically, the majority of the unincorporated area (65 percent) is reliant on groundwater-dependent districts or private wells that are managed separately from SDCWA (County of San Diego, 2017). Thus, these areas are completely reliant on groundwater resources and are impacted by its availability.

The agricultural sector also relies on groundwater resources, and is considered one of the "large quantity" groundwater users (County of San Diego, 2017). These groundwater resources are often limited due to unfavorable geology, resulting in aquifers with limited groundwater in storage volume and/or groundwater recharge. Several areas throughout the county that are groundwater-dependent, specifically the unincorporated county, face groundwater hydrology issues. Given that agricultural users are not regulated or metered for water quantity, these large quantity users can create localized groundwater problems throughout the groundwater dependent areas (County of San Diego, 2017).

It is clear that water resources, availability, and supply are major focuses for the county, especially the agricultural sector. With the need to limit water use to allow for profits, water concerns continue to be a driving force for the conservation efforts of San Diego's farming community.

3.0. Regional Climate Change Impacts

It is projected that over the next several decades, California will continue to experience several changes associated with climate change, including sea level rise, precipitation patterns, and temperatures. Amid historic coastline and mountains, San Diego region encompasses many diverse climate zones. In turn, the region will likely experience a myriad of changes with dynamic, complex, and compounded effects. As a result, the county will face several challenges that could ultimately threaten the natural and human landscapes that it supports. While the region's diverse ecological systems, industries and communities have adapted to San Diego's variable and seasonal climate, climate change could exacerbate these conditions and ultimately threaten the survival of these valuable systems (Jennings et al., 2018). As one of the most "climate-challenged" regions in North America, it is critical that the county understand these regional variations in climate impacts and vulnerability (Jennings et al., 2018).

3.1 Temperature

In the region, climate change will significantly increase yearly average temperature over the next several decades, with projections ranging from 5-10° Fahrenheit (°F) depending on the Representative Concentration Pathway (RCP) greenhouse gas (GHG) concentration and region (Kalansky et al., 2018). San Diego and neighboring areas will face varying changes in the average hottest day per year, daily maximum temperature (Tmax) and daily minimum temperature (Tmin) because of the region's diverse topography and distinct microclimates. Under RCP 8.5, representing a high concentration scenario, the average hottest day per year will increase from the historic range of 90-100° F to 100-110° F in coastal zones, and from 105-115° F to 110-125° F in desert regions (Kalansky et al., 2018).

Temperature extremes are projected to increase, with climate warming increasing duration, frequency, and intensity of heat waves compared to historic climate (Figure 5) (Jennings et al., 2018). The probability of heat waves varies regionally, with some locations expected to have a greater probability of increase in the number of extremes, and in either daytime or nighttime heat waves. Extreme temperature events and increasing Tmax will further intensify the impacts of drought (Kalansky et al., 2018).

Figure 5:

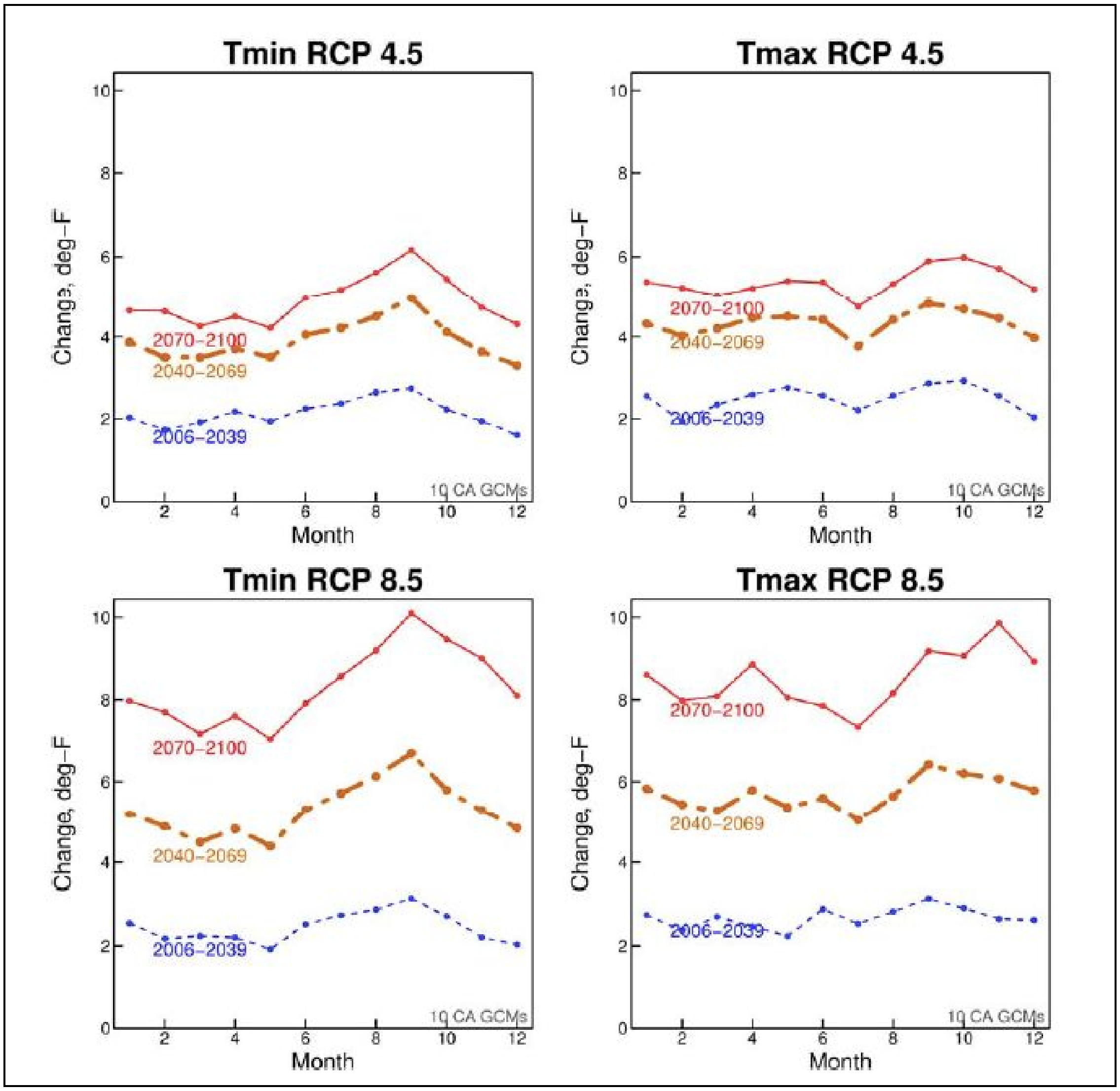


FIGURE 5: Projected shifts in Tmax and Tmin under RCP 4.5 and RCP 8.5 for 2006-2039 (dotted blue line), 2040-2069 (brown dahed line) and 2070-2100 (solid red line) **(SD Ecosystems report)**

3.2 Precipitation Variability

Although it is projected that there will be fewer total wet days and a decrease in the number of ARs globally, these wet events will likely increase in width and length by 25%, in addition to intensity (Smith, 2018). With a Mediterranean climate that is uniquely balanced between both mid-latitude storms and expanding subtropical zones, projections for California’s precipitation regime show more uncertainty and variability compared to most other Mediterranean climates around the world. While models consistently project future drying over Mediteranean climates globally, projections for California diverge from these trends, becoming wetter in winter aggregate and experiencing increases in mean precipitation (Polade et al., 2017).

As a result, the region will likely experience wetter winters yet longer, dryer warm seasons, contributing to increased year-to-year variability. With intensified extreme precipitation events, climate models indicate that the variable character of Southern California's precipitation will continue to increase (Kalansky et al., 2018). Climate change also has an impact on seasonal changes and timing of precipitation. It is projected that precipitation will increase during the region's concentrated wet winter season, while decreasing in both autumn and spring (Kalansky et al., 2018). Warmer temperatures are causing winter precipitation to fall in the form of rain rather than snow, meaning that the snowpack that acts as a natural reservoir for the state's water supply will be diminished (Figure 6) (Flint et al., 2015). As less precipitation is stored in these snowpack reservoirs, compounded with warming temperatures, the state is experiencing earlier springtime snowmelt (Figure 4). These projected changes in snowpack, precipitation and springtime snowmelt will continue to challenge many regions of California, defining the state's current and future water resources (Flint et al., 2015). Although local snowpack is not significant, loss of snowpack in the state overall will negatively impact the imported water supplies that San Diego relies upon.

Figure 6:

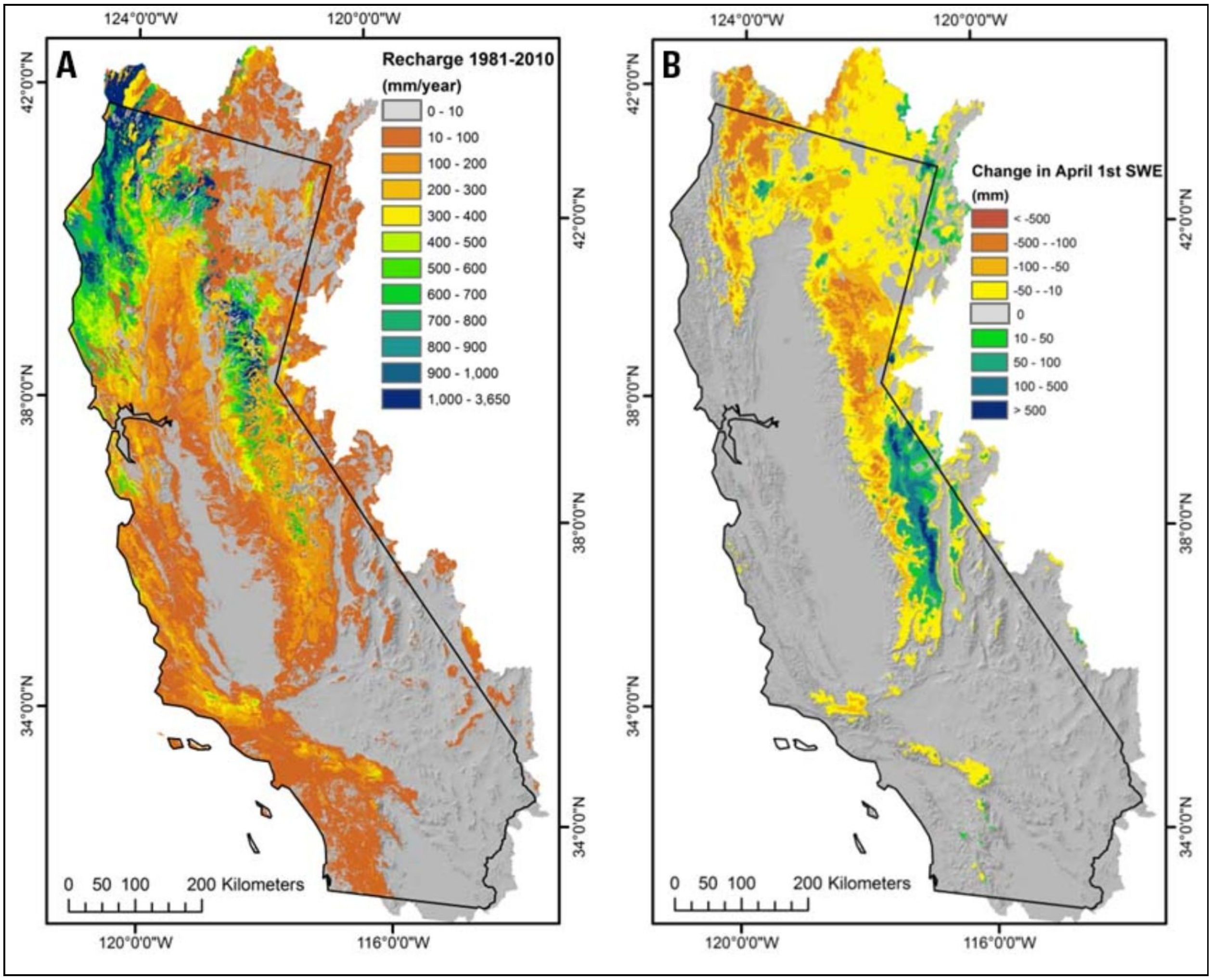


FIGURE 6: a) Recharge estimates for the period 1981-2010 in California **b)** Change in average April 1st snow water equivalent in California for the period 1951-1980 and 1981-201

3.3 Coastal Low Clouds and Fog

Coastal low clouds and fog (CLCF) that migrate along the West Coast fluctuate on annual and decadal scales, as a response to a combination of naturally occurring climate and weather patterns (Kalansky et al., 2018). Offering relief from the consistently hot, dry, drought conditions of summer, CLCF play an important role in hydrological regime and ambient temperature (Jennings et al., 2018). Although CLCF are a distinct component of San Diego's climate, it relies on highly variable, complex factors. Thus, the net effect of climate change on CLCF remains uncertain (Kalansky et al., 2018). However, observational records exhibit that California CLCF has declined over the last decade, and that this decline can be attributed to urban warming (Williams et al., 2015). Future research on the response of San Diego's CLCF to climate change is critical in understanding the implications for coastal and inland ecosystems and human communities.

3.4 Drought

Despite intensified extreme events, it is likely that droughts will increase in both frequency and intensity (Kalansky et al., 2018). San Diego will experience more dry years as the subtropical zone expands and leads to a decrease in the number of wet days (Kalansky et al., 2018). More dry days will intensify already depleting soil moisture content. This will cause earlier spring soil drying and extended drying through the late fall into winter, and thus elongate seasonal dryness in California. The combination of longer periods of dryness, expanding subtropical zones, and warming temperatures, will lead to more dry years. With more dry years and dry antecedent conditions, it is projected that future droughts will increase in duration, severity, and frequency, which will also increase the region's vulnerability to wildfire occurrence. The relative impacts of drought are likely to be more intense as well, as increased temperatures continue to create drier conditions. As the climate warms, drought conditions worsen, and Santa Ana wind events continue, it is likely that wildfire risk will also increase (Kalansky et al., 2018).

3.5 Impacts on the Region's Water Supply Sources

Given San Diego's water supply portfolio and its dependence on imported water, it is critical to consider the climate change impacts on the regions that supply much of San Diego's water supplies. These regions, largely Northern California and Colorado, are likely to experience changes in precipitation (increased variability), temperature, and thus altered snowpack and runoff patterns (Bedsworth et al., 2018).

Changing hydrologic trends throughout California will directly impact San Diego's water supply (Table 1). Water from Northern California, specifically snowpack in the Sierra Nevada Mountains, is expected to decrease due to higher rain and snow elevations, and earlier snowmelt and spring runoff. Snowpack will be reduced by more than 60% by the middle of the century, with positive feedbacks further exacerbating these warming and snowmelt trends (Kalansky et al., 2018). Increased evapotranspiration and decreased snowpack will also cause decreases in water supply in the Colorado Basin (Bureau of Reclamation, 2012). Over the next fifty years, droughts lasting five or more years are projected to occur fifty percent of the time. These impacts will reduce the water in these areas which supply San Diego, as well as counties across California and along the Colorado Basin, resulting in worsened water resource challenges. Thus, it is imperative that San Diego consider alternative sources of water and infrastructure developments, in addition to enhanced water-use efficiency across all sectors.

