Carbon Storage and Sequestration Assessment for Four Watersheds of San Diego County, California

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Acronyms and Abbreviations

Acronym/Abbreviation	Definition
CAL FIRE	California Department of Forestry and Fire Protection
CARB	California Air Resources Board
CH_4	methane
CO_2	carbon dioxide
CO_2e	carbon dioxide equivalent
FIA	Forest Inventory and Analysis
GHG	greenhouse gas
GIS	geographic information system
InVEST	Integrated Valuation of Ecosystem Services and Tradeoffs
IPCC	Intergovernmental Panel on Climate Change
LULC	Land Use Land Cover
MMT	million metric tons
MT	metric ton
MT C/ac	metric tons carbon per acre
N_2O	nitrous oxide
NWL	natural and working land
SANDAG	San Diego Association of Governments
USFS	U.S. Forest Service
USGS	U.S. Geological Survey

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Executive Summary

The San Diego Canyonlands, with funding provided by the San Diego River Conservancy, directed the preparation of this assessment of the storage and sequestration of the natural and working lands for the Otay River, San Diego River, Sweetwater River, and Tijuana River Watersheds of San Diego County, California, to guide policy and management actions in this region.

Carbon is stored in the vegetation and soils of natural and working (i.e., agricultural) lands. To estimate current carbon storage in the study area, estimated carbon stock values, based on authoritative existing sources, were assigned to the land cover and soil types based on existing resource mapping to build a "baseline" carbon inventory for the natural and working lands. This baseline carbon inventory was integrated into a geographic information system (GIS) based model referred to as InVEST (Integrated Value of Ecosystem Services and Tradeoffs) to map and quantify carbon storage. Additionally, carbon sequestration (i.e., carbon accumulation and storage over time) was evaluated by building carbon inventories based on minimum carbon stock values and maximum carbon stock values to assess the carbon sequestration over time from young, new growth to mature, old growth vegetation.

The approximately 822,700-acre study area is comprised of the Otay River Watershed (12% of the study area), San Diego River Watershed (34% of the study area), Sweetwater River Watershed (18% of the study area), and Tijuana River Watershed (36% of the study area). The study area supports 115 vegetation and land cover types within 9 general land cover classes: chaparral, forest, grassland, marsh, riparian, scrub, woodland, agriculture, and other. Based on this study's baseline carbon inventory based on average carbon stock values, total landscape carbon storage in the study area was approximately 21,630,000 metric tons of carbon. Chaparral and forest vegetation types store the bulk of the carbon in the study area, at 52% and 14% respectively. Carbon storage in scrub (13% of the total) and woodland (10% of the total) also play an important role in the study area.

Using minimum and maximum carbon stock values for land cover types, the study area has a minimum carbon storage of approximately 11,162,000 metric tons of carbon and a maximum carbon storage of approximately 27,284,000 metric tons of carbon. This assessment yielded a maximum carbon sequestration potential of up to 14,576,000 metric tons of carbon in the natural vegetation assuming static carbon sequestration rates with no changes in land use or active carbon management. Assuming that the baseline carbon inventory represents current carbon storage in the study area, the natural vegetation has a potential to sequester approximately 5,635,000 metric tons of carbon with no changes in land use or active carbon management.

This assessment focused on quantifying and mapping carbon storage and sequestration using the best data and approaches to represent the local conditions and characteristics of the watersheds in the study area to inform on-the-ground management actions. There are no standardized data or approaches for developing landscape carbon storage assessments, and there are inherent uncertainties and limitations in the evaluation results. Additionally, the current and future effects of climate change have potentially strong influences on landscape carbon storage and sequestration potential. To maximize landscape carbon storage, active management strategies are available including natural land management activities such as habitat restoration, fire management, and planning and management to avoid natural land conversion; working land management; and urban land management.

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1 Introduction

1.1 Purpose and Funding

The San Diego River Conservancy, in collaboration with San Diego Canyonlands, has a vested interest in the conservation and management of natural and working (i.e., agricultural) lands in the watersheds of San Diego County, California. This assessment was prepared to better understand the current carbon storage and carbon sequestration potential of the San Diego River, Sweetwater River, Otay River, and Tijuana River Watersheds and to inform the potential carbon storage implications of future conservation and management actions in this region. This study was funded by San Diego Canyonlands through a grant from the San Diego River Conservancy under the California Drought, Water, Parks, Climate, and Coastal Protection and Outdoor Access for All Act of 2018 (Proposition 68).

1.2 Content and Process

This carbon storage and sequestration assessment followed a stepped process, and the elements and process of the assessment are summarized as follows:

Background (Chapter 2). This study provides a background discussion that explains the technical basis for carbon storage and sequestration, including vegetation carbon sequestration, the natural carbon cycle, and carbon pools. Chapter 2 also presents a summary of greenhouse gas (GHG) emissions and climate change to understand the metrics used in this analysis and provide the foundation of why carbon storage matters in the context of climate change.

Landscape Carbon Inventory (Chapter 3). The first step in the study process was to estimate total landscape carbon storage for the watersheds in the study area. This process used publicly available spatial data sets on land cover, land use, and soils, combined with national and state agency reports and data and peer-reviewed scientific literature on carbon stock values to estimate the "baseline" carbon inventory (total carbon storage) for the study area.

Carbon Sequestration Evaluation (Chapter 4). Carbon sequestration (i.e., carbon storage over time) potential was evaluated by building vegetation age-class carbon inventories representing the minimum carbon storage and the maximum carbon storage for the vegetation types in the study area. This allowed for an examination of how each vegetation type in the study area accumulates carbon over time and estimated carbon sequestration projections.

Discussion (Chapter 5). The study approach and data, study findings, and other management considerations are discussed.

Conclusion (Chapter 6). The conclusion presents a general summary of the study results.

Acknowledgements and Preparers (Chapter 7). This chapter acknowledges the individuals and agencies who assisted in preparation and guidance of this assessment.

References (Chapter 8). This report concludes with a list of references cited.

1.3 Intended Uses

The main use of this study is to increase the knowledge on the amount and geographic distribution of carbon stored in the landscape and ascertain the potential implications of land use and land management on the carbon storage in natural and working lands. This study aimed to employ methods and data focused on estimating carbon storage and sequestration potential at the finest resolution possible to inform local/watershed-level conservation and management actions for natural and working lands within the study area. As explained in the California Air Resources Board (CARB) Draft 2022 Scoping Plan Update, natural and working lands "are a critical sector in California's fight to achieve carbon neutrality and build resilience to the impacts of climate change. Healthy land can sequester and store atmospheric CO_2 [carbon dioxide] in forests, soils, and wetlands. Healthy lands also can reduce emissions of powerful SLCPs [short-lived climate pollutants], limit the release of future GHG emissions, protect people and nature from the impacts of climate change, and build our resilience to future climate risks. Unhealthy lands have the opposite effect—they release more GHGs than they store and are more vulnerable to future climate change impacts" (CARB 2022).

2 Background

2.1 Carbon Storage and Sequestration Background

Carbon sequestration is a fundamental process by which CO_2, which is a principal GHG, is removed from the atmosphere and stored in a carbon reservoir, such as vegetation. Vegetation (e.g., trees, shrubs, grasses) takes in CO_2 from the atmosphere during photosynthesis, breaks down the CO_2, stores the carbon within plant biomass, and releases the oxygen back into the atmosphere. Landscape carbon storage capacity and sequestration rates vary across the landscape and are influenced by numerous intrinsic and extrinsic factors, such as vegetation and land cover types, vegetation stand age, soils, land management regimes, and environmental factors.

The earth's carbon cycle involves the exchange of carbon between the atmosphere, biosphere (plants, animals, and other life forms), hydrosphere (water bodies), pedosphere (soils), and lithosphere (earth's crust and mantles, including rocks and fossil fuels). Carbon moves between land types (e.g., forests and grasslands) and carbon pools (e.g., wood, roots, and soils) due to natural processes (growth, decay, and succession) and disturbances (e.g., wildfire) or anthropogenic forces such as land use change (CARB 2018). "Carbon pools" include aboveground live biomass (boles, stems, and foliage in shrubs, trees, grasses, and herbaceous vegetation), aboveground dead biomass (standing or downed dead wood and litter), belowground live biomass (roots in shrubs, trees, grasses, and herbaceous vegetation), and soil organic matter (organic carbon in the top 30 centimeters of soil) (CARB 2018). Carbon inventories can provide stored carbon "snapshots" and give insight into the location and magnitude of natural and working lands' carbon stocks at discrete moments in time.

There are approximately 5,340 million metric tons of ecosystem carbon in the carbon pools that CARB has quantified. To put it into context, 5,340 million metric tons of carbon in land is equivalent to 19,600 million metric tons of atmospheric CO_2 currently existing in the biosphere and pedosphere as carbon cycles through the earth's carbon cycle. Forest and shrubland contain the vast majority of California's carbon stock because they cover the majority of California's landscape and have the highest carbon density of any land cover type. All other land categories combined comprise more than 35% of California's total acreage, but only 15% of its carbon stocks. Roughly half of the 5,340 million metric tons of carbon resides in soils and half resides in plant biomass (CARB 2018).

2.2 Greenhouse Gases and Climate Change

A GHG is any gas that absorbs infrared radiation in the atmosphere; in other words, GHGs trap heat in the atmosphere. As defined in California Health and Safety Code, Section 38505(g), for purposes of administering many of the state's primary GHG emissions reduction programs, GHGs include CO_2, methane (CH_4), nitrous oxide (N_2O), hydrofluorocarbons, perfluorocarbons, sulfur hexafluoride, and nitrogen trifluoride. Some GHGs, such as CO_2, CH_4, and N_2O, occur naturally and are emitted into the atmosphere through natural processes and human activities. Natural sources of CO_2 include respiration of bacteria, plants, animals, and fungus; evaporation from oceans; and decomposition of dead organic matter, in addition to anthropogenic changes in land use. CH_4 is produced through flooded rice fields, animal digestion, and decomposition of animal wastes, and sources of N_2O include soil cultivation practices (microbial processes in soil and water), especially the use of commercial and organic fertilizers, and manure management.

Climate change refers to any significant change in measures of climate, such as temperature, precipitation, or wind patterns, lasting for an extended period of time (i.e., decades or longer). The earth's temperature depends on the balance between energy entering and leaving the planet's system. Many factors, both natural and human, can cause changes in earth's energy balance, including variations in the sun's energy reaching earth; changes in the reflectivity of earth's atmosphere and surface; and changes in the greenhouse effect, which affects the amount of heat retained by earth's atmosphere (EPA 2017).

The greenhouse effect is the trapping and build-up of heat in the atmosphere (troposphere) near the earth's surface. The greenhouse effect traps heat in the troposphere through a threefold process, as follows: short-wave radiation emitted by the sun is absorbed by the earth, the earth emits a portion of this energy in the form of long-wave radiation, and GHGs in the upper atmosphere absorb this long-wave radiation and emit it into space and toward the earth. The greenhouse effect is a natural process that contributes to regulating earth's temperature and creates a pleasant, livable environment on earth. Human activities that emit additional GHGs into the atmosphere increase the amount of infrared radiation that gets absorbed before escaping into space, thus enhancing the greenhouse effect and causing earth's surface temperature to rise.

The scientific record of earth's climate shows that the climate system varies naturally over a wide range of time scales, and that, in general, climate changes prior to the Industrial Revolution in the 1700s can be explained by natural causes such as changes in solar energy, volcanic eruptions, and natural changes in GHG concentrations. Recent climate changes, however, in particular the warming observed over the past century, cannot be explained by natural causes alone. Rather, it is extremely likely that human activities have been the dominant cause of that warming since the mid-twentieth century and are the most significant drivers of observed climate change (EPA 2017; IPCC 2013). Human influence on the climate system is evident from the increasing GHG concentrations in the atmosphere, positive radiative forcing, observed warming, and improved understanding of the climate system (IPCC 2013). The atmospheric concentrations of GHGs have increased to levels unprecedented in the last 800,000 years, primarily from fossil fuel emissions and secondarily from emissions associated with land use changes (IPCC 2013). Continued emissions of GHGs will cause further warming and changes in all components of the climate system.

2.3 Regulatory Context

Climate change from human activities is a global challenge that requires local participation, and reducing GHG emissions is a critical environmental and societal duty. Combating human-caused climate change and the detrimental effects globally requires ambitious efforts locally. The state has taken numerous actions to address climate change through executive orders, legislation, and CARB plans and requirements. Specifically, Executive Order S-3-05 (June 2005) established the statewide goal of reducing GHG emissions 80% below 1990 levels by 2050, Assembly Bill 32 provided initial direction on creating a comprehensive multiyear program to limit California's GHG emissions at 1990 levels by 2020 and initiate the transformations required to achieve the state's long-range climate objectives, Senate Bill 32 (September 2016) codified the 2030 emissions reduction goal of Executive Order B-30-15 by requiring CARB to ensure that statewide GHG emissions are reduced to 40% below 1990 levels by 2030, and Executive Order B-55-18 (September 2018) established a new statewide goal "to achieve carbon neutrality as soon as possible, and no later than 2045, and achieve and maintain net negative emissions thereafter."

The importance of carbon storage and sequestration in the natural and working lands (NWLs) sector of California was emphasized in the 2017 Climate Change Scoping Plan: The Strategy for Achieving California's 2030 Greenhouse Gas Target (CARB 2017). CARB's 2017 Scoping Plan specified "California's climate objective for natural and working lands to maintain them as a carbon sink (i.e., net zero or negative GHG emissions), and where appropriate, minimize the net GHG and black carbon emissions associated with management, biomass utilization, and wildfire events." Two important state strategies for the natural and working lands sector are protection of land and land uses, and enhancement of carbon sequestration and resilience through management and restoration.

CARB released the Draft 2022 Scoping Plan Update in May 2022, which outlines the state's plan to reach carbon neutrality by 2045 or earlier, while also assessing the progress the state is making toward reducing GHG emissions by at least 40% below 1990 levels by 2030, as is required by Senate Bill 32 and laid out in the Second Update. The carbon neutrality goal requires CARB to expand proposed actions from just the reduction of anthropogenic sources of GHG emissions to also include those that capture and store carbon (e.g., through natural and working lands, or mechanical technologies). The Draft 2022 Scoping Plan Update emphasizes that there is no realistic path to carbon neutrality without carbon removal and sequestration, and to achieve the state's carbon neutrality goal, carbon reduction programs must be supplemented by strategies to remove and sequester carbon, highlighting the importance of nature-based solutions through preservation and deliberate management of the state's NWLs. Modeling conducted for the Draft Scoping Plan shows that California's NWLs are projected to be a net source of emissions (i.e., releasing more CO_2 emissions than they store) through 2045, which is historically due to human activities, such as land use change, and natural disturbances, such as wildfire. Therefore, the ability of the state's NWLs to act as a net sink (i.e., sequester and store more atmospheric CO_2 than they release) to help support the state's carbon neutrality goals is dependent on climate-smart land management (CARB 2022).

Executive Order N-82-20 (October 2020) directs state agencies to deploy nature-based strategies to remove carbon from the atmosphere and store it in the state's NWLs. The order sets a goal to conserve 30% of the state's land and coastal waters by 2030. To implement Executive Order N-82-20, the California Natural Resources Agency developed the Natural and Working Lands Climate Smart Strategy, which defines the natural and working landscapes and identifies land management actions that will help achieve carbon neutrality in alignment with Executive Order B-55-18 and the Draft 2022 Scoping Plan (CNRA 2022).

The California Natural Resources Agency's Natural and Working Lands Climate Smart Strategy was developed, in part, to identify land management actions specific to California's NWLs to help achieve carbon neutrality goals to align with the 2022 Scoping Plan and statewide goals. The Climate Smart Strategy contains priority actions and approaches for the eight NWL types, including forests, shrublands and chaparral, developed lands, wetlands, seagrasses and seaweeds, croplands, grasslands, and sparsely vegetated lands.

For California to meet its ambitious GHG reduction targets, state and local governments must work together as partners with landowners and land managers.

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3 Landscape Carbon Inventory

3.1 Methods

3.1.1 Study Area

The study area for this assessment included the San Diego River, Sweetwater River, Otay River, and Tijuana River Watersheds in San Diego County, California. Standardized boundaries for major watersheds (hydrologic units) in California were used to define this study area (CalWater 2004). Figure 1 shows the study area for this assessment.

3.1.2 Spatial Data Compilation

The landscape carbon inventory for the study area was developed by assigning estimated carbon stock values to the mapped vegetation types and soils in the study area. The following describes the compilation of the key land cover and soils datasets for use in developing the landscape carbon inventory.