Table 1:

Impacts of Climate Change on California's Hydrologic Processes:
• **Soil moisture** • **Recharge/runoff ratios** • **Snowpack and springtime melt** • **Climatic water deficit** • **Evaporation** • **Impacts of land use changes to impervious surfaces**

Trends in California's Changing Hydrology:
• **Condensed wet season** • **Increase in magnitude and frequency of extremes (precip, extended dry periods, peak flows)** • **Depleted amount of water stored in mountain snowpack** • **Earlier and warmer spring runoff** • **Mountain snowpack melting faster earlier**

Sources: (Flint, 2013).

4.0 Climate Change and Agriculture

As a sector that is greatly dependent on climate and highly sensitive to environmental conditions (especially water resources), agriculture is exceptionally vulnerable to the effects of a warming world. With ongoing shifts in natural processes that dictate agricultural practices, productivity, and costs, the future of agriculture is one with distinct and palpable challenges. Because the effects of climate change on agriculture are highly dependent on variables such as climate, geography, soils, and customary agricultural practices, the net impact felt by regions will vary greatly. In some areas, it is projected that climate change may result in beneficial consequences for agriculture, while in others, consequences could be detrimental. Therefore, it is necessary to develop regionally and locally unique solutions for these changes (Walthall et al., 2013).

4.1 Climate Change Impacts on Agriculture

Most Mediterranean regions, such as San Diego, will feel the greatest impacts from increasing variability in precipitation compounded with increasing temperatures. Precipitation and temperature are deeply embedded within the hydrologic cycle, and thus, as these climate variables continue to shift, they will alter many hydrologic processes. Furthermore, increased climate variability making adaptation increasingly difficult for the farming community (Satterthwaite et al., 2010). Ongoing changes, such as the timing and frequency of precipitation, reduced snowpack levels, and earlier snowmelt, present several challenges for the region's water resources (Flint et al., 2015). These water-related challenges are inextricably linked to the overall functioning and viability of agriculture, and are thus paramount in determining the persistence and growth of San Diego agriculture.

There are several key hydrologic variables that play a role in the overall functioning of a landscape, and as these hydrologic variables change, agricultural lands are impacted. Table 2 outlines these hydrologic variables, their impact on a landscape, and projections for future climate scenarios. These hydrologic variables include: CWD, AET, runoff and recharge. One of the major hydrologic variables San Diego's landscape is climatic water deficit (CWD). CWD is the amount of additional water that would have evaporated/transpired if soil water was not limiting, combining the effects of evapotranspiration, solar radiation, and air temperature on watersheds, given the soil moisture level from precipitation ("Climatic Water Deficit"). CWD can be translated to direct impacts for agriculture. In Mediterranean climates, it is considered a proxy for water demand based on irrigation needs ("Climatic Water Deficit"). Another important hydrologic variable that heavily impacts landscapes is actual evapotranspiration (AET), which is the amount of water actually lost by the vegetated surface. For the farming community, AET translates to above ground net primary productivity (NPP) and is used as a proxy for productivity of a landscape (Flint et al. 2018). Changes in AET and CWD can be used in quantifying the additional water necessary to maintain vegetation or crops in a landscape ("Climatic Water Deficit"), effectively identifying the amount of irrigation demand needed to cover seasonal deficit (Flint et al., 2015).

Table 2: Key Hydrologic Variables:

Variable	What is it?	What does it represent?	How is it changing?
Actual Evapotranspiration *(AET)*	**Amount of water that leaves the surface through evaporation and transpiration, when water is limiting**	**Net Primary Productivity; Forage production in rangelands; Crop yield in croplands**	**AET depends on the availability of water in soils and thus drier soils in future drought conditions could decrease AET**
Climatic Water Deficit *(CWD)*	**Potential - Actual Evapotranspiration. The annual evaporative demand that exceeds the available water**	**Proxy for water demand, irrigation needs, drought stress on soils/plants. Changes in CWD represent amount of water needed to maintain current veg cover/ag crops.**	**General increase with climate change, peaking in all model scenarios by the end of summer months**
Recharge/runoff	**Water will either infiltrate into the ground (recharge) versus run off the surface (runoff)**	***Recharge* corresponds to increased soil moisture and more water available for vegetation; *Runoff* can act to increase soil erosion and agricultural runoff**	**With precipitation occurring in shorter duration, extreme events, water accumulates at a rate faster than it can infiltrate into the ground, leading to an increased runoff to recharge ratio.**

Sources: ("Climatic Water Deficit"), (Anabalon et al., 2017), (Flint et al., 2018), and (Flint et al., 2014).

Almost all future climate scenarios indicate an increase in CWD and evapotranspiration, translating to exacerbated water challenges for the region's agricultural community. Figure 7 from the San Diego Ecosystems Assessment highlights projected changes in CWD throughout San Diego, indicating less available moisture in the future during extended droughts in many areas (Jennings et al., 2018).

Figure 7:

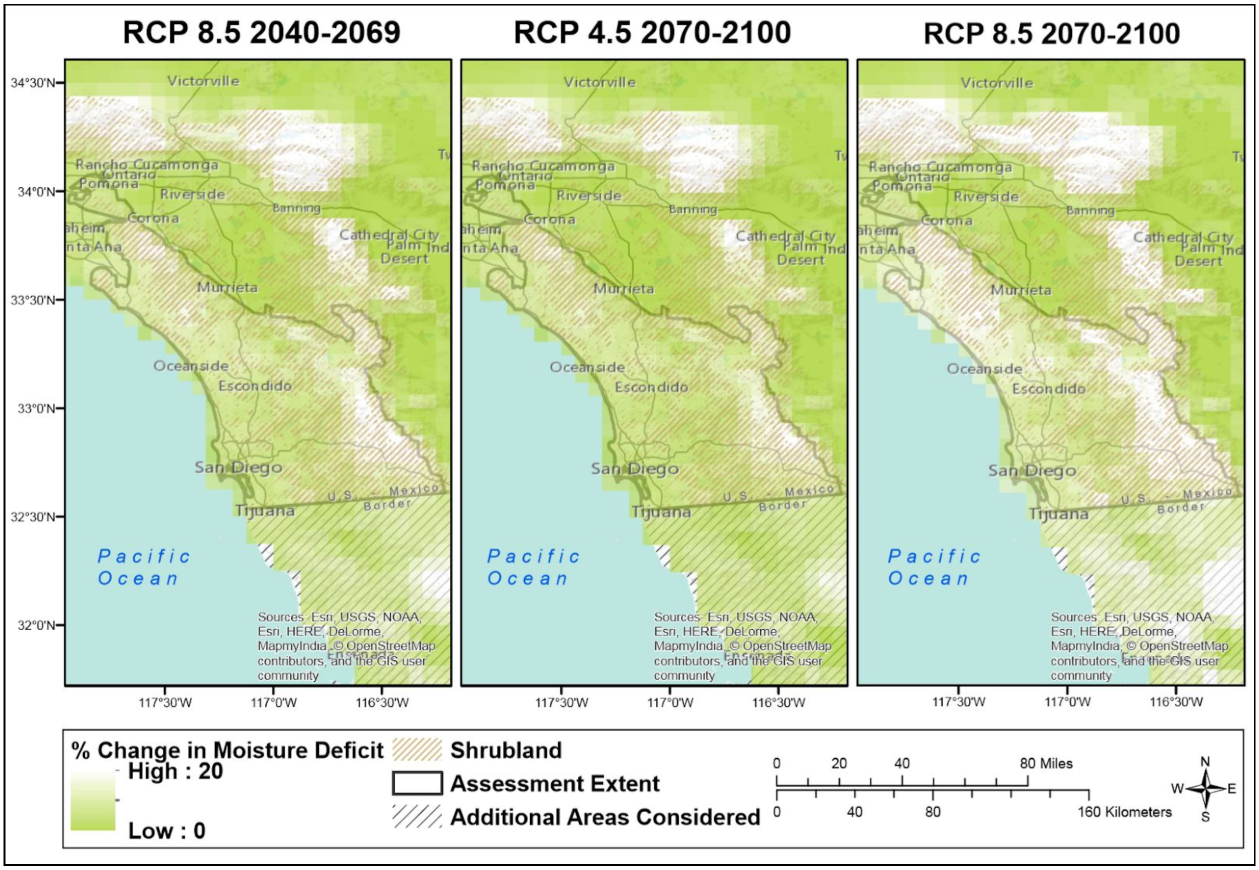


FIGURE 7: Projected percent change in CWD throughout San Diego (Jennings et al., 2018)

Changing hydrologic processes threaten the ability of various ecosystems to provide valuable ecosystem services, with implications for water quality and quantity. Both near-term and long-term changes in these services will result in lasting effects for San Diego agriculture, from determining soil processes and characteristics, to changing regional and seasonal water resources (Walthall et al., 2013). As the climate continues to change and these hydrologic processes are altered statewide, so too will San Diego's agricultural lands (Table 3).

Table 3:

Impacts on Vegetation, Landscapes, and Agriculture:

- **Increased water loss rates of many crops**
- **Changes in crop type and pollination**
- **Reduced amount of quality forage**
- **Decrease in crop yields**
- **New varieties of weeds, diseases, and pests**
- **Expanding ranges of existing weeds, disease, and pests**
- **Heat stress on plants**
- **Irrigation demand and costs**

Sources: (“California Climate Adaptation”), (Howitt, 2014), and (“Climate Impacts on”, 2016).

4.2 Agriculture Impacts on Climate

Critical to the relationship between climate change and natural landscapes is understanding the contribution of agriculture to increasing GHGs and in turn, climate change. Degrading and eroding soil from intense grazing, plowing, and clear-cutting, has throughout time, played a significant role in the increasing concentration of atmospheric GHGs (Velasquez, 2018). Long-term degradation of important features of natural lands, such as soils, forests, and wetlands, is one of the key drivers of a warming world (Velasquez, 2018). Relative emissions and impact, however, vary with region depending on soil properties and agricultural practices.

In the San Diego region, agriculture contributes approximately five percent (163,696 MTCO2e) of total unincorporated county emissions (Batra, 2018). In general, most farm-related carbon dioxide (CO2) emissions result from a variety of soil, livestock, and manure management practices, including soil tillage, overgrazing, farm equipment, livestock and fertilizer use (“Carbon Farming”).

5.0 Carbon Sequestration and Climate Mitigation Opportunities

With extensive loss of fertile topsoil over the last century, the agricultural sector has heavily contributed to climate change while increasing its own vulnerability (“Soils Help to Combat”, 2015). Although agriculture accounts for a significant portion of GHG emissions both globally and in San Diego, intentional preservation of these landscapes and soils can also offset these impacts by reducing and storing carbon, one of the major GHGs causing climate change to accelerate.

5.1 Carbon Sequestration in Soils

The world's soils play a critical role in food production, water resources, both quantity and quality, and increased net primary productivity. Enriched with soil organic matter (SOM), soil has the ability to recycle dead matter into mineral-rich nutrients vital for plants and other organisms. Additionally, soil provides the distinct and critical service of removing gases from the atmosphere. Through the biological process of carbon sequestration, carbon dioxide (CO2) is removed from the atmosphere and stored as sinks in soils. This service helps keep terrestrial and atmospheric carbon levels in a balance ("Integrate Carbon Farming").

Carbon is the primary component of SOM and provides soil with defining characteristics such as water-retention capacity, filtering capabilities, structure, and fertility (Schwartz, 2014). Because pools of soil organic carbon (SOC) aggregates are stable and robust, they provide the largest store of terrestrial carbon and have the ability to be sequestered for up to a millennia (Ontl, 2015). The length of time and amount of carbon that remains in the soil is largely influenced by ecosystem and environmental processes, depending on vegetation, soil properties, water drainage, and climatic conditions**.** Thus, levels of SOC varies on large-scale global patterns and on smaller-scale regional and subregional basis (Brashears et al., 2008).

The unique capability of soil to nourish vegetation and capture carbon long-term helps buffer the implications of climate change for both society and ecosystems alike. Additionally, with the likelihood of increased flood events, agriculturally managed lands could play a role in retaining flood waters for flood risk reduction as well as possible groundwater recharge.
However, the ability of soils to provide these services is contingent on its overall quality. The length of time and amount of carbon that remains in the soil is largely influenced by management practices, in addition to ecosystem and environmental processes ("The Benefits of Fertile", 2018). If soils are poorly managed with unsustainable agricultural

practices, soils can release CO2, contributing to atmospheric concentrations. Alternatively, if healthy, soils can enhance sequestration and continue to play an essential role in climate change mitigation. Thus, promoting healthy soil is critical to ensuring the resilience of landscapes, agriculture, and society.

5.2 Agricultural Practices for Enhancing Sequestration

Recently research has focused on the potential of enhancing SOC sequestration to help moderate high levels of atmospheric carbon. On a large scale, SOC sequestration could hypothetically sequester all current annual GHG emissions globally, at approximately 52 gigatonnes of CO2 equivalent ("Regenerative Organic"). This research highlights the ability of soils to offset increasing atmospheric CO2, where restored SOC pools could promote productivity, fertility, and resiliency to a variety of climate extremes.

Table 5: Benefits & Co-Benefits of Enhancing Carbon Sequestration

Increases in:
Soil water holding capacity (WHC)
Pollinators and biodiverse habitats
Soil fertility and nutrient cycling
Crop and forage yields
Habitat biodiversity and microclimates

Reductions in:
Atmospheric GHGs
Soil erosion
Irrigation needs/demand
Fertilizer and water purchases/costs for farmers
Landfill
Pests

Sources: (Batra, 2018)

There are a variety of carbon farming practices that farmers can adopt in order to achieve these benefits (Table 6). Table 6 outlines some of the common on-farm conservation practices recognized by the Natural Resource Conservation Service (NRCS) to improve soil health, sequestration rates, and associated co-benefits ("Carbon Farming"). From permanent crops, compost and mulch application, windbreak renovation, no-till row crops, to cover cropping, the agricultural community has several options when it comes to implementation ("Carbon Farming"). Overall effectiveness, in terms of sequestration rate, GHG reduction, and benefits will depend on various climatic and environmental factors. Thus, suitability of practices vary by region and individual agricultural context.