Land Cover

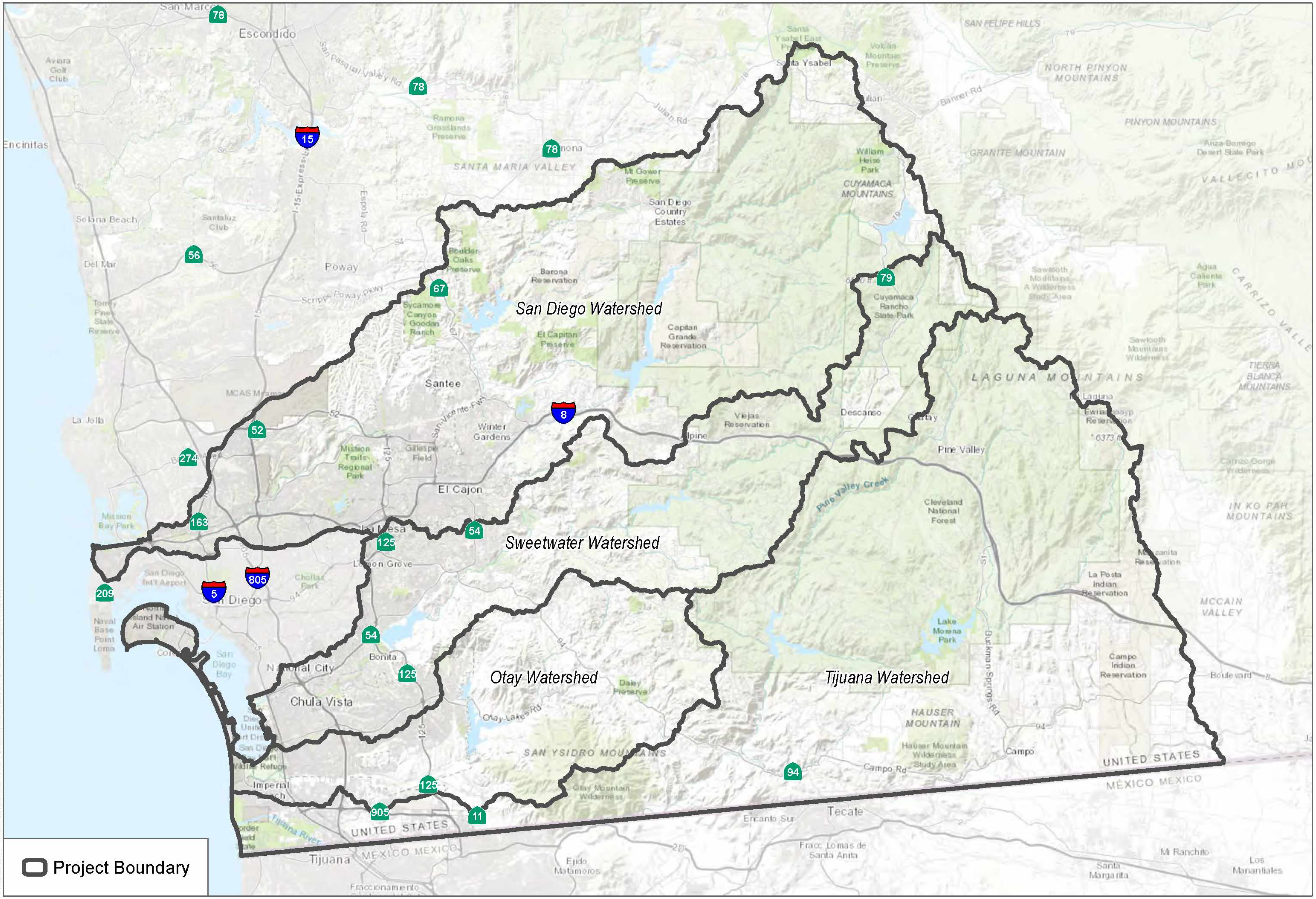
Land cover mapping data provide the basis for assigning the carbon stock values for the non-soil carbon pools (see Section 3.1.3) of the landscape carbon inventory of the study area. The San Diego Association of Governments (SANDAG) maintains a regional, geospatial vegetation community dataset for the entire county (SanGIS 2020). This dataset is updated periodically using aerial imagery to reflect land use changes and uses a classification system based on the Preliminary Descriptions of the Terrestrial Natural Communities of California (Holland 1986). Vegetation communities and other land covers are described and classified at two hierarchical levels: a broad, generalized level (referred to herein as land cover classes) and a more detailed vegetation/land cover type level (referred to herein as land cover or vegetation types). Carbon stock assignments in this study were made at the detailed land cover type level. The SANDAG regional vegetation community dataset was considered the best source for land cover mapping for use in this study. It is the standard land cover mapping dataset used by local municipalities and agencies for describing existing vegetation communities and land cover in the county, it provides a relatively fine-resolution mapping and classification of the local/watershed-level vegetation types in the study area, and it is updated to reflect current conditions. Other sources of land cover and vegetation community mapping were considered but not selected for use during study development; these are discussed further in Section 5.1, Study Approach and Data.

Soils

Soil mapping data provide the basis for estimating the soil carbon pool of the landscape carbon inventory. For this study, ISRIC World Soil Information SoilGrids 2.0 (ISRIC 2022; Poggio et al. 2021) was used to provide mapping of the soil organic carbon of the soils in the study area. SoilGrids includes worldwide spatial data of soil properties modeled at 250-meter resolution based on inputs from 240,000 field plot locations, including over a thousand locations in California and 87 in San Diego County, integrating over 400 environmental covariates. This state-of-the-art dataset provides medium resolution spatial information on soil properties, including soil organic carbon in the upper 30 centimeters. This dataset was considered the best source for soil organic carbon mapping for use in this study because it provides the finest resolution estimate of soil organic carbon available and is based on a model that integrates field plots throughout California, including a fairly robust set of inputs from San Diego County. Alternative sources and related methods for estimating soil organic carbon were considered during study development; these are discussed in Section 5.1.

Land Cover – Soils Composite

The land cover mapping and soil mapping layers were combined to create a composite layer of unique combinations of land cover types and soils. This composite land cover–soils spatial layer was used for assigning carbon stock values as described in Section 3.1.3 and is the basis of the Land Use Land Cover (LULC) layer used in the carbon storage modeling (Section 3.1.4).



SOURCE: SANDAG 2022

DUDEK

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FIGURE 1

Study Area

Carbon Storage and Sequestration Assessment for Four Watersheds of San Diego County, California

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3.1.3 Land Cover Carbon Stock Values

The landscape carbon inventory was developed by assigning carbon stock values to the non-soil (i.e., vegetation) and soil carbon pools. As discussed in Section 2.1, Carbon Storage and Sequestration Background, the carbon pools are defined by CARB as follows (CARB 2018):

- Aboveground Live Biomass: boles, steams, and foliage in shrubs, trees, grasses, and herbaceous vegetation
- Belowground Live Biomass: roots in shrubs, trees, grasses, and herbaceous vegetation
- Dead Organic Matter: standing or downed dead wood and litter
- Soil Organic Matter: organic carbon in the top 30 centimeters of soil

A review of authoritative international, national, state, regional, and local sources was conducted to identify the best and most appropriate carbon stock values (typically expressed in units of metric tons of carbon per hectare but converted to metric tons of carbon per acre (MT C/ac) when reported in this document) to assign to non-soil and soil pools. One of the goals of this study was to develop an estimate of carbon storage and sequestration potential that reflects the local conditions and characteristics as accurately as possible. This goal drove the selection of the land cover and soil datasets used (Section 3.1.2, Spatial Data Compilation) and also dictated the selection of the most appropriate carbon stock values.

Estimating carbon storage on the landscape has become increasingly common at the international and national levels since the 1996 Intergovernmental Panel on Climate Change (IPCC). The IPCC (2006) provided guidelines and best practices for conducting national GHG inventories as they related to agriculture, forestry, and other land use. In the United States, the Environmental Protection Agency reports out the national GHG inventory consistent with the IPCC guidelines using the best available methods and data at the national level (EPA 2022), which relies primarily on the U.S. Forest Service (USFS) Forest Inventory and Analysis (FIA) database and methods (Burrill et al. 2017; USFS 2021). Carbon storage in aboveground and belowground vegetation and soils is included in these inventories; however, there are inherent limitations to these global and national data and approaches, particularly related to scale/resolution of these inventories and the emphasis on forest types.

At the state level, CARB has supported extensive research to refine California's GHG inventory related to carbon stocks in wildlands (e.g., Battles et al. 2013; CARB 2013, 2018; Gonzalez et al. 2015; Saah et al. 2016). These statewide efforts provide useful advancements; however, like the national approaches, their broad scale fails to capture some of the local land cover types and variability, particularly for Southern California natural lands.

Scientific research and biomass studies on individual vegetation types provide valuable sources for carbon stock values, particularly for vegetation types unique to Southern California. A thorough review of biomass studies for the land cover types in the study area was conducted to identify carbon stock values for this assessment. Where appropriate and particularly for the chaparral, grassland, scrub, woodland and riparian vegetation types, data from scientific literature and studies were used to derive carbon stock values used in this study. Recent research conducted by San Diego State University, Carbon Valuation in San Diego's Natural Landscapes, reviewed sources for carbon stock values for natural lands in San Diego County (Jennings et al. 2021). Literature sources provided in Jennings et al. (2021) were also reviewed and carbon stock values from those sources were used in this study, as appropriate.

Carbon stock value information from multiple sources were synthesized and combined for use in this study, and in some cases where certain biomass components were not reported in the source data, assumptions or calculations were made to address incomplete information. The following provides a summary of the data information sources used to derive the carbon stock values used for each land cover type for this assessment, summarized below by land cover class.

Chaparral

Carbon stock values for the chaparral vegetation types were obtained from Bohlman et al. (2018), which provides a comprehensive review and synthesis of available shrubland biomass data from California-based studies. The review compiles data from 37 studies published over 72 years and includes estimates of aboveground biomass, leaf biomass, stem biomass, litter biomass, and belowground biomass for California mixed chaparral and chamise chaparral communities.

Forest

Forest vegetation carbon stock values were obtained from the USFS FIA program. The USFS FIA data are compiled through a collection of nationwide forest monitoring surveys used to track status and trends in forest extent, cover, growth, mortality, removals, and overall health (USFS 2021). The USFS EVALIDator tool (version 1.8.0.01) provided values for the forest vegetation types for the aboveground, belowground, dead, and litter carbon pools. For the forest vegetation types present in the study area, carbon stock values for the following USFS FIA forest types were used.

- Interior live oak
- Coast live oak
- Canyon live oak
- California black oak
- Miscellaneous western softwoods
- California mixed conifer
- Coulter pine
- California mixed conifer
- Jeffrey pine
- Other hardwoods

Grassland

For the grassland and meadow (except montane meadow) vegetation types, CARB's Inventory of Ecosystem Carbon in California's Natural & Working Lands (CARB Inventory) was used to estimate carbon stock values. CARB's inventory was developed consistent with IPCC guidelines using ground-based measurements, remote sensing data, and other default assumptions where necessary for California lands. The CARB inventory includes estimates for aboveground live biomass, belowground live biomass, dead biomass, and litter carbon pools. For the grassland vegetation types present in the study area, CARB inventory values for California Central Valley and Southern Coastal Grassland and California Annual Grassland vegetation types were used. Carbon stock values for the montane meadow vegetation types were obtained from a recent study on ecosystem-level carbon inputs and outputs for meadows spanning a range of conditions throughout the California Sierra Nevada (Reed et al. 2021). The carbon pools reported and used here include peak aboveground live biomass and belowground live (root) biomass.

Riparian

Riparian vegetation carbon stock values were obtained from a recent report on the carbon sequestration potential of California riparian forests (Matzek et al. 2018). The report assembled a database of over 600 forest inventory plots of known age together with allometric equations to estimate biomass by age (0–100 years in 5-year increments) for six riparian vegetation types. The data includes carbon estimates for canopy (live tree and standing dead, aboveground and belowground), downed dead wood, forest floor, and understory. Carbon values for riparian woodland, cottonwood-willow, upland riparian forest, mixed riparian forest, and riparian willow scrub were used to represent the riparian vegetation types present in the study area.

Marsh

Carbon stock values for the marsh vegetation types were obtained from CARB's inventory, which was developed consistent with IPCC guidelines using ground-based measurements, remote sensing data, and other default assumptions where necessary for California lands. The CARB inventory includes estimates for aboveground live biomass, belowground live biomass, dead biomass, and litter carbon pools. For the marsh vegetation types present in the study area, CARB inventory values for Pacific coastal marsh systems and California Central Valley riparian herbaceous vegetation types were used.

Scrub

Carbon stock values for scrub vegetation types were obtained from Bohlman et al. (2018), which provides a comprehensive review and synthesis of available shrubland biomass data from California-based studies. The review compiles data from 37 studies published over 72 years and includes estimates of aboveground biomass, leaf biomass, stem biomass, litter biomass, and belowground biomass for California mixed chaparral, chamise chaparral, and coastal sage scrub communities.

Woodland

Carbon stock values for the oak woodland vegetation types were provided by the California Oak Foundation's Inventory of Carbon and California Oaks report, which used 6 years of USFS FIA plot data for locations throughout the State of California combined with California Department of Forestry and Fire Protection (CAL FIRE) Fire and Resource Assessment Program vegetation maps (Gaman 2008). The report provides carbon stock values for 10 oak species by region, including mixed oak, black oak, coast oak, and Engelmann oak, which were used for the study area.

Agriculture

Carbon stock values for the agricultural land cover types were obtained from CARB's inventory and include carbon estimates for the aboveground live biomass, belowground live biomass, dead biomass, and litter pools. For the agricultural land cover types in the study area, CARB carbon stock values for western warm temperate orchard, western warm temperate row crop, and western warm temperate pasture and hayland were applied appropriately.

Other

Land cover types in the "Other" land cover class include waterbodies (e.g., open water, wetlands, bays), as well as urban development and disturbed lands. CARB inventory carbon stock values for open water, barren, western warm temperate undeveloped ruderal grassland, California Central Valley riparian herbaceous, Pacific coastal marsh systems, and Sonoran Desert sparsely vegetated types were applied to the relevant "Other" land cover types in the study area. USFS FIA data for eucalyptus were used for carbon stock values for the non-native eucalyptus woodland type in the study area.

For urban and developed lands, carbon stock values were obtained from a 2015 report on the biomass and carbon sequestration potential of trees in urban environments in California (Bjorkman et al. 2015) used in the CARB inventory by assigning the estimated value for San Diego County.

3.1.4 Carbon Storage Modeling

This study used the InVEST (Integrated Valuation of Ecosystem Services and Tradeoffs) model for quantifying and mapping landscape carbon storage. The InVEST model is a free, open-source, geographic information system (GIS) based modeling package for mapping and valuing ecosystem services such as carbon storage and sequestration (Sharp et al. 2018; Butsic et al. 2017). The InVEST model uses a raster (grid) based platform, and all data were converted into 20-meter (400-square-meter resolution) rasters. For each unique vegetation-soil combination in the LULC layer covering the study area, carbon stock values were assigned to the three land cover carbon pools (i.e., aboveground live, aboveground dead, belowground live) based on the sources described in Section 3.1.3., and carbon stock values were assigned to the soil carbon pool based on the soil organic carbon layer described in Section 3.1.2.

3.2 Landscape Carbon Inventory

The following summarizes the land cover (Section 3.2.1), soils (Section 3.2.2), and carbon stock values (Section 3.2.3) used to estimate the baseline carbon storage (Section 3.2.4) for the study area. Summary information for each individual watershed is provided in Appendix A.

3.2.1 Land Cover

The 822,692-acre study area is comprised of four watersheds, including Otay (98,309 acres), San Diego (278,770 acres), Sweetwater (146,668 acres), and Tijuana (298,944 acres). In terms of natural vegetation communities, chaparral and scrub vegetation types comprise the majority of the study area, 49.0% and 13.2% respectively. Other natural vegetation types in the study area include woodlands (4.8%), forests (4.7%), grasslands (4.4%), riparian (2.1%), and marsh (0.2%). Other land cover types (developed, disturbed areas, and other sparsely vegetated lands) comprise 18.4% of the study area and agricultural areas cover 3.1% of the study area. Table 1 summarizes the land cover classes and land cover types by watershed in the study area and Figure 2 shows the land cover classes in the study area.

Table 1. Land Cover Class and Type by Watershed in the Study Area

Land Cover Class	Otay	San Diego	Sweetwater	Tijuana	Total
Land Cover Type	Acres				
Chaparral	**22,959**	**103,675**	**63,192**	**213,201**	**403,027**
Chamise Chaparral	1,679	8,258	3,048	11,671	24,656
Chaparral	12,654	16,592	13,531	15,508	58,285
Coastal Sage-Chaparral Transition	1,749	5,856	1,791	4,302	13,697
Granitic Chamise Chaparral	—	2,205	2,432	20,007	24,645
Granitic Northern Mixed Chaparral	1,325	18,367	11,360	95,803	126,856
Granitic Southern Mixed Chaparral	—	4,751	11,778	59	16,588
Interior Live Oak Chaparral	—	644	8	506	1,158
Mafic Chamise Chaparral	—	257	1,091	792	2,140
Mafic Northern Mixed Chaparral	151	2,870	2,033	10,511	15,565
Mafic Southern Mixed Chaparral	—	1,338	390	4	1,732
Mixed Montane Chaparral	—	58	—	—	58
Montane Ceanothus Chaparral	—	—	—	170	170
Montane Chaparral	—	764	302	—	1,067
Montane Manzanita Chaparral	—	—	460	2,421	2,881
Montane Scrub Oak Chaparral	—	164	772	5,057	5,993
Northern Mixed Chaparral	2,275	8,159	6,985	30,787	48,206
Red Shank Chaparral	—	—	—	4,467	4,467
Scrub Oak Chaparral	46	305	14	6,726	7,091
Semi-Desert Chaparral	—	—	—	1,074	1,074
Southern Mixed Chaparral	3,079	33,085	7,198	3,336	46,698
Forest	**3,976**	**16,343**	**4,501**	**14,191**	**39,011**
Black Oak Forest	—	—	121	919	1,040
Canyon Live Oak Forest	—	419	7	94	520
Coast Live Oak Forest	—	—	224	346	570
Coulter Pine Forest	—	31	—	—	31
Jeffrey Pine Forest	—	1,207	3,483	8,508	13,198
Lower Montane Coniferous Forest	—	—	—	—	—
Mixed Evergreen Forest	—	351	—	—	351
Mixed Oak/Coniferous/Bigcone/Coulter Forest	—	5,382	419	2,053	7,854
Oak Forest	—	40	—	—	40
Sierran Mixed Coniferous Forest	—	8,913	214	488	9,615
Southern Interior Cypress Forest	3,976	—	33	1,784	5,792
Grassland	**7,397**	**12,269**	**6,106**	**10,807**	**36,580**
Alkali Seep	—	—	44	418	462
Dry Montane Meadows	—	1,031	8	120	1,159
Foothill/Mountain Perennial Grassland	—	2,231	278	1,359	3,868
Freshwater Seep	—	334	58	1,326	1,719