Table 6: On-Farm Conservation Practices

Carbon Farming Practices:
• **Compost/mulching application** • **No till/ low till tillage management** • **Silvopasture establishment** • **Hedgerow planting** • **Cover and alley cropping** • **Residue and tillage management** • **Anaerobic digester** • **Multi-story cropping** • **Windbreak/Shelterbelt establishment** • **Nutrient management** • **Tree/shrub establishment** • **Forest Stand improvement** • **Riparian restoration** • **Vegetative barrier** • **Alley cropping** • **Riparian herbaceous cover** • **Range planting** • **Critical area planting** • **Filter strip** • **Grassed waterway** • **Hedgerow planting** • **Cross wind trap strips conservation cover** • **Wetland restoration**

Sources: ("Carbon Farming")

Many studies have shown that compost application is one of the most impactful practices for carbon sequestration rates. Field and model results from a report within California's Fourth Climate Change Assessment indicate that a one-time ¼ " application of compost to California's range and croplands can lead to increased carbon sequestration and net primary production (NPP) rates in soils maximized after 15 years (Flint et al., 2018). In another study conducted by the Marin Carbon Project, it was shown that a one-time application of a ½ layer of compost on grazed rangeland was able to increase carbon storage by 1 ton of carbon per hectare. This resulted in both increased forage production and water holding capacity (Batra, 2018).

6.0 Methodology and Procedures

6.1 Use of Climate and Hydrologic Modeling Data

This study uses downscaled statewide modeling data to analyze hydrologic response in San Diego as it relates to agricultural land evaluation, based on a report for California's Fourth Climate Change Assessment (CA 4th Assessment) by Flint et al. 2018. The Basin Characteristization Model (BCM) is a grid-based model that combines climate inputs, watershed, and landscape characteristics to calculate the water balance. By combining fine-scale data, the BCM can generate detailed assessments of coupled climate and hydrologic response (Flint et al., 2014). Precipitated water can act in various ways as it enters into a landscape, from evaporation and transpiration, recharge, or runoff. Given climate data, governed by latitude, longitude, elevation, slope, and aspect, in addition to soil properties, and characteristics of deep soil materials, the BCM can effectively model the response of these hydrologic factors (Flint et al., 2013).

Figure 8:

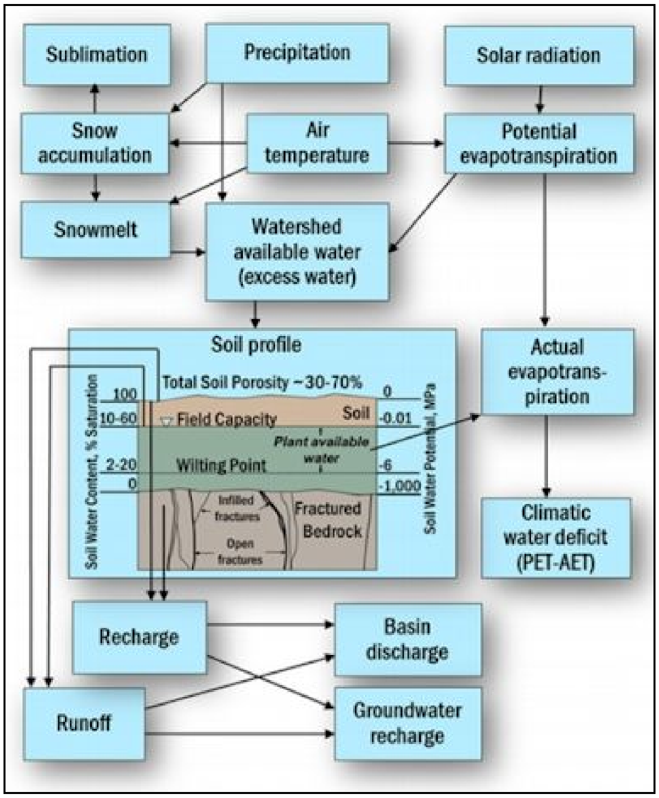


FIGURE 8: Diagram detailing the major elements of the BCM (Flint et al., 2018)

Flint et al. 2018 utilized a revised version of the BCM to include SOM percentage for calculations of WHC. Using this modified version of the BCM, Flint et al. calculate how increases in SOM changes hydrologic response to climate (Flint et al., 2018). The study assesses changes in WHC as a result of additional SOM, and the impact that changes in WHC have for hydrologic variables such as recharge, runoff, AET, and CWD throughout the state. Table 6 outlines the predicted hydrologic response to these changes, however, response is dependent on several factors, including precipitation.

Figure 10 shows the high variability of potential hydrologic benefits from increases in SOM for the period of 1981-2010 across the state's working lands (Figure 10) (Flint et al., 2018). These results showcase the diversity of climates and soil properties throughout the state's landscape, and the impacts these factors have for potential benefits in forage production, landscape stress, irrigation demand, and water supply (Table 8) (Flint et al., 2018).

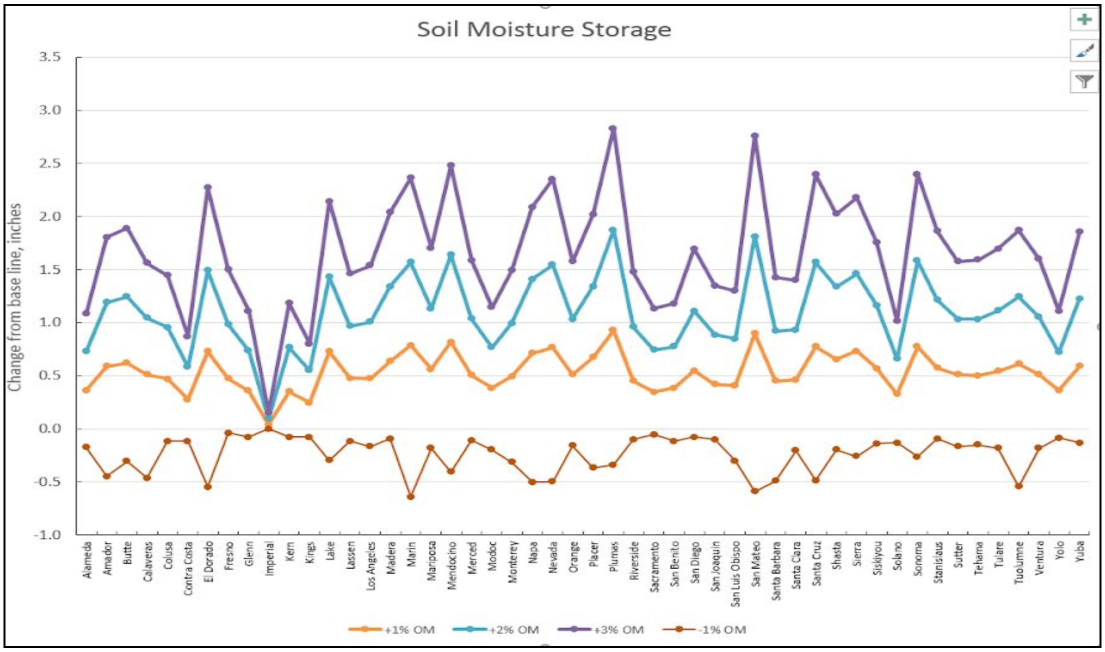


FIGURE 10: Results show the county averaged change in WHC, AET, and recharge from baseline SOM conditions to varying increases of SOM (1%, 2% and 3%) for 1981-2010 period (Flint et al., 2018).

Table 8:

Translating Improved Hydrologic Conditions to Co-Benefits:
- Increased infiltration, percolation, soil porosity → improved WHC; soil moisture; drought resilience; carbon capture capacity
- Increased recharge → reduced soil erosion; agricultural runoff; stormwater
- Reduced soil erosion → improved surface water quality
- Increased AET → Improved NPP; crop and forage yields
- Reduced CWD → Less irrigation demand; landscape stress

6.2 Methodology

This report uses a regional application of BCM output data to show hydrologic response of individual hydrologic variables to increasing SOM throughout San Diego. Figure 11 shows the response of CWD and AET to soil management, measured as the difference from baseline conditions (without added SOM) under a scenario of 3% increase in SOM (Figure 11).

Figure 11:

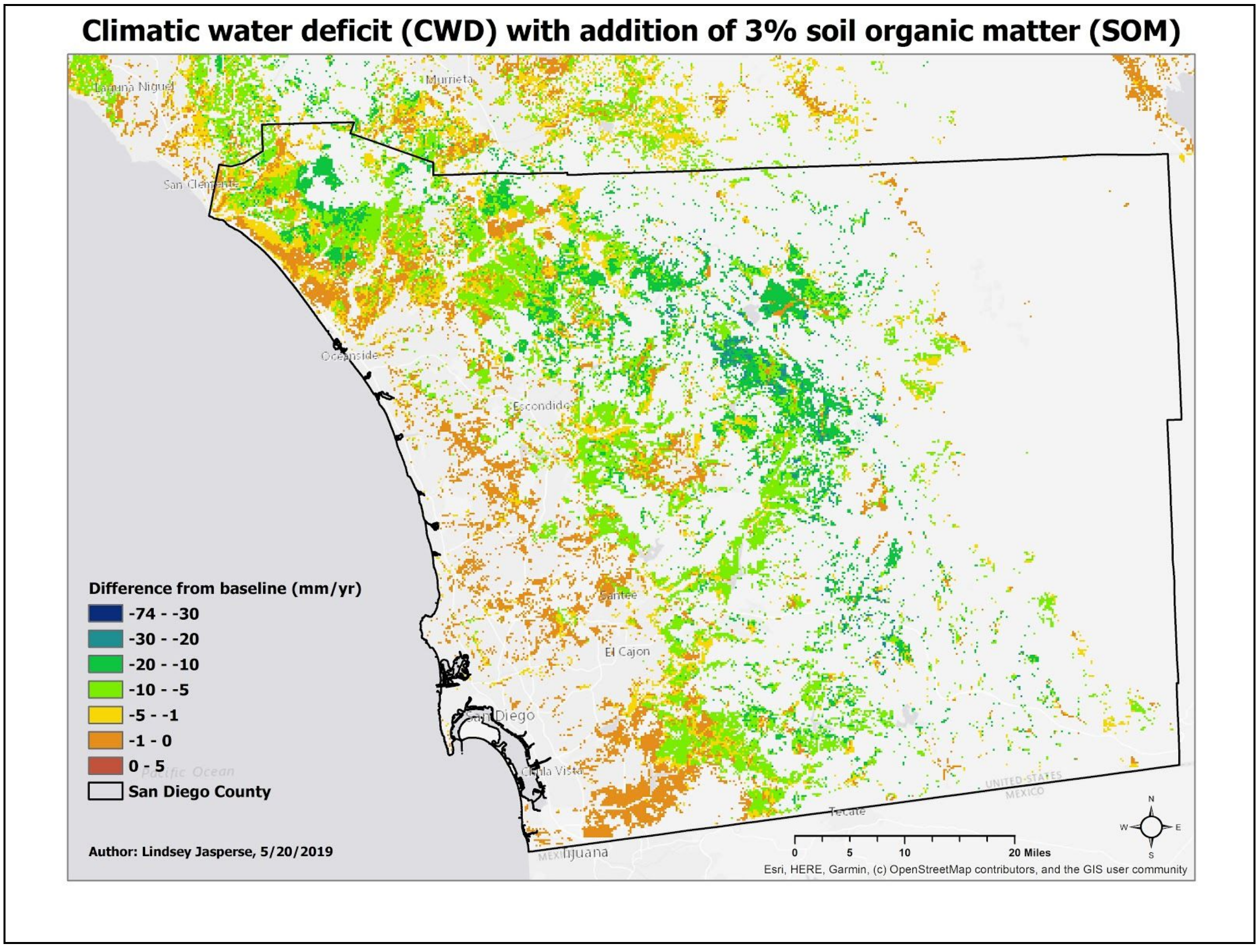


FIGURE 11a: Difference from baseline conditions (1981-2011) for **a)** CWD (mm/yr) from addition of 3% SOM

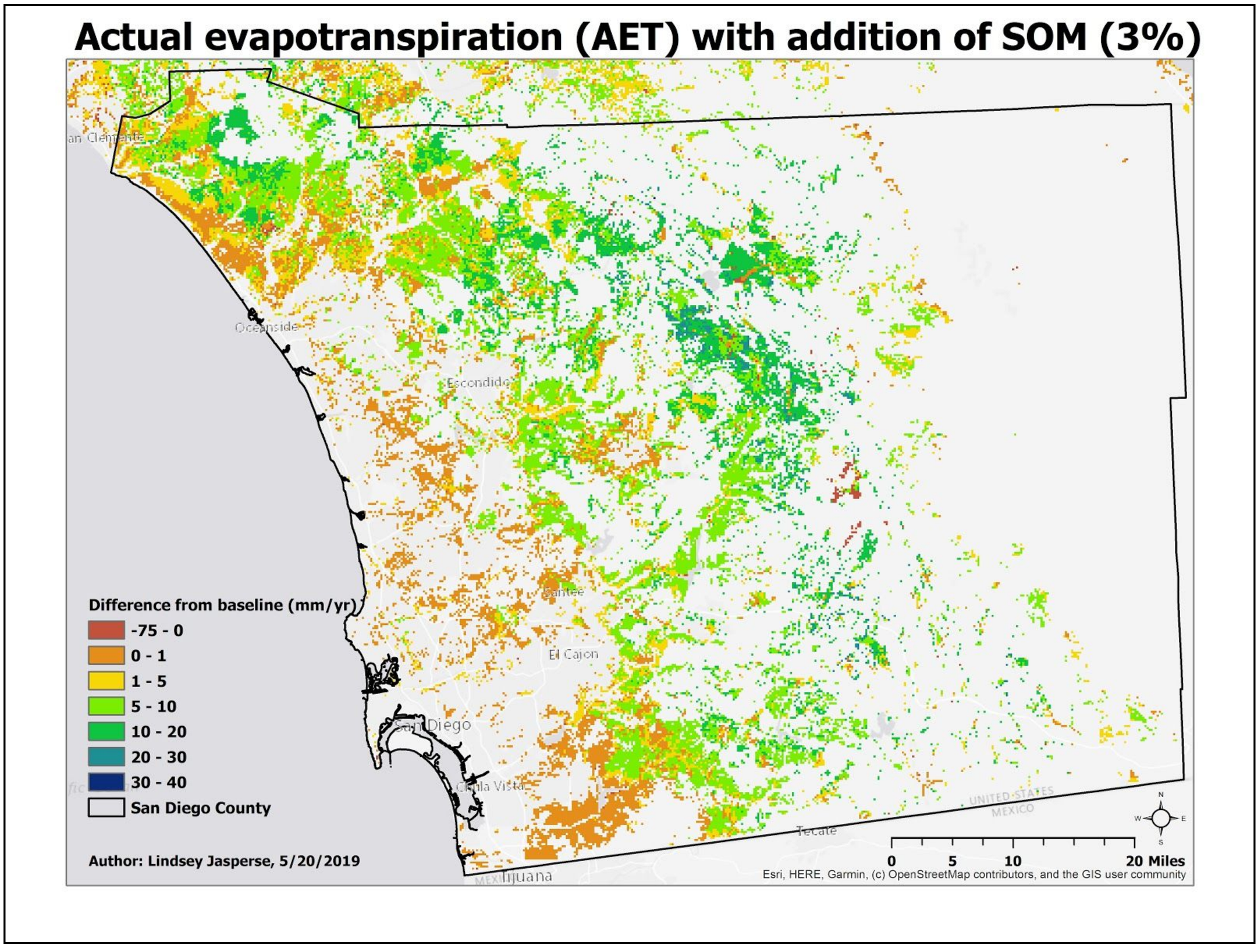


FIGURE 11b: Difference from baseline conditions (1981-2011) for **b)** AET (mm/yr) from addition of 3% SOM

Hydrologic benefit is calculated using a hydrologic index from changes in these variables, specifically increases in AET and recharge, and decreases in CWD (Flint et al., 2018). The hydrologic index is binned into three classifications of benefit based on index value, including “no benefit”, “minimum benefit”, “moderate benefit”, and “maximum benefit”. Hydrologic benefit is mapped for the entire county (Figure 12a), the unincorporated county excluding the incorporated areas (Figure 12b), and the incorporated county (Figure 12c). Areas showing “no benefit” or that were not included in statewide calculations were not included in mapping analyses. These areas of no benefit are likely due to a combination of factors, including soil properties such as high clay or sand soils, and organic-rich soils.