Table 1. Land Cover Class and Type by Watershed in the Study Area

Land Cover Class	Otay	San Diego	Sweetwater	Tijuana	Total
Land Cover Type	Acres				
Montane Meadow	—	69	567	207	844
Native Grassland	160	67	—	48	275
Non-Native Grassland	1,751	2,310	1,866	4,775	10,703
San Diego Mesa Vernal Pool	456	—	—	—	456
Valley and Foothill Grassland	4,767	4,904	2,401	1,158	13,230
Valley Needlegrass Grassland	263	254	—	2	518
Valley Sacaton Grassland	—	—	46	324	369
Vernal Pool	—	—	—	—	—
Wet Montane Meadow	—	882	—	845	1,727
Wildflower Field	—	186	838	224	1,248
Marsh	**439**	**211**	**308**	**791**	**1,749**
Cismontane Alkali Marsh	149	3	—	5	157
Coastal and Valley Freshwater Marsh	91	56	45	12	204
Freshwater Marsh	125	71	7	137	341
Southern Coastal Salt Marsh	74	44	255	636	1,009
Transmontane Freshwater Marsh	—	37	—	—	37
Riparian	**1,561**	**6,498**	**3,647**	**5,558**	**17,264**
Arundo donax Dominant/Southern Willow Scrub	15	—	—	—	15
Mule Fat Scrub	72	7	5	5	89
Riparian and Bottomland Habitat	3	35	—	—	39
Riparian Forests	1	—	—	5	6
Riparian Scrubs	—	4	—	2	6
Riparian Woodlands	—	34	458	—	492
Southern Arroyo Willow Riparian Forest	—	22	—	29	50
Southern Coast Live Oak Riparian Forest	633	3,551	1,968	2,669	8,822
Southern Cottonwood-Willow Riparian Forest	—	315	312	226	852
Southern Riparian Forest	52	1,418	422	406	2,299
Southern Riparian Scrub	51	877	438	2,080	3,447
Southern Riparian Woodland	53	—	—	—	53
Southern Sycamore-Alder Riparian Woodland	8	106	—	—	114
Southern Willow Scrub	253	59	36	84	433
Tamarisk Scrub	420	4	—	5	430
White Alder Riparian Forest	—	63	9	47	118
Scrub	**29,300**	**44,858**	**17,730**	**17,100**	**108,988**
Alluvial Fan Scrub	—	3	—	58	60
Big Sagebrush Scrub	—	36	50	352	439
Coastal Scrub	—	—	—	7	7

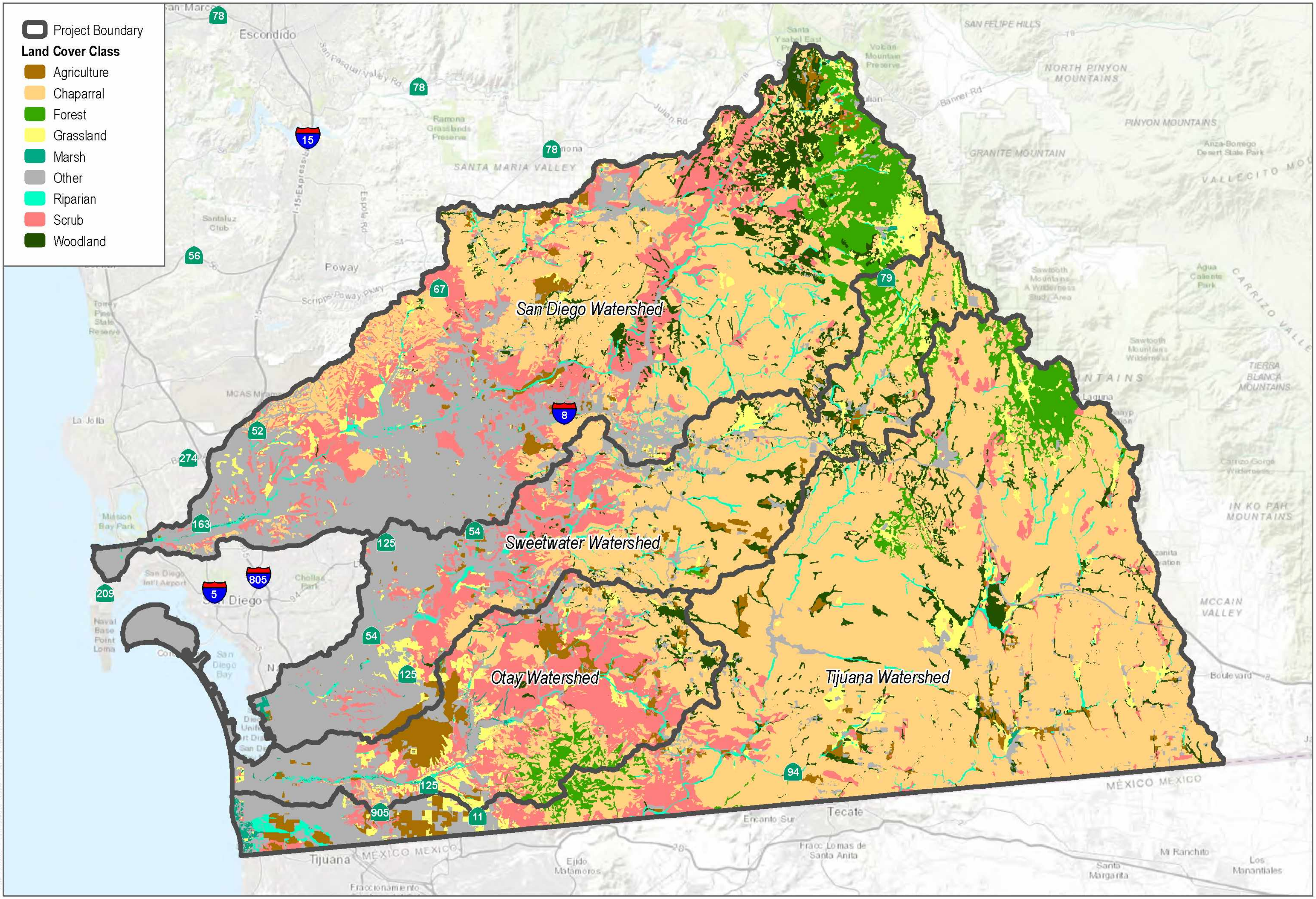
Table 1. Land Cover Class and Type by Watershed in the Study Area

Land Cover Class	Otay	San Diego	Sweetwater	Tijuana	Total
Land Cover Type	Acres				
Diegan Coastal Sage Scrub	28,846	44,318	17,527	11,019	101,711
Diegan Coastal Sage Scrub: Coastal form	—	9	1	—	9
Diegan Coastal Sage Scrub: Inland form	—	10	—	7	17
Maritime Succulent Scrub	454	—	4	51	508
Mojavean Desert Scrub	—	—	—	90	90
Montane Buckwheat Scrub	—	482	134	3,935	4,551
Riversidian Upland Sage Scrub	—	—	5	—	5
Sagebrush Scrub	—	—	10	1,524	1,534
Upper Sonoran Subshrub Scrub	—	—	—	57	57
Woodland	**2,074**	**20,010**	**5,587**	**12,121**	**39,792**
Black Oak Woodland	—	1,994	382	74	2,449
Cismontane Woodland	—	—	—	—	—
Coast Live Oak Woodland	214	314	36	60	624
Dense Coast Live Oak Woodland	1,458	6,389	3,099	7,741	18,688
Dense Engelmann Oak Woodland	—	2,772	181	129	3,082
Engelmann Oak Woodland	1	196	—	—	198
Mixed Oak Woodland	—	3,288	3	46	3,336
Non-Native Woodland	3	192	—	—	195
Oak Woodland	—	—	39	16	55
Open Coast Live Oak Woodland	—	1,238	10	3,056	4,304
Open Engelmann Oak Woodland	393	3,258	1,790	795	6,236
Peninsular Pinon Woodland	—	—	—	8	8
Undifferentiated Open Woodland	—	354	39	138	531
Woodland	5	14	8	58	85
Agriculture	**8,421**	**5,128**	**3,919**	**7,807**	**25,274**
Extensive Agriculture - Field/Pasture, Row Crops	8,067	3,389	2,445	4,275	18,176
Field/Pasture	—	706	158	2,037	2,900
General Agriculture	7	43	1,021	983	2,055
Intensive Agriculture - Dairies, Nurseries, Chicken Ranches	155	152	179	454	941
Orchards and Vineyards	192	553	115	58	917
Row Crops	—	284	—	—	284
Other	**22,182**	**69,778**	**41,677**	**17,370**	**151,007**
Beach	441	28	—	94	563
Deep Bay	—	—	—	—	—
Disturbed Habitat	3,821	4,362	2,745	3,070	13,998
Disturbed Wetland	81	45	51	195	372
Emergent Wetland	—	—	—	—	—

Table 1. Land Cover Class and Type by Watershed in the Study Area

Land Cover Class	Otay	San Diego	Sweetwater	Tijuana	Total
Land Cover Type	**Acres**				
Estuarine	4	26	—	83	113
Eucalyptus Woodland	118	173	50	42	383
Freshwater	981	2,499	193	1,286	4,960
Intermediate Bay	—	—	—	—	—
Non-Native Vegetation	139	85	1	—	224
Non-Vegetated Channel or Floodway	50	434	184	240	908
Open Water	10	277	1,307	—	1,594
Saltpan/Mudflats	132	—	—	94	226
Shallow Bay	68	2	32	—	102
Southern Foredunes	87	—	—	86	173
Subtidal	3	—	—	—	3
Urban/Developed	16,247	61,847	37,113	12,180	127,387
Total	98,309	278,770	146,668	298,944	822,692

Notes: Land cover class and type based on SanGIS (2020). Land cover type classification according to Holland (1986).



SOURCE: SANDAG 2022

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FIGURE 2

Land Cover

Carbon Storage and Sequestration Assessment for Four Watersheds of San Diego County, California

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3.2.2 Soils

The majority of the study area (59.2%) is comprised of soils with relatively moderate soil organic carbon values (12.5 to 16.2 MT C/ac) (Table 2). Approximately 12.2% of the study area has soil organic carbon values ranging from 8.5 to 12.1 MT C/ac and 13.9% of the study area has soil organic carbon values ranging from 16.6 to 20.2 MT C/ac. Soils with relatively high soil organic carbon values ranging from 20.6 to 25.9 MT C/ac characterize approximately 0.4% of the study area. Urban areas and waterbodies were excluded from the soil dataset due to lack of data and underrepresentation in the underlying soil surveys; therefore, approximately 14.3% of the study area had no assigned soil organic carbon value. Figure 3 maps the soils organic carbon in the upper 30 centimeters of the soil profile within the study area.

Table 2. Soil Organic Carbon by Watershed in the Study Area

Soil Organic Carbon (MT C/ha; MT C/ac in parentheses)	Otay	San Diego	Sweetwater	Tijuana	Total
	acres				
n.d.	19,888	54,809	33,112	9,494	117,304
21–30 (8.5-12.1)	17,992	12,190	4,917	65,453	100,552
31–40 (12.5-16.2)	57,362	169,147	82,697	178,187	487,393
41–50 (16.6-20.2)	3,068	40,593	25,653	45,066	114,379
51–60 (20.6-24.3)	0	1,942	289	730	2,961
61–64 (24.7-25.9)	0	89	0	14	103

Notes: Soil organic carbon in the upper 30 centimeters based on the ISRIC World Soil Information SoilGrids 2.0 originally reported in metric tons carbon per hectare (MT C/ha) and converted to metric tons of carbon per acre (MT C/ac) for this report. n.d. indicates urban areas and waterbodies with no available soil organic carbon data.

3.2.3 Carbon Stock Values

Carbon stock values were assigned to the three non-soil carbon pools (i.e., aboveground, belowground, dead) for each land cover type based on the source information and data as described in Section 3.1.3. A summary of the carbon stock values for each land cover class broad category is provided in Table 3, including the minimum, average, and maximum values. Average carbon stock values were used to estimate the baseline carbon storage (Section 3.2.4) and the minimum and maximum carbon stock values were used to evaluate carbon sequestration potential (Chapter 4). Refer to Appendix B for the detailed inventory that provides carbon stock values for each vegetation and land cover type in the study area.

Table 3. Summary of Carbon Stock Values by Land Cover Class

Land Cover Class	Minimum	Average	Maximum
	MT C/ac		
Chaparral	2.51	13.33	20.54
Forest	19.49	57.95	89.34
Grassland	1.47	2.04	2.94
Marsh	1.87	2.52	3.57
Riparian	1.48	35.51	48.79
Scrub	0.67	4.39	6.05

Table 3. Summary of Carbon Stock Values by Land Cover Class

Land Cover Class	Minimum	Average	Maximum
	MT C/ac		
Woodland	4.17	41.78	69.61
Agriculture	2.81	2.81	2.81
Other	0.84	2.02	2.94

Notes: Carbon stock values reported in metric tons of carbon per acre (MT C/ac). Minimum, average, and maximum carbon stock values summarized here by land cover class; refer to Appendix B for detailed carbon stock values for each vegetation type. Average carbon stock values for each vegetation type used in the baseline carbon storage analysis, and minimum and maximum carbon stock values for each vegetation type used for the carbon sequestration analysis.

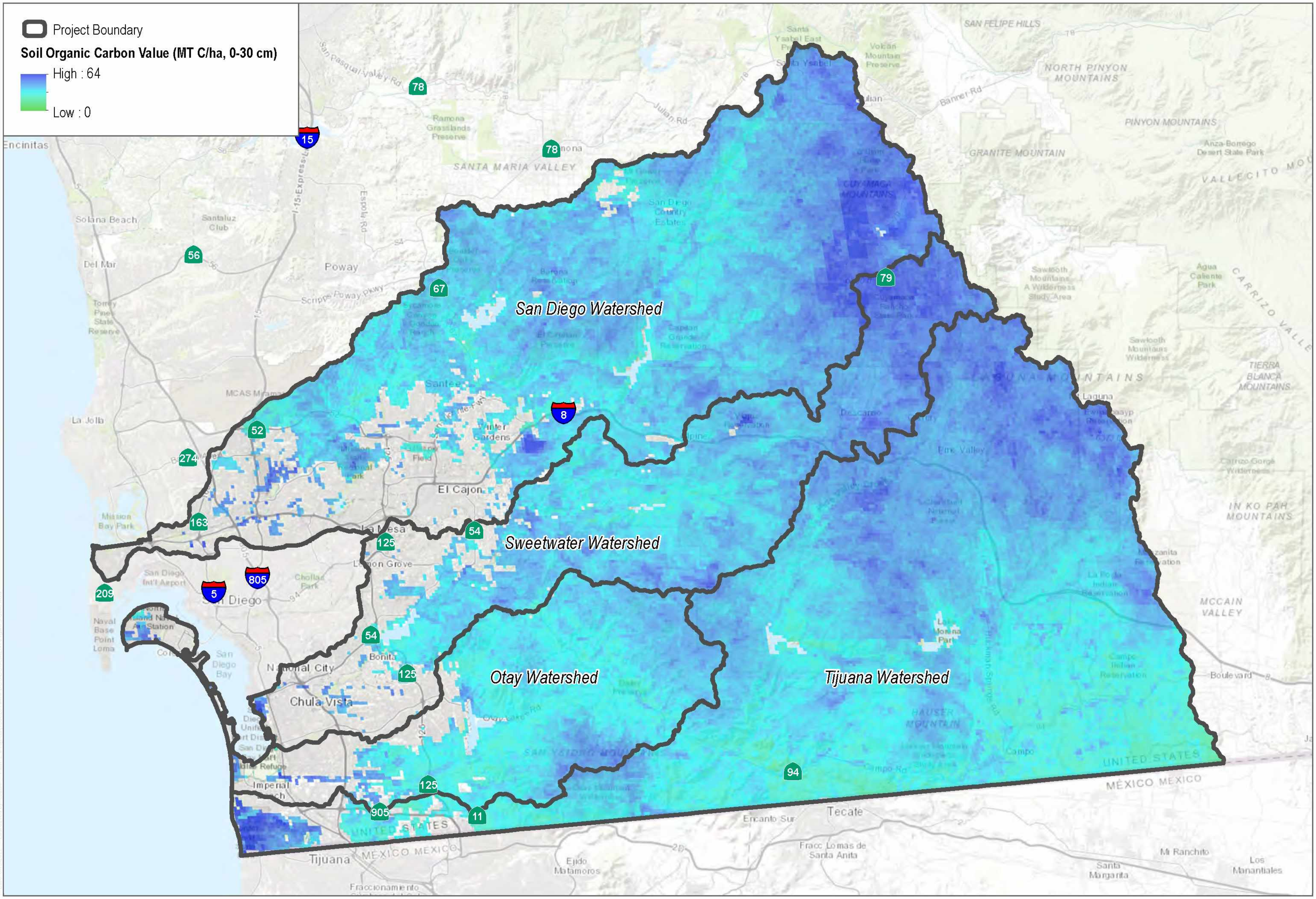
3.2.4 Baseline Carbon Storage Results

Total baseline carbon storage in the study area is approximately 21,630,000 MT C with 40% of the storage in the Tijuana Watershed, 35% of the storage in the San Diego Watershed, 16% of the storage in the Sweetwater Watershed, and 9% of the storage in the Otay Watershed. Chaparral vegetation types comprise the bulk of the carbon storage in the study area (52.2%) and cover the most acreage (49.0%). Due to the high carbon density of forest and woodland vegetation types, forests store approximately 14.5% of the carbon in the study area but only cover 4.7% of the study area, and woodlands store approximately 10.6% of the carbon in the study area but only cover 4.8% of the study area. Similarly, riparian areas cover only 2.1% of the study area but store approximately 4.0% of the carbon. Scrub vegetation types make of 13.2% of the study area and store 8.9% of the carbon. Grassland and marsh vegetation types store a relatively small portion of the carbon in the study area, 2.6% and 0.1% respectively. Agricultural areas store 1.4% of the carbon in the study area, and other land cover types store 5.6% of the carbon in the study area. Table 4 provides a summary of the total baseline landscape carbon storage and Figure 4 maps the distribution of the total baseline carbon storage in the study area. See Appendix A for summaries and mapping of baseline carbon storage for each watershed of the study area.