Figure 12:

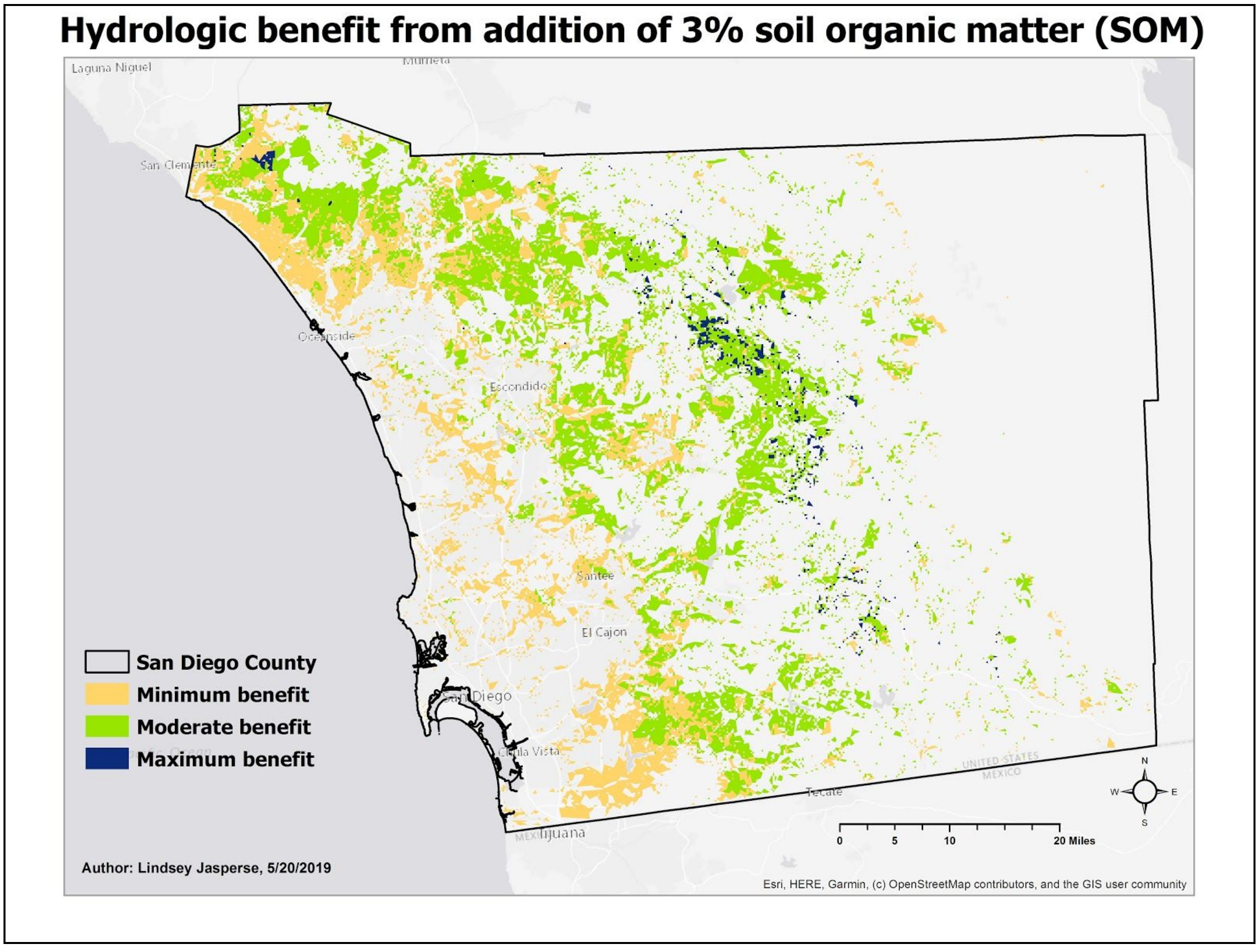


FIGURE 12a: Hydrologic benefit from addition of 3% SOM using index combining AET, recharge, and CWD. Hydrologic benefit shown for **a)** entire San Diego region.

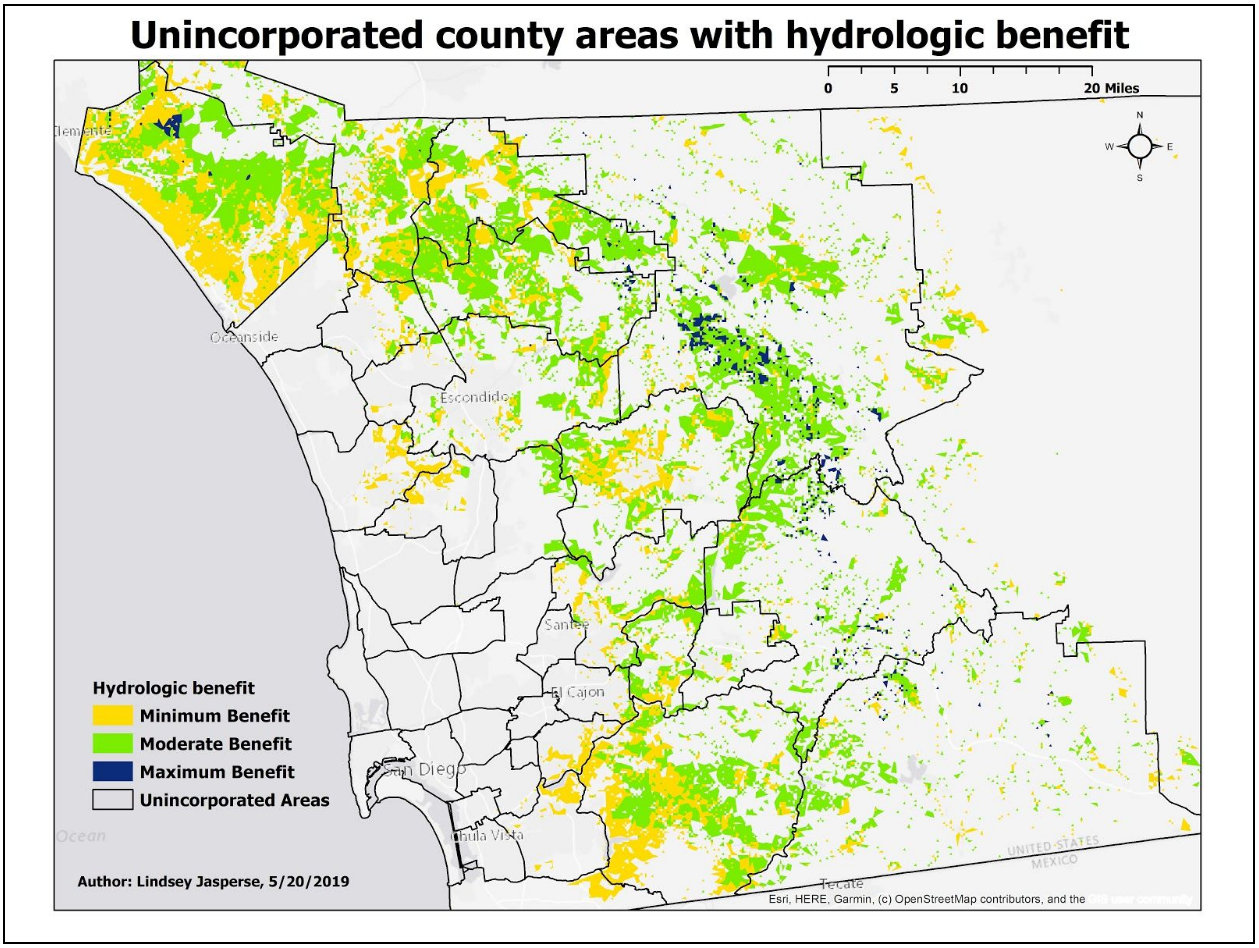


FIGURE 12: Hydrologic benefit from addition of 3% SOM using index combining AET, recharge, and CWD shown for **b)** unincorporated areas of San Diego

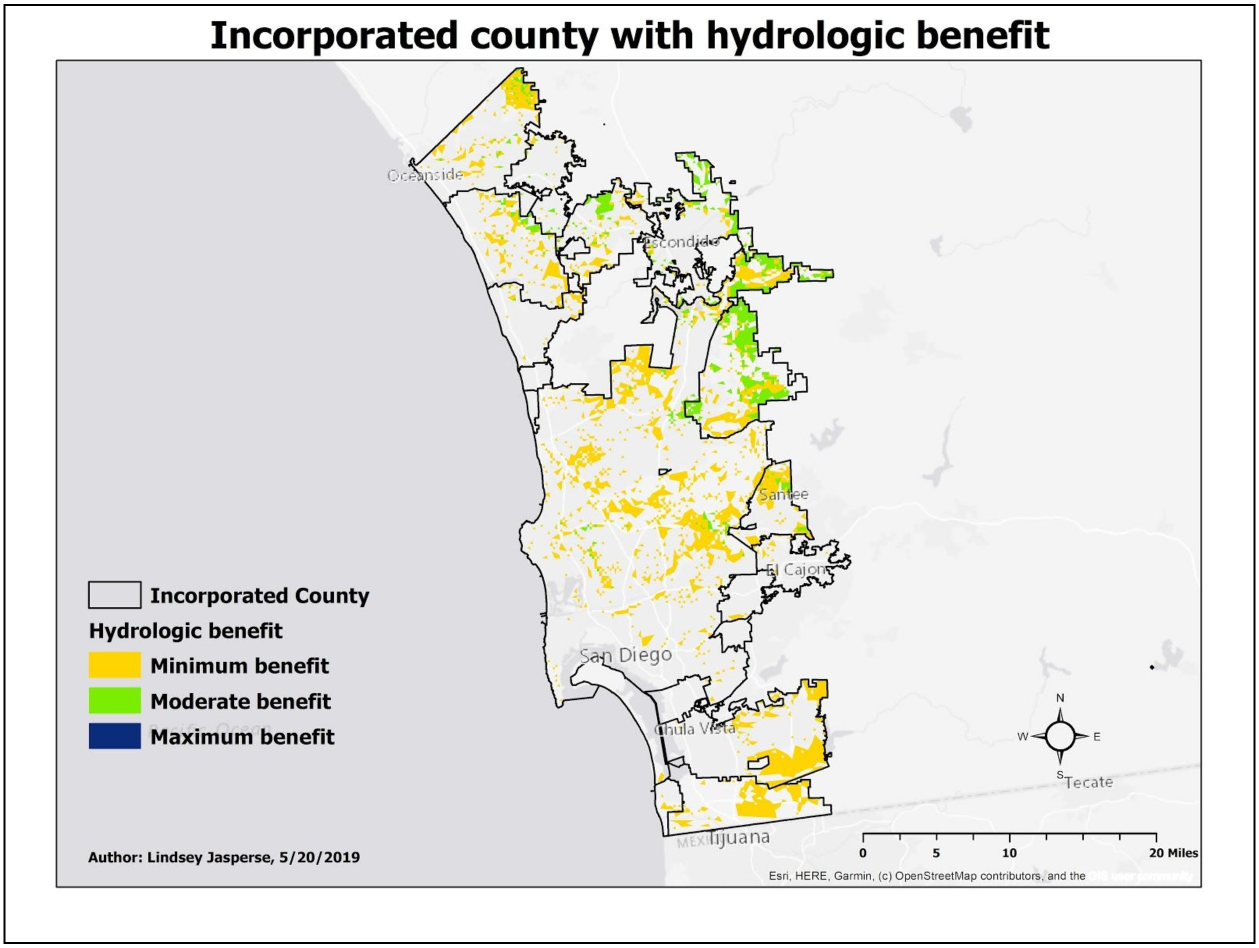
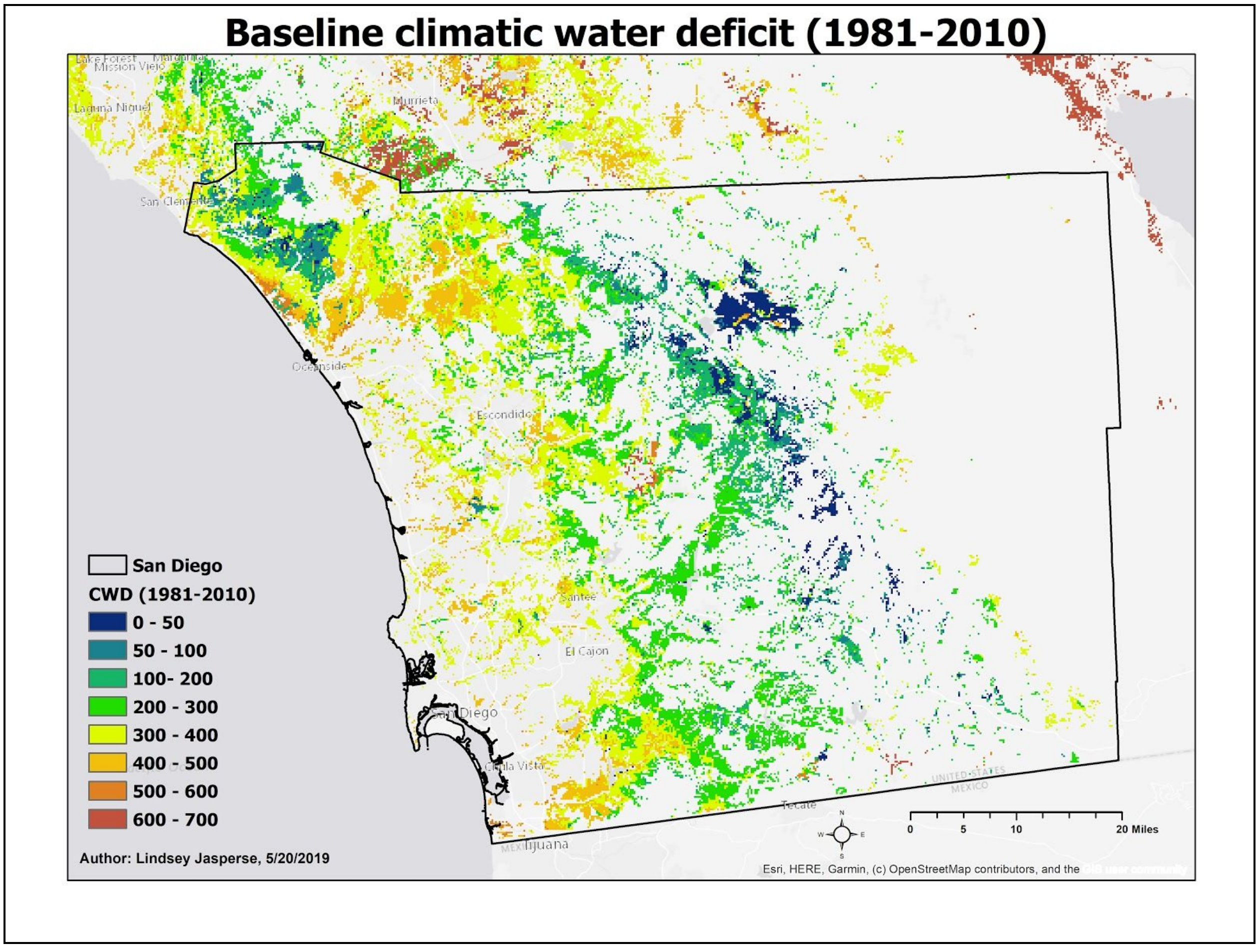


FIGURE 12: Hydrologic benefit from addition of 3% SOM using index combining AET, recharge, and CWD shown for **c)** incorporated county of San Diego

Analysis includes projections of climate impacts on CWD for a hot and wet future (CanESM2) for RCP8.5 (Flint et al., 2018). The CanESM2 model accounts for a high range of precipitation variability from year-to-year compared to hot and dry future models (Flint et al., 2018). Projections of hydrologic response for CWD in a future climate scenario shows the percent difference in CWD by 2099 due to an addition of 3% SOM compared to baseline conditions for 1981-2010 (Figure 13).

Figure 13:



Baseline climatic water deficit (1981-2010)

Author: Lindsey Jasperse, 5/20/2019

Esri, HERE, Garmin, (c) OpenStreetMap contributors, and the GIS user community

FIGURE 13 a) CWD for baseline conditions for 1981-2010 (mm/yr)

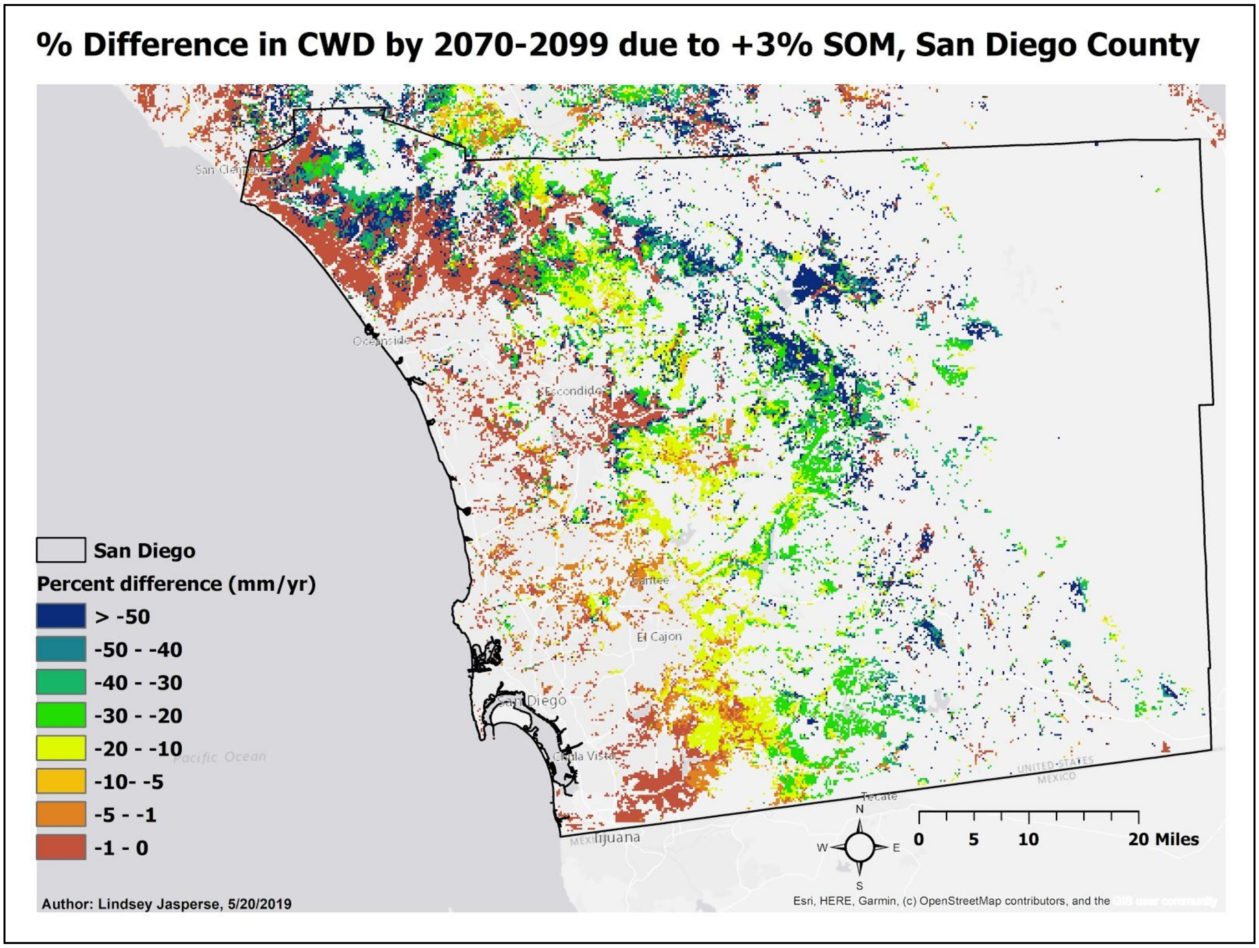


Figure 13b) Percent difference of CWD by 2099 due to addition of 3% SOM for CanESM2 RCP8.5 climate projection

To help evaluate a more accurate representation of agricultural lands in San Diego unincorporated county, this study combines two agricultural data sources. These sources include the Farmland Mapping and Monitoring Program (FMMP) and agriculture listed in SANDAG's current land use. FMMP aims to show the relationship between the quality of soils for agricultural production and the land's use for agricultural, urban, and other purposes ("Prime Farmland"). Agricultural land is ranked as "unique", "prime", "grazing lands", and "important" locally and/or statewide based on soil quality as a metric for quality and irrigation status as a metric for status of use ("San Diego Land Use Conversion") (Figure 14a).

Figure 14:

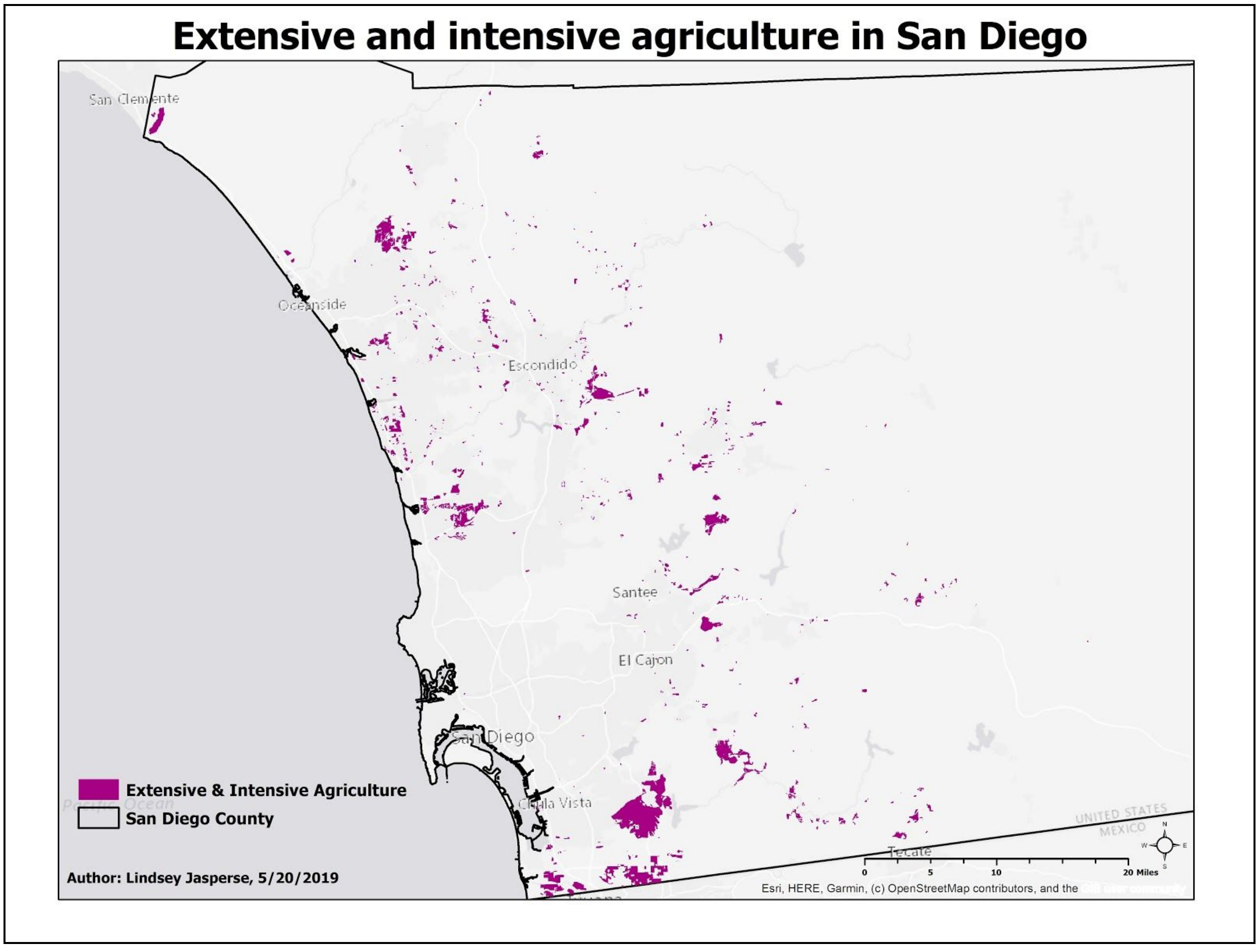


FIGURE 14: a) "Extensive Agriculture" and "Intensive Agriculture" in San Diego

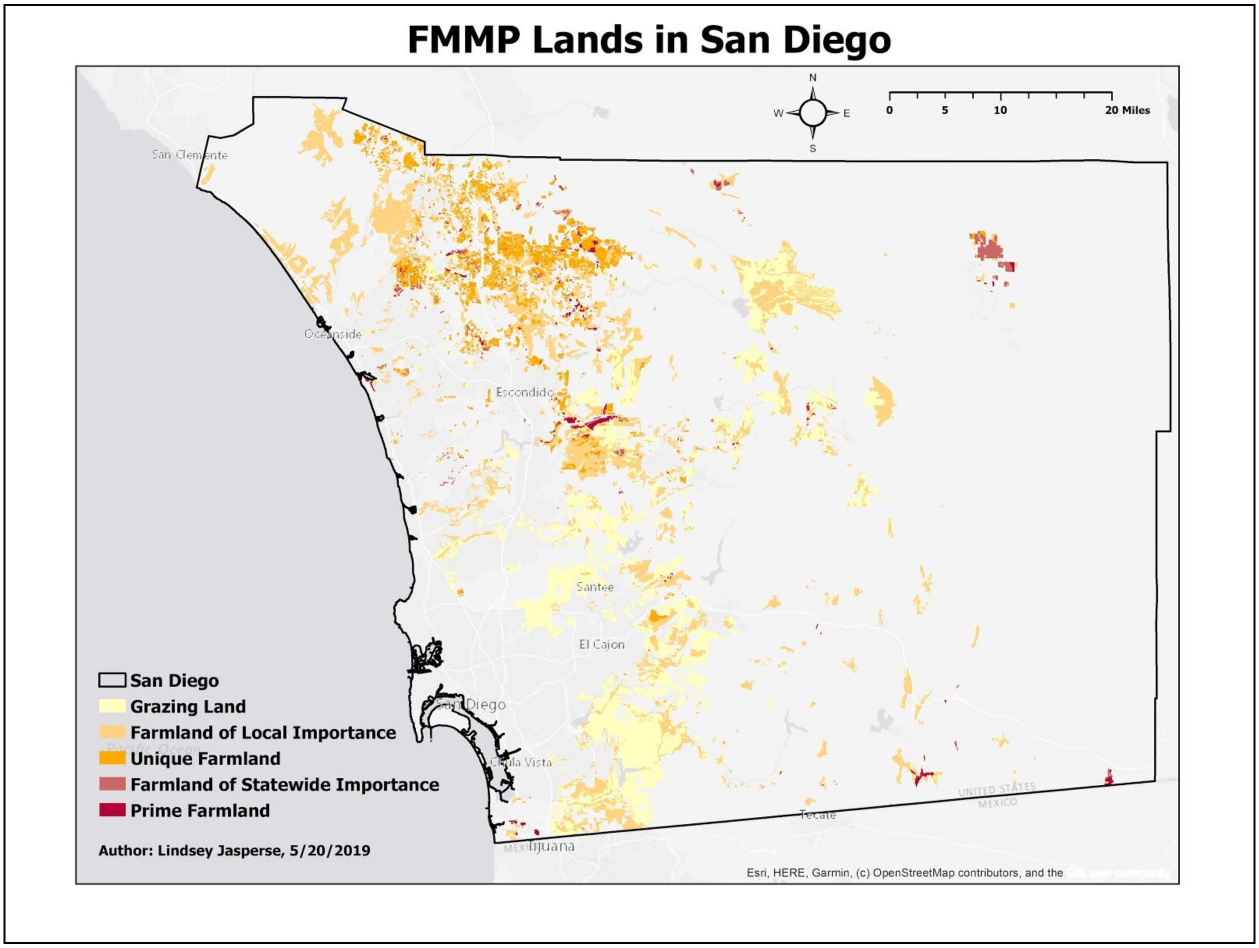


Figure 14: b) Ranked FMMP lands from highest to lowest total area (acres)

While FMMP helps identify the quality and location of the region's designated farmland, it is important to consider that FMMP may under represent the total agricultural land that exists in San Diego. Furthermore, the lands that are not represented and/or classified with FMMP are important features of the region, and are thus important to include in analysis. Current land use maps from the county's data portal utilize "extensive" (field/pasture, row crops) and "intensive" (dairies, nurseries, chicken ranches) to illustrate current agricultural land (Figure 14b).