Table 4. Total Baseline Landscape Carbon Storage Summary

Land Cover Class	Otay	San Diego	Sweetwater	Tijuana	Total
	MT C				
Chaparral	645,070	2,956,314	1,835,794	5,860,253	11,297,431
Forest	242,109	1,533,565	339,290	1,014,279	3,129,243
Grassland	104,325	201,658	90,832	163,994	560,809
Marsh	5,214	2,942	4,258	15,622	28,036
Riparian	69,602	333,991	190,949	273,731	868,273
Scrub	516,399	795,208	310,643	310,976	1,933,227
Woodland	121,260	1,136,292	323,438	705,032	2,286,022
Agriculture	83,830	86,165	41,629	100,656	312,280
Other	167,355	522,458	320,996	203,489	1,214,299
Total	**1,955,165**	**7,568,594**	**3,457,830**	**8,648,031**	**21,629,620**

Notes: Carbon storage values summarized here by land cover class in metric tons of carbon (MT C). Total baseline landscape carbon storage based on average carbon stock values for each land cover type as described in Section 3.2.3.



SOURCE: ISIRC 2022

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FIGURE 3

Soils

Carbon Storage and Sequestration Assessment for Four Watersheds of San Diego County, California

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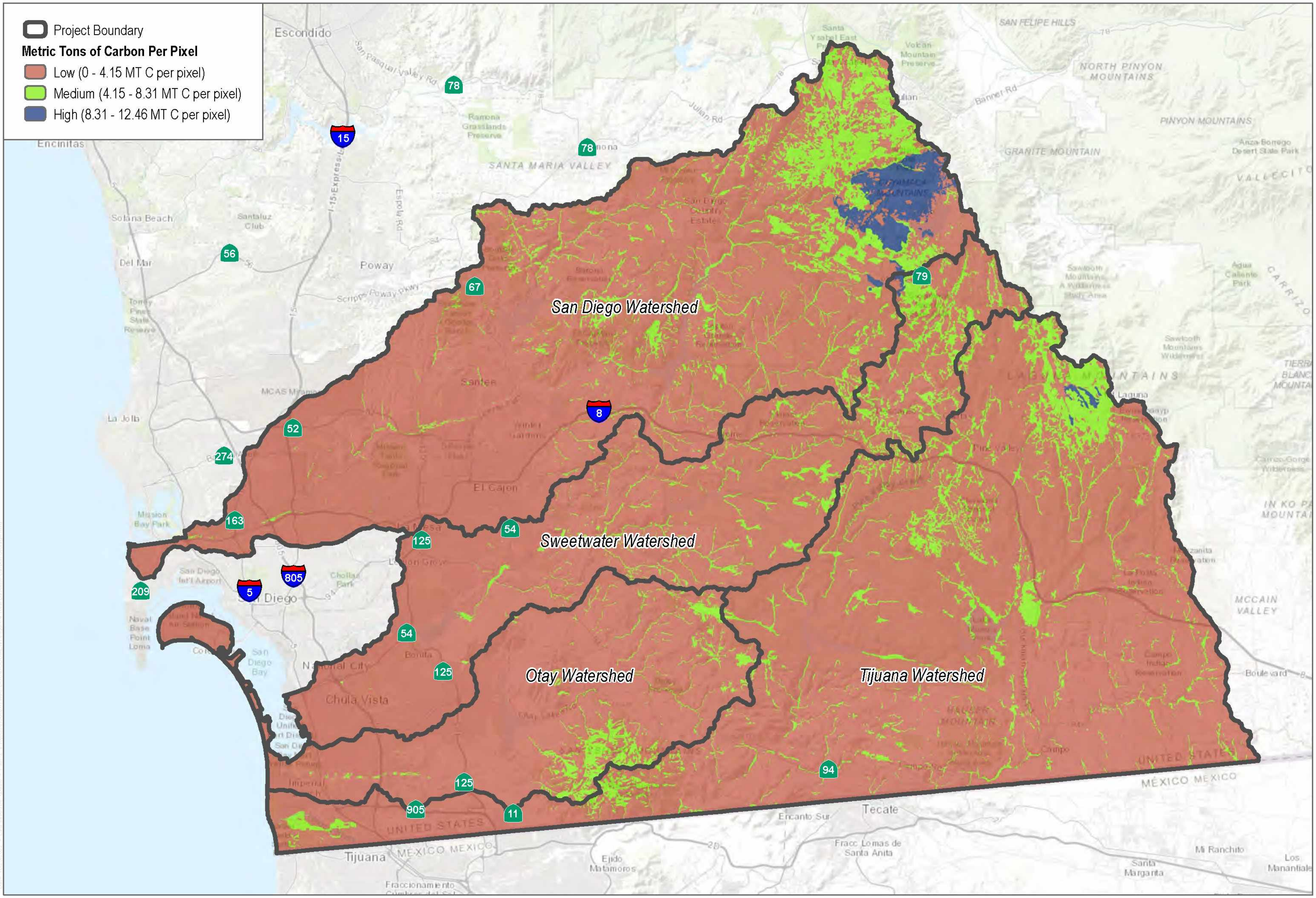

SOURCE: ESRI 2022

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FIGURE 4

Total Baseline Carbon Storage

Carbon Storage and Sequestration Assessment for Four Watersheds of San Diego County, California

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4 Carbon Sequestration Evaluation

4.1.1 Methods

To estimate future sequestration in the study area, minimum and maximum carbon stock values were obtained from the sources outlined in Section 3.1.3 and assigned to the appropriate vegetation and land cover types. Minimum carbon stock values were based on the earliest age class biomass estimates available for each vegetation type, and the maximum carbon stock values were based on the latest age class biomass estimates available for each vegetation type. As with the baseline storage calculation, for each unique vegetation-soil combination in the LULC layer covering the study area, the minimum and maximum carbon stock values were assigned to the three non-soil carbon pools (i.e., aboveground live, aboveground dead, belowground live). Soil carbon stock values were held constant[1] and the values used for the baseline inventory described in Section 3.1.2 were assigned to the soil carbon pool.

Sequestration was calculated in InVEST as the difference between maximum carbon storage estimate and minimum carbon storage estimate, and therefore represents an estimated theoretical upper limit of carbon accumulation over time, or sequestration *potential*, for the study area assuming static sequestration rates, no land use changes, and no active management actions to increase carbon storage or sequestration.

4.1.2 Carbon Sequestration Values

Minimum and maximum carbon values for the sequestration analysis were obtained from the same sources used for the baseline carbon inventory, as described in Section 3.1.3. Table 3 provides a summary of the minimum and maximum carbon density values by land cover class used for the sequestration analysis. Detailed minimum and maximum carbon stock values for each vegetation type are provided in Appendix B.

4.1.3 Sequestration Projections

The following summarizes the minimum carbon storage estimate, the maximum carbon storage estimate, and the carbon sequestration potential of the study area.

Minimum Carbon Storage

Total minimum carbon storage in the study area, based on the minimum carbon stock values for each land cover type, is approximately 12,276,000 MT C, which includes approximately 11,162,000 MT C in natural vegetation and approximately 1,114,000 MT C in agricultural and other land covers. Figure 5 maps the total minimum carbon storage in the study area based on the minimum carbon stock values.

Maximum Carbon Storage

Total maximum carbon storage in the study area, based on the maximum carbon stock values for each land cover type, is approximately 27,284,000 MT C, which includes approximately 25,738,000 MT C in natural vegetation and

1 Consistent with the IPCC's Guidelines for National GHG Inventories (IPCC 2006) that soil organic carbon eventually plateaus to a "spatially-averaged, stable value specific to the soil, climate, and land-use and management practices."

approximately 1,546,000 MT C in agricultural and other land covers. Figure 6 maps the total maximum carbon storage in the study area based on the maximum carbon stock values.