Extensive and intensive lands are combined with FMMP lands to provide a more accurate and complete context of existing agriculture. Combined, these lands represent the agricultural lands study area used throughout this report. Several conservation programs exist in efforts to preserve San Diego's agricultural lands. Easements and formal protection of land listed on the California Conservation Easement Database (CCED) and California Protected Areas Database (CPAD) are included in analyses to understand the areas of agricultural land study area that are currently protected (Figure 15).

Figure 15:

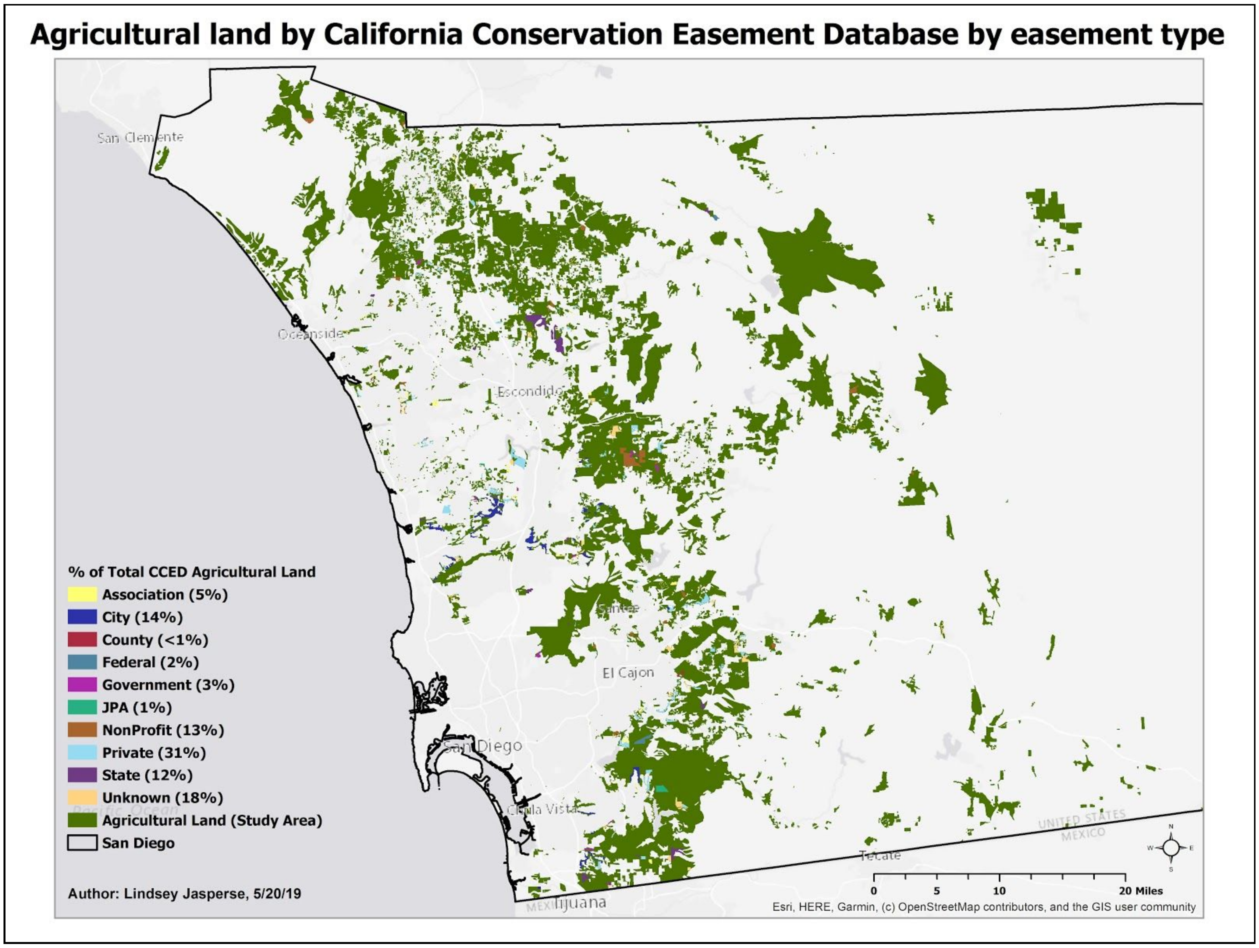


Figure 15: "Agricultural Land" categorized as areas of preserved land by **a)** conservation easement type under CCED

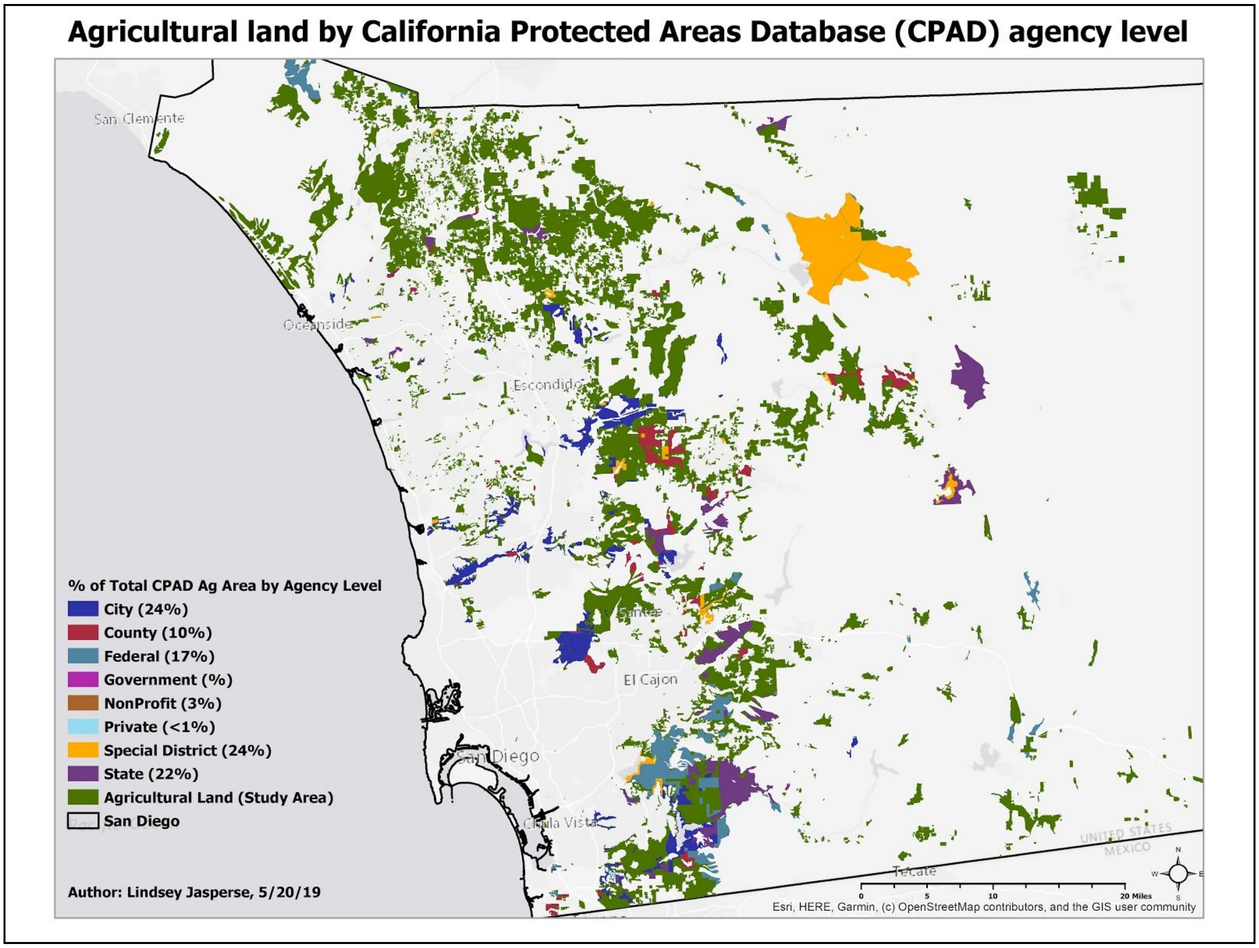
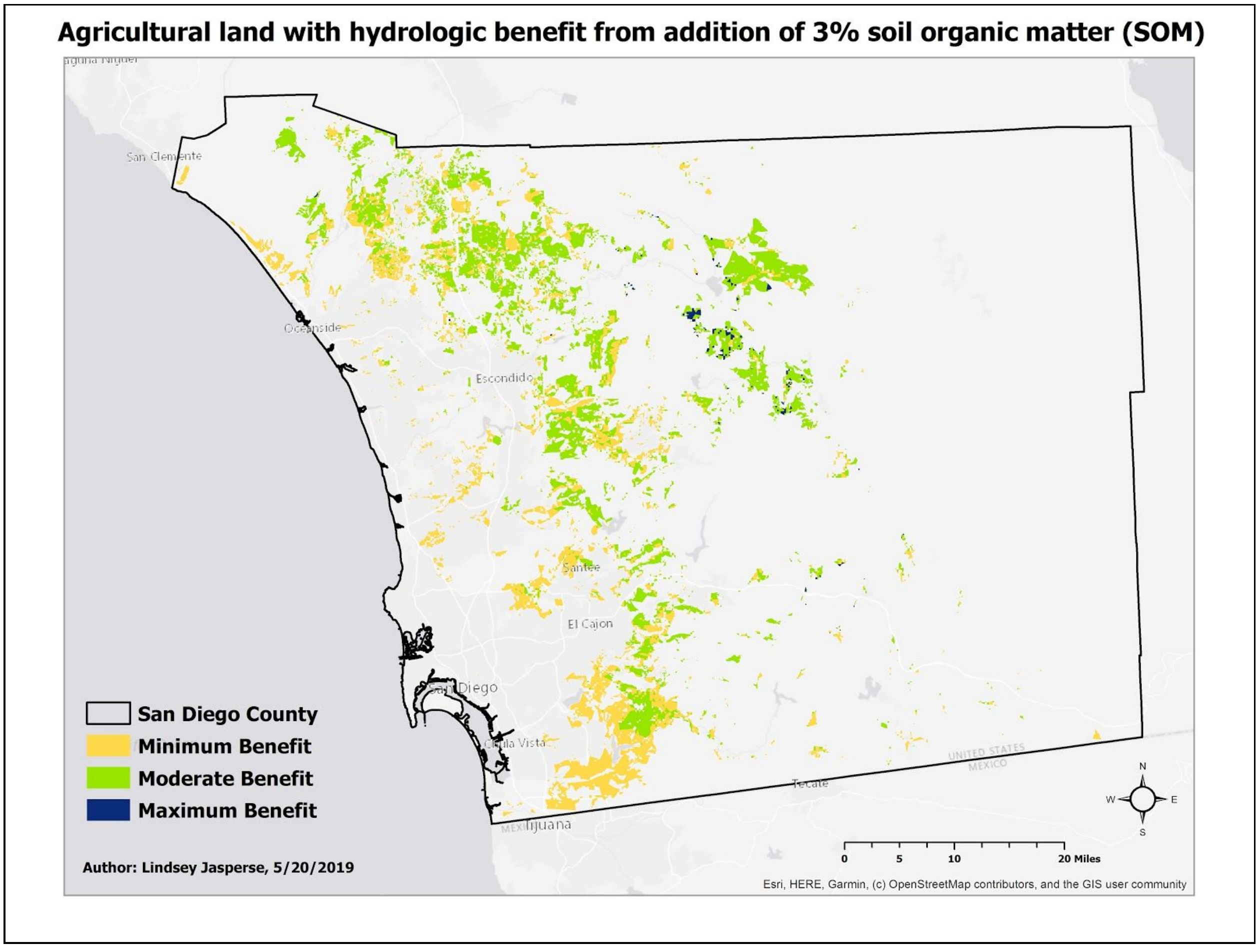


Figure 15: “Agricultural Land” categorized as areas of preserved land by **b)** ownership agency type under CCED

Potential hydrologic benefit from the BCM hydrologic index are overlaid on the agricultural study area to exhibit the existing agricultural lands showing potential hydrologic benefit from soil management of SOM 3% (Figure 16).

Figure 16:



Agricultural land with hydrologic benefit from addition of 3% soil organic matter (SOM)

Author: Lindsey Jasperse, 5/20/2019

Esri, HERE, Garmin, (c) OpenStreetMap contributors, and the GIS user community

FIGURE 16: Total area of agricultural land intersected with hydrologic benefit index from addition of 3% SOM for San Diego county

Planned land use layers from SANDAG Regional GIS Data Warehouse are created for the Regional Growth Forecast, outlining projected growth for the San Diego region to suitable areas. Planned land use projections are categorized in terms of planned land use designation. Non-agricultural land use types are separated as “urban”, including commercial, industrial, and/or urban designation, or non-urban, including water and open space/parks. Land use data planned for urban use by 2050 are overlaid with existing agricultural lands to identify agricultural lands threatened by future urban development (Figure 17).

Figure 17:

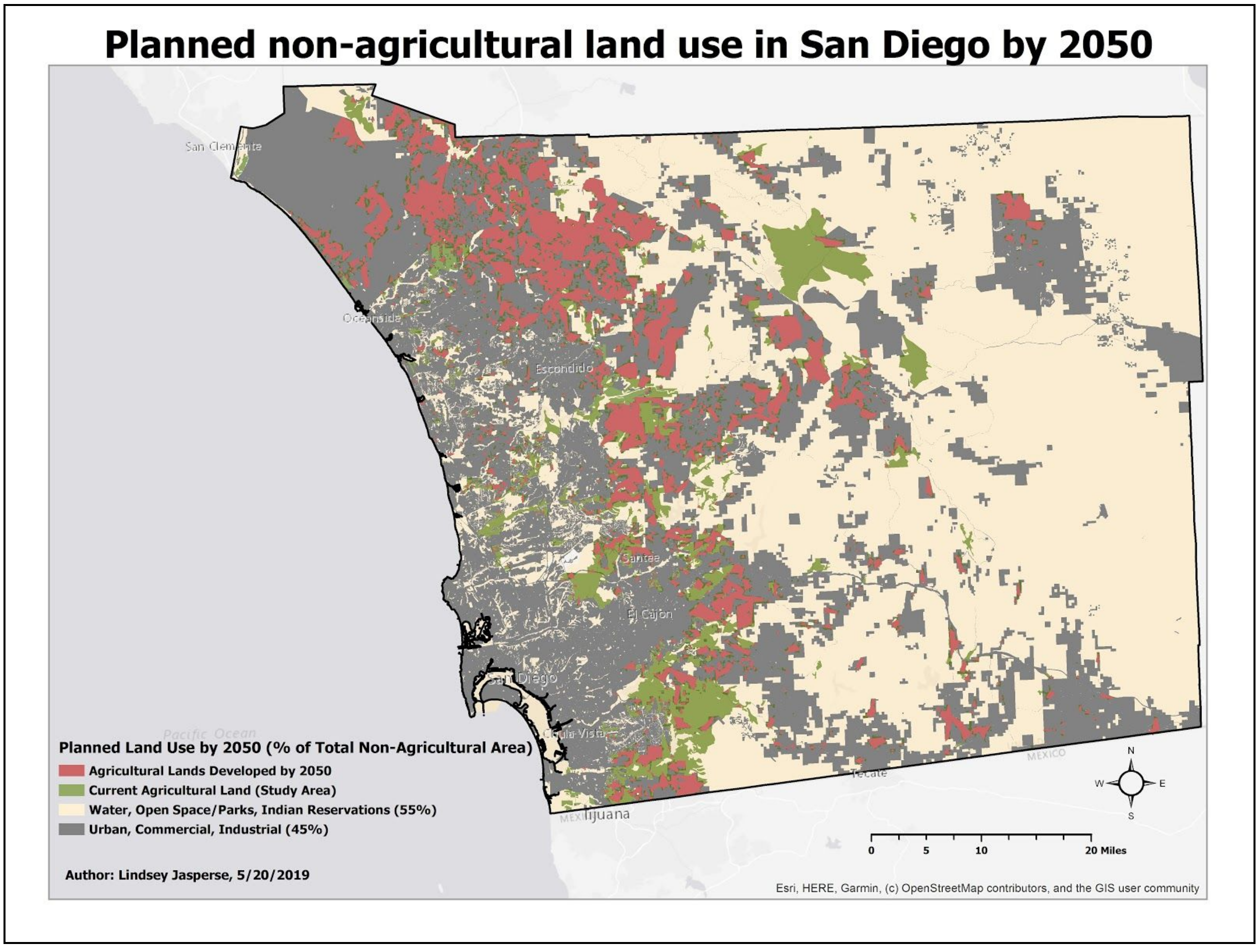
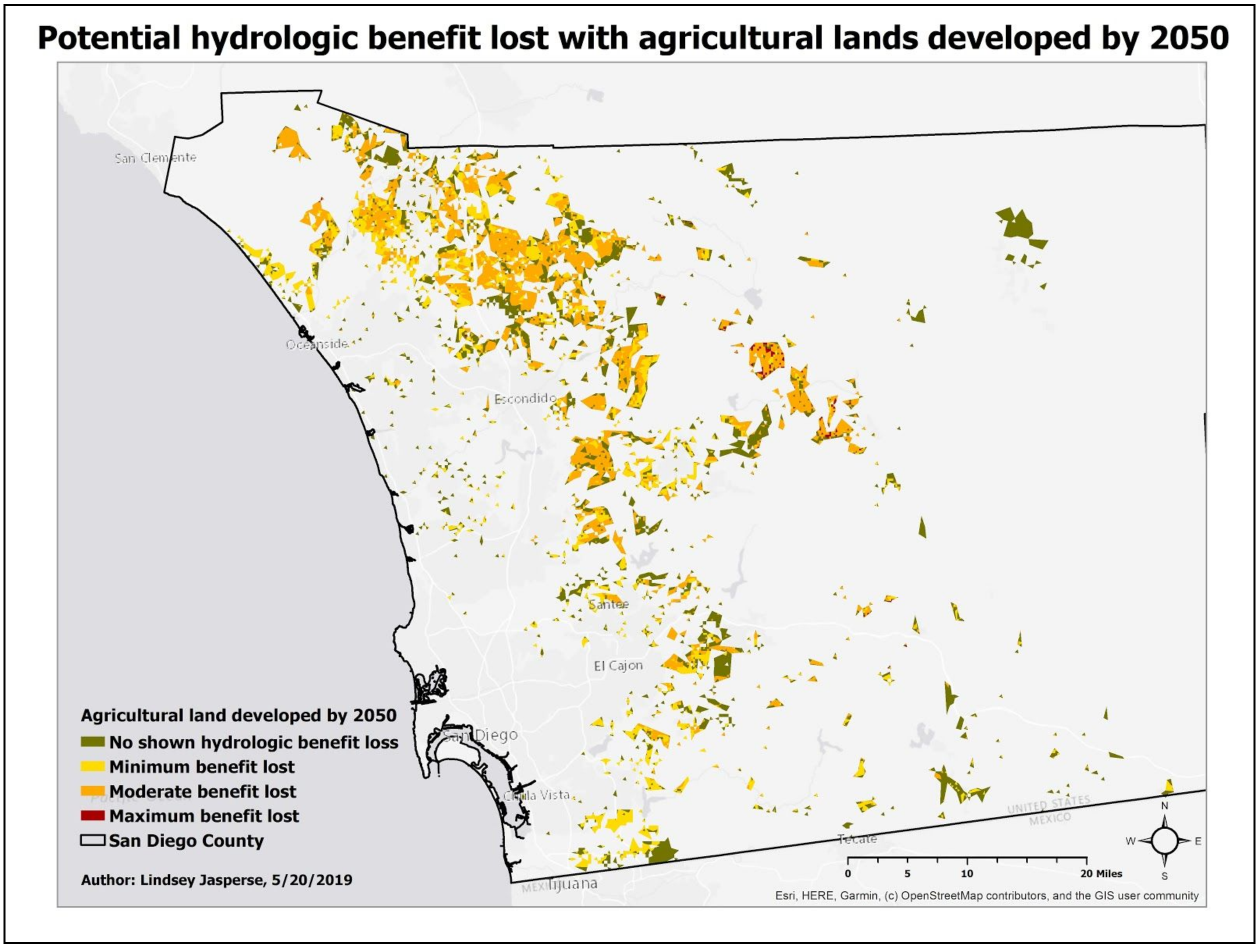


FIGURE 17: Current agricultural lands with planned non-agricultural land use by 2050; red areas represent current agricultural lands that intersect with planned urban development (urban, commercial, industrial land use)

The potential hydrologic benefit corresponding to addition of SOM 3% on these threatened agricultural lands are used to illustrate the lost opportunity for hydrologic benefit if agricultural lands are developed and thus no longer viable for soil management practices and enhanced sequestration (Figure 18).

Figure 18:


Potential hydrologic benefit lost with agricultural lands developed by 2050

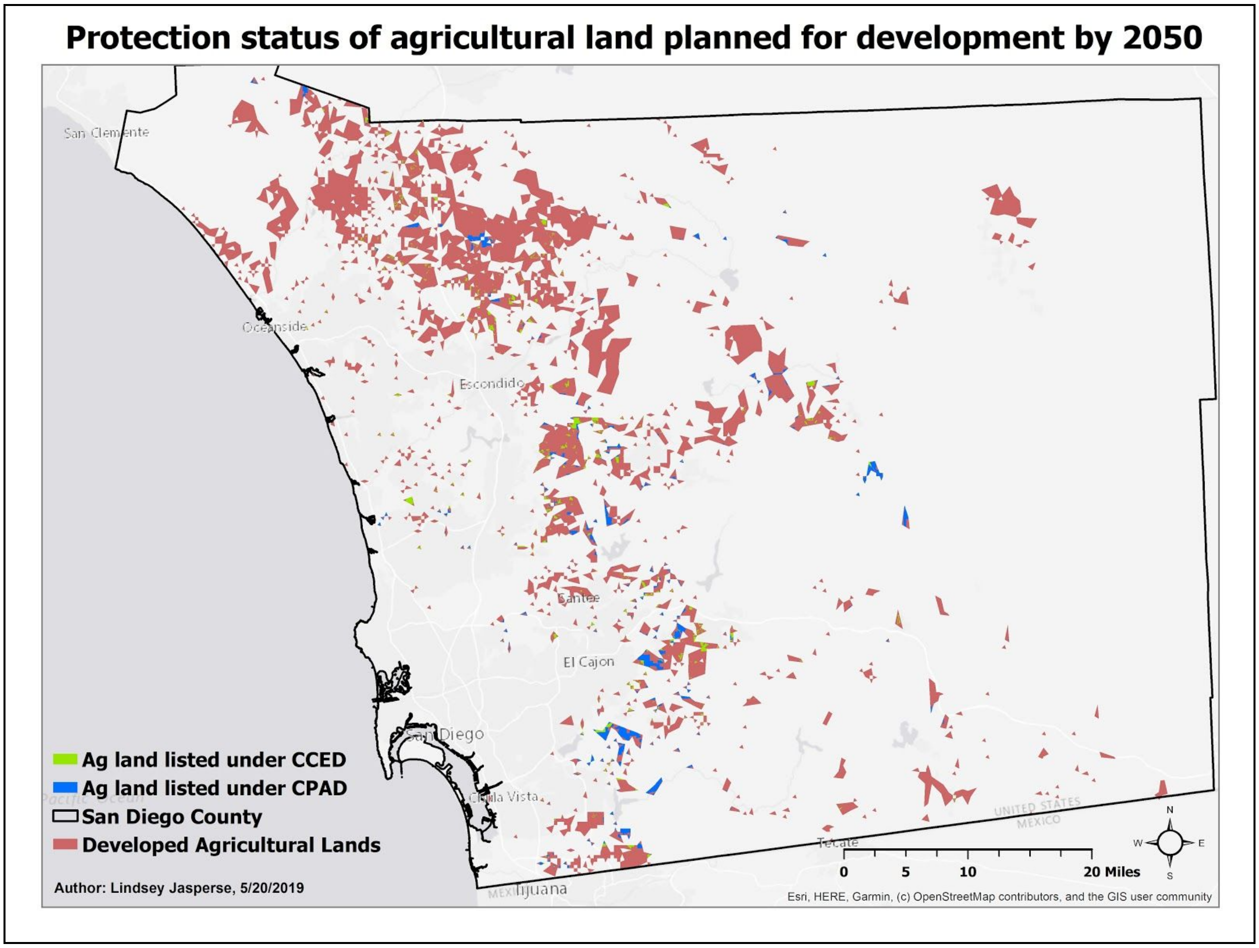
Author: Lindsey Jasperse, 5/20/2019

Esri, HERE, Garmin, (c) OpenStreetMap contributors, and the GIS user community

FIGURE 18: Potential benefit corresponding with existing agricultural lands planned urban development by 2050

These agricultural lands threatened by urban development are then overlaid with CCED and CPAD protection status to identify the portion of land listed as protected (Figure 19).

Figure 19:



Author: Lindsey Jasperse, 5/20/2019

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FIGURE 19: Protection status of existing agricultural lands threatened from urban development by 2050

7.0 Results

The county-averaged difference from the baseline scenario (with no added SOM) is -0.25 inches per year (in/yr) for CWD and 0.25 in/yr for AET. This represents that soil management of 3% added SOM can yield a -0.25 (in/yr) change in CWD from the baseline average of 15 (in/yr) and a 0.25 (in/yr) change in AET from the baseline average of 10 in/yr. Additionally, soil moisture has an average change of 1.69 (in/yr) from the baseline average of 9.1 (in/yr). The entire San Diego region shows a total hydrologic benefit area of 590,582 acres, with 14% of benefit area within the incorporated county and 86% of benefit area within the unincorporated county. These results indicate that many areas in San Diego have the potential to experience increase in forage production (AET), reduced landscape stress and irrigation demand (CWD), and increased hydrologic resilience to climate change (Table 9). Analyses show that CWD and AET have the most significant changes under a +3% SOM management scenario, and thus, the hydrologic benefit index is heavily reflective of these two variables.

Table 9: County averaged hydrologic response variables compared to baseline averages (1981-2010)

Hydrologic Variable	Average Baseline (in/yr)	Average Change from baseline (in/yr)
CWD	**15**	**-0.25**
AET	**10**	**0.25**
Soil Moisture Storage	**9.1**	**1.69**

Of the total agricultural land study area, a total area of 238,457 acres agricultural lands fall within an area of hydrologic benefit. A total of 223,383 acres of FMMP lands coincide with areas hydrologic benefit from increased SOM (3%), representing 66% of total FMMP lands. Notably, FMMP "Farmland of Statewide" and "of Local Importance" land classes show a total benefit area of 102,549 acres.

Planned city land use projections show further increases in urban extents by 2050, with 45% of non-agricultural lands planned for commercial, industrial, or commercial land uses. As these urban areas expand, agricultural lands are increasingly at risk of conversion. Figure 17 illustrates the total area (220,610 acres) of current agricultural land that could be lost by 2050 based on planned urban development. These losses can be quantified in terms of the potential hydrologic benefit estimated for soil management on these agricultural lands that will be lost if converted to urban use. The lost potential hydrologic benefit associated with soil management on current agricultural lands spans a total area of 144,804 acres, representing a 65% loss of the total potential hydrologic benefit on current agricultural lands. Within the total area of lands at-risk of urban development, 13% are listed as protected under CCED and/or CPAD.

8.0 Discussion of Results

San Diego's agricultural community is especially sensitive to the impacts of a changing hydroclimate, making water resources a main area of focus for climate resiliency in the region. The region's agricultural lands, and the multifaceted benefits they provide, are utilized across society. Thus, as the county continues to expand its efforts in climate mitigation, partnering with agricultural partners presents a key opportunity to ensure a resilient region (Batra, 2018). With model agreement over increased precipitation variability, and resulting changes in water availability, quality, and quantity over time, it is critical that a spectrum of strategies be implemented that can especially buffer the region's changing water resources.

As a state faced with distinct water-resource challenges, there is an increased need for planning and management decisions based at the local and regional level. While coarse spatial resolution model projections of temperature and precipitation trends provide much of the available information for land and resource managers and climate assessments, recent modeling developments, such as the BCM, greatly enhance available data (Flint et al., 2014). Data on the response of these hydrologic variables presents highly valuable information on quantification of recharge, runoff, irrigation need, landscape stress, and the spatial distribution of hydrologic processes throughout a watershed (Flint et al., 2013). These modeling capabilities can now model the spatial distribution of hydrologic processes throughout a watershed at fine-scales, producing much needed high-resolution data and confident estimates that previous modeling lacked.

There is a much needed opportunity to use these highly detailed and spatially explicit model projections for local resource management decisions and policy development (Flint et al., 2013).While the BCM's advanced modeling capabilities improves the state's understanding of hydrologic processes, soil management, and sequestration potential across the state's terrestrial landscapes (Flint et al., 2013), it can also be used for informing local, regional, and water-shed specific assessments. The grid based regional water balance model can provide valuable insight on the role of precipitation in San Diego's terrestrial ecosystems (Flint et al., 2014). Modeling the dynamic relationship between the pathways of precipitated water with landscape features can allow for more precise projections of both historical and future climate-hydrology assessments (Flint et al., 2014).

Application of the BCM for San Diego provides a quantification of the benefit of carbon farming practices in both 1981-2011 assessments and future projections. This analysis exhibits that San Diego's agricultural lands have the potential to improve hydrologic conditions with strategic management. Increases in WHC can allow for more water to stay in the watershed, maintaining baseflow in low-flow periods, groundwater infiltration and recharge, while also minimizing the impacts of peak runoff during extreme precipitation events (Flint et al., 2018). For the unincorporated county, which shows a significant portion of the potential hydrologic benefit, soil management practices could significantly reduce water related challenges. Given that 65% of the unincorporated area is considered a groundwater-dependent area and subject to localized groundwater availability problems, practices that enhance hydrologic processes and contribute to overall water-use efficiency could greatly benefit this region. Most notably, San Diego could experience significant decreases in CWD in addition to increases of AET. As a result, the farming community could see improvements in soil moisture, irrigation costs, landscape stress, net primary productivity (NPP). Thus, these potential improvements ultimately enhance resilience to droughts and extreme events (Flint et al., 2018). Results further illustrate that, even in scenarios with projected climate change impacts, there are many areas throughout San Diego with potential increases in AET and decreases in CWD, if soil management practices are implemented. Projections highlight the ability of these practices to buffer the impacts of future drought conditions.

Combining hydrologic benefit estimates with knowledge of existing regional agricultural lands can inform strategic, on-the-ground implementation efforts and direct carbon farming farming projects. Existing agricultural lands constitute a large portion of the total area of estimated hydrologic benefit with increased SOM. Results can provide informed prioritization of feasible lands and management practices in addition to natural resource allocation across the region. Areas that intersect both hydrologic benefit and existing agricultural land can be used to identify areas where carbon farming efforts could be most attainable and readily employed. Translating potential hydrologic changes to their associated economic and productivity benefit provides a critical link between scientific research and practical on-farm application.

Carbon farming practices aim to not only build SOC levels, but to ensure that these pools remain in the soil for many years. Thus, it is important to consider the agricultural areas vulnerable to land conversion for implementation of carbon farming projects, as these lands may not be able to sequester carbon for the long-term if converted. Areas at the intersection of current agricultural land and future urban development can be used to identify areas where demonstration sites and farming programs may be short-lived. Analyses identify the areas in which implementation of carbon farming sites and programs may not be able to yield benefits overtime, if not designated for production in years to come. With conversion of farmland in recent years ("San Diego Land Use Conversion") and continued plans for urban development, there is a need to invest in programs that sustain the existing value of these lands while also supporting additional growth. Analyses indicate that only 13% of the total threatened agricultural lands are protected under CCED and/or CPAD conservation plans. Threatened areas showing the highest benefit values can advise future preservation strategies to target these priority lands. As the county faces demand for development, how we reconcile these pressures with the importance of agricultural lands is a critical piece to San Diego's ultimate climate resilience. In light of these trade-offs, results such as these can help tell the story of these agricultural lands and the case for their preservation. Identifying these opportunities through scientifically based analyses helps portray the potential of carbon farming in the region, and articulate the value agricultural lands hold for their sequestration potential and co-benefits.

9.0 Agricultural Carbon Sequestration Potential for San Diego Context:

On many fronts, California has adopted the role of a global leader in climate action, implementing an array of proactive technical instruments and political strategies ranging from the local to federal level. As agriculture is a critical backbone of the state's booming economy, it is necessary that California put agriculture at the forefront of climate planning (Bedworth et al., 2018). Recognizing the benefits that well-managed soils provide, carbon farming has recently gained attention throughout the state as a promising form of climate adaptation and mitigation. However, for carbon sequestering practices to be effective, feasible, and widespread, it requires collaboration among interdisciplinary stakeholders. It is necessary that policy makers, environmental advocates, scientists, farmers, and economists join forces to spearhead these opportunities.

Given the great diversity within the state's 58 counties, appropriate soil management practices look different for each region. Additionally, regional climate impacts and specific areas of vulnerability differ between regions, and this may translate to unique goals. Thus, the tools and practices needed to address specific regional context, will vary. Home to the greatest number of small farms and certified organic farms of any county in the U.S. (Batra, 2018), San Diego's agricultural setting presents unique opportunities and strengths for addressing climate challenges through widespread implementation of sustainable agriculture (Batra, 2018). Regional application of scientific tools, such as the BCM, can be used as a basis for advising interdisciplinary efforts to address specific county needs, such as water resources. While economic programs and supportive partnerships are essential for promoting the adoption of carbon farming practices, the BCM is a critical component to maximizing opportunities. With advanced science and modeling capabilities, a supportive and proactive network of entities, and the political will and economic incentives in place, opportunities for increasing carbon sequestration in California are more pertinent now than ever. The alignment of these factors makes this the opportune time for San Diego to embrace and advance powerful farming strategies.

9.1. Economic Incentives and Programs

Reducing barriers and streamlining viability of opportunities are key factors in advancing sustainable agricultural practices. Economic incentives and supportive programs, at both the state and local levels, are key components to encouraging farmers to engage with these practices. Given that the average age of farmers in the region is 62 (Batra, 2018), we need to do more to recruit and retain the next generation of climate-smart farmers.

Implementation of conservation practices requires that farmers shift their management methods, while also assuming they pay the costs and repercussions of trial-and-error periods. Thus, incentivizing these actions with the appropriate financial safeguarding is necessary. California recognizes the economic value of carbon sequestering abilities in forests and working lands. The state has initiated a cap-and-trade market that promotes the selling of offsets for GHG emissions (Batra, 2018), In the past, carbon markets have generally failed to involve agriculture because the protocols for standardized offsets does not exist. However, as new economic programs and protocols are increasingly established, landowners have the ability to generate financial returns from their conservation efforts. Recently, the rangeland compost application has been approved as a viable practice for generating carbon offsets by the American Carbon Registry and the California Air Pollution Control Officers Association GHG Reduction Exchange (Batra, 2018). Incorporating agriculture in carbon markets gives farmers, ranchers, and forestland owners the opportunity to mitigate and adapt the impacts of climate change that directly affect them. Carbon markets encourage landowners to shift their practices to enhance carbon sequestration, generating quantifiable benefits such as enhanced carbon sequestration and soil health ("Greenhouse Gas Markets"). The inclusion of agriculture in the carbon market can be expanded to encompass more land conservation practices, for instance, by approval of carbon farming as California Environmental Quality Act (CEQA) GHG mitigation (Batra, 2018). While the county's CAP has proposed developing a local offsets registry, approving carbon farming methods as CEQA certified GHG mitigation practices could reduce costs from credit development and 3rd party verification (Batra, 2018). Compliance Offset Protocol Rice Cultivation Projects highlight a case study program for encouraging sustainable farming methods by quantifying reductions in GHG emissions. The protocol develops a market solution for a rice carbon offset protocol that helps facilitate agricultural

Programs administered by the Natural Resources Conservation Services (NRCS) and the California Department of Food and Agriculture (CDFA), such as the Healthy Soils Program and Conservation Innovation Grants (CIG), present grant opportunities that can drive agricultural innovation in resource conservation ("Conservation Innovation"). Although there remain barriers that have ultimately limited farmer involvement, carbon credit programs have the potential to financially encourage the adoption of sequestering agricultural practices. With several options for carbon crediting and market involvement, large-scale implementation of carbon farming throughout the county is becoming more viable.

In addition to these economic incentives, there are programs that also offer financial support for transitioning land management methods. As part of San Diego's Climate Action Plan (CAP), the county proposed establishing a Local Direct Investment Programs that aims to fund and implement local direct investment projects approved as GHG emission reductions protocols by the state ("Preliminary Assessment", 2017). The CAP strategy is an opportunity for conservation projects such as carbon farming protocols to directly feed into CAP GHG reduction goals while also financially backing landowners. As local carbon farming protocols continue to develop and more are approved as acceptable recipients of investment funds, this can help provide economic incentive, promote carbon farming, and increase recognition of these practices as investments in county-wide resilience (Batra, 2018). As these programs that directly support farmers and offer funding, farmers are increasingly willing and able to invest in the transformation of land into carbon sinks. Thus, there is an opportunity to capitalize on these already existing programs and economic tools to further implementation efforts.

As analysis result indicate, San Diego's agricultural lands are at great risk of conversion to urban use in the coming years. Thus, programs that promote the growth of agricultural land are critical to safeguarding these valuable lands. The Urban Agricultural Incentive Zone (UAIZ) is an example program that utilizes incentives to encourage the growth of agriculture in the city's urban neighborhoods. UAIZ allows for private landowners in urban areas to receive a tax incentive for leasing lands to growers, farmers, and/or gardeners for agricultural use. To receive these incentives, zones must be designated for agricultural use for at least five years ("Urban Agriculture").

9.2. Involved Agencies

In addition to these economic and scientific resources, it is critical that farmers are supported with a network of agencies and partners that can provide both the guidance and political will needed to encourage local carbon farming initiatives. As carbon farming is increasingly recognized as a viable method of climate adaptation and mitigation, entities have started to join forces to facilitate carbon farming ideas and initiatives to on-the-ground implementation and demonstration projects. The county's Resource Conservation Districts (RCDs) are integral in providing technical assistance, advice, and planning ("Carbon Farming", RCD). Through comprehensive planning and monitoring, the RCDs are working to help farmers implement effective practices on their land ("Carbon Farming", RCD). RCDs of Greater San Diego are following in the footsteps of RCDs statewide, developing carbon farming plan templates for assessing opportunities and related practices for landowner implementation of conservation systems that address resource concerns (Richards et al., 2017). In addition, San Diego has a Task Force specifically designed to promote and scale out carbon farming throughout San Diego ("Carbon Farming"). The Task Force is comprised of diverse stakeholders from over 40 multi-sector organizations, representing producers, industry, local independent farmers, scientists, and philanthropic groups ("Carbon Farming"). Expanding carbon farming from demonstration projects to region-wide implementation requires that farmers and landowners are well supported by these resources and agencies. As this network continues to grow, it presents a promising opportunity for sizeable carbon farming application and thus tangible GHG reductions and co-benefits.

It is critical that San Diego leverage these advanced scientific tools to further maximize existing and developing programs. The combination of incentive programs, carbon farming projects, and scientific research presents a powerful opportunity to make tangible change. If the county can capitalize on these opportunities, it will help ensure that agricultural lands continue to exist and contribute value for the region in future years.

10.0. Barriers, Challenges, Recommendations

Fine-scale hydrologic models at the regional level can provide useful information about water-shed specific hydrologic response. While the BCM is able to generate confident, high resolution projections, the results are dependent on underlying NRCS soil properties used as an input. As these NRCS soil maps may not accurately reflect existing conditions, it is important that conditions are assessed locally and case-by-case to help achieve projected benefits (Flint et al., 2018). It is thus vital that science-based decision support tools, such as the BCM and model input data, are updated, maintained, and improved to continue to inform stakeholders and decision makers.

Integrated analysis helps portray where areas of benefit coincide with existing agricultural lands, and areas of benefit at risk of conversion. However, it is important to note that in many ways, San Diego lacks a comprehensive understanding of the region's agricultural landscape. With many small, dispersed farms, data illustrative of all agricultural land in the region is limited. As a result, the "agricultural land" area is likely not representative of the entirety of San Diego's working lands. The lack of recognition of the agricultural lands throughout the county presents many challenges for planners, natural resource managers, and entities at the forefront of San Diego county planning. Without accurate spatial records and data of agricultural lands, it is difficult to target both land preservation and carbon farming efforts. If the county plans on continuing its efforts to preserve these valuable lands in the years to come, it is critical to utilize tools, such as the BCM, that highlight the potential benefits of maintaining lands in partnership with soil management practices. For BCM results to be best utilized in targeting carbon farming and preservation planning, there is a need for accurate agriculture data. In addition, understanding the status of lands and the agencies involved in ownership and preservation can help streamlight efforts. As shown in figure 19, there are lands listed as protected under CPAD and CCED that are also planned for urban development, highlighting a need for more synthesis between land use planning and programs aimed at protecting these agricultural lands.

11.0. Discussion

These analyses illustrate areas that exhibit natural resource characteristics amenable to carbon sequestration that coincide with existing agriculture and thus help identify lands with existing opportunities for building resiliency of agriculture against climate change impacts in the San Diego region. Results can be leveraged a tool to inform how farmers consider possibilities for farming strategies, and for designing and directing programs to best support these efforts. Additionally, studies can depict the unparalleled role that these agricultural lands play in providing critical ecosystem services throughout San Diego, especially taking into account the threats of climate change and urbanization. Agricultural lands not showing hydrologic benefit under a 3% BCM soil management scenario are not necessarily unable to produce hydrologic benefit, and thus should not be disregarded from considerations of carbon farming implementation. However, areas showing the highest degree of potential benefit may be prioritized with the most feasible and immediate opportunity for implementation. While results may not give exact quantification of hydrologic benefits, due to potential misrepresentation of soils and agricultural land, these local applications help conceptualize the potential value of our region.

The rapidly changing climate necessitates that conservation efforts are more immediate and poignant than ever. With projections showing a future of water related challenges, how San Diego acts now will have implications regarding resiliency of agriculture for both the short and long-term future. This study has highlighted the important and unique role that San Diego agriculture can play in addressing these growing challenges. Results indicate that San Diego's agricultural lands contribute many benefits throughout the region's institutional and natural landscapes. When managed sustainably, these lands have the potential to improve water resources across the region and become more resilient to forecasted climate impacts. Carbon farming practices can not only result in immediate benefits, but can also ensure that lands sustain these benefits for years to come.

To ensure that agricultural lands and their benefits remain in the future, supportive programs and economic incentives must continue to assist farmers in implementing and bearing the costs of carbon farming practices. Additionally, quantifying benefits at a regional scale can help identify opportunities and direct these efforts to be most effective. Regional application of advanced, fine-scale hydrologic modeling can inform policy and programs, while encouraging farmers to adopt practices. It can also serve to quantify the value lost and opportunity cost if future development plans are pursued. The region's agricultural sector, which is directly impacted by the impacts of climate change, has the ability to become a source of regional climate resilience. With advanced climate modeling, a strong agricultural community, and a network of supportive entities, partnerships, and programs, San Diego is poised to lead the way in California's carbon farming movement.

Appendix: Table of acronyms:

GHGs: Greenhouse gases
CPAD: California Protected Areas Database
CCED: California Conservation Easements Database
FMMP: Farmland Mapping and Monitoring Program
SDCWA: San Diego County Water Authority
MWD: Metropolitan Water District
Tmin: Minimum temperature
Tmax: Maximum temperature
ARs: Atmospheric Rivers
CLCF: Coastal Low Clouds and Fog
CWD: Climatic Water Deficit
AET: Actual Evapotranspiration
RCP: Representative Concentration Pathway
SOM: Soil Organic Matter
SOC: Soil Organic Carbon
NPP: Net Primary Productivity
WHC: Water Holding Capacity
BCM: Basin Characterization Model
CAP: Climate Action Plan
CEQA: California Environmental Quality Act
NRCS: Natural Resources Conservation Services
CDFA: California Department of Food and Agriculture
CIG: Conservation Innovation Grants
UAIZ: Urban Agricultural Incentive Zone
RCDs: Resource Conservation Districts

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