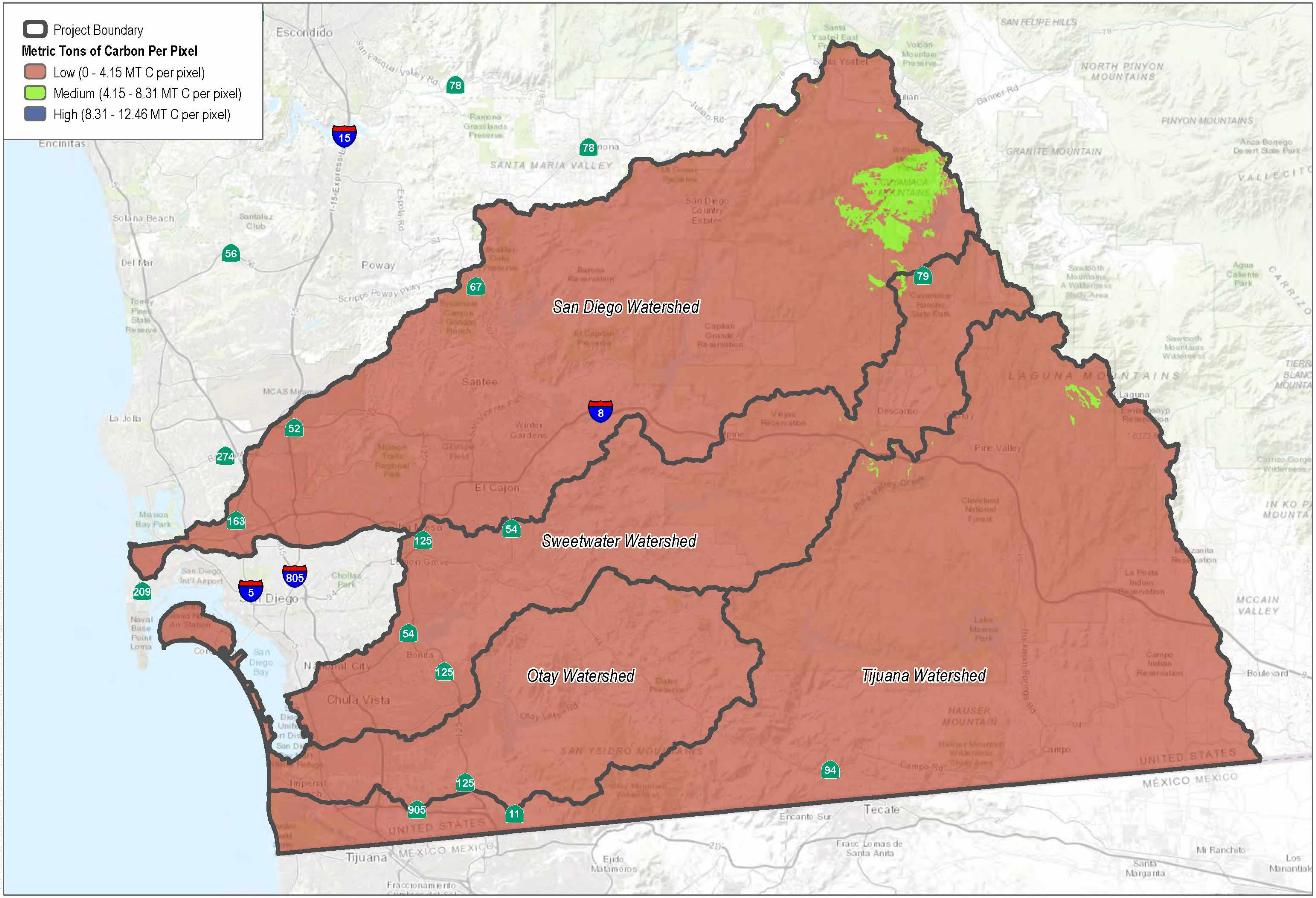
Carbon Sequestration Potential

The natural vegetation[2] in the study area has a maximum carbon sequesteration potential of up to approximately 14,576,000 MT C. This represents an estimated theoretical upper limit of carbon accumulation over time for the study area assuming static sequestration rates from minimum carbon storage to maximum carbon storage, no land use changes, and no active management actions to increase carbon storage or sequestration. Actual carbon sequestration potential is influenced by numerous factors, as discussed further in Chapter 5, notably the existing age class of the vegetation. Early successional vegetation has the potential to sequester more carbon over time, whereas the carbon in older, mature vegetation has already been stored and additional sequestration slows or levels off.

Under an assumption that the current carbon storage in the study area is most appropriately represented by the baseline carbon storage model described in Section 3.2.4, the natural vegetation[2] in the study area has the potential to sequester approximately 5,635,000 MT C. This represents estimated carbon accumulation over time for the study area assuming static sequestration rates from baseline carbon storage to maximum carbon storage, no land use changes, and no active management actions to increase carbon storage or sequestration. Figure 7 maps the total carbon sequestration potential in the study area from the baseline carbon storage model to the maximum carbon storage model.

Less carbon dense vegetation types that reach maturity early, like grassland, marsh, and scrub, sequester their maximum carbon within the first 20 years. More carbon dense vegetation types that take longer to reach maturity, including chaparral, forest, riparian, and woodland, continue sequestering carbon over long periods, in some cases well beyond 80 years. The sequestration trend by land cover class is illustrated in Figure 8. Carbon sequestration in the study area, like baseline storage, is strongly associated with acreage; however, over longer timeframes, land cover classes in the study area with high carbon density and sequestration potentials but lower relative acreage become increasingly important to the overall carbon storage (i.e., forest, woodlands, and riparian).

[2] Although carbon sequestered in agricultural areas and other land covers is important, these areas were excluded from the carbon sequestration analysis because they are largely managed and manipulated areas where carbon sequestration potential is directly influenced by human activities that are difficult to predict. Section 5.3.2, Management Strategies for Maximizing Carbon Storage, provides a discussion of working land management and urban land management.



SOURCE: ESRI 2022

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FIGURE 5

Total Minimum Carbon Storage

Carbon Storage and Sequestration Assessment for Four Watersheds of San Diego County, California

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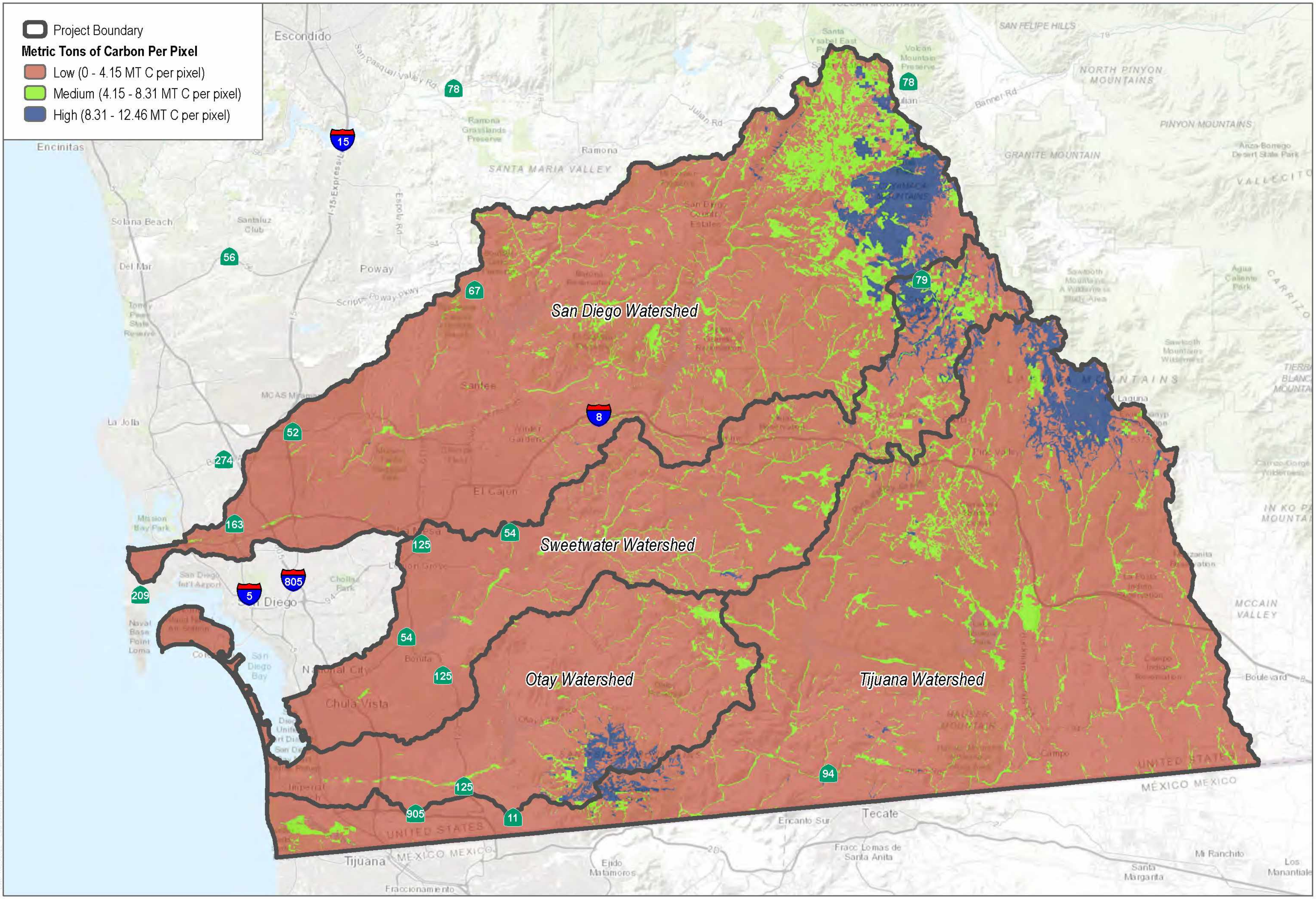

SOURCE: ESRI 2022

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FIGURE 6

Total Maximum Carbon Storage

Carbon Storage and Sequestration Assessment for Four Watersheds of San Diego County, California

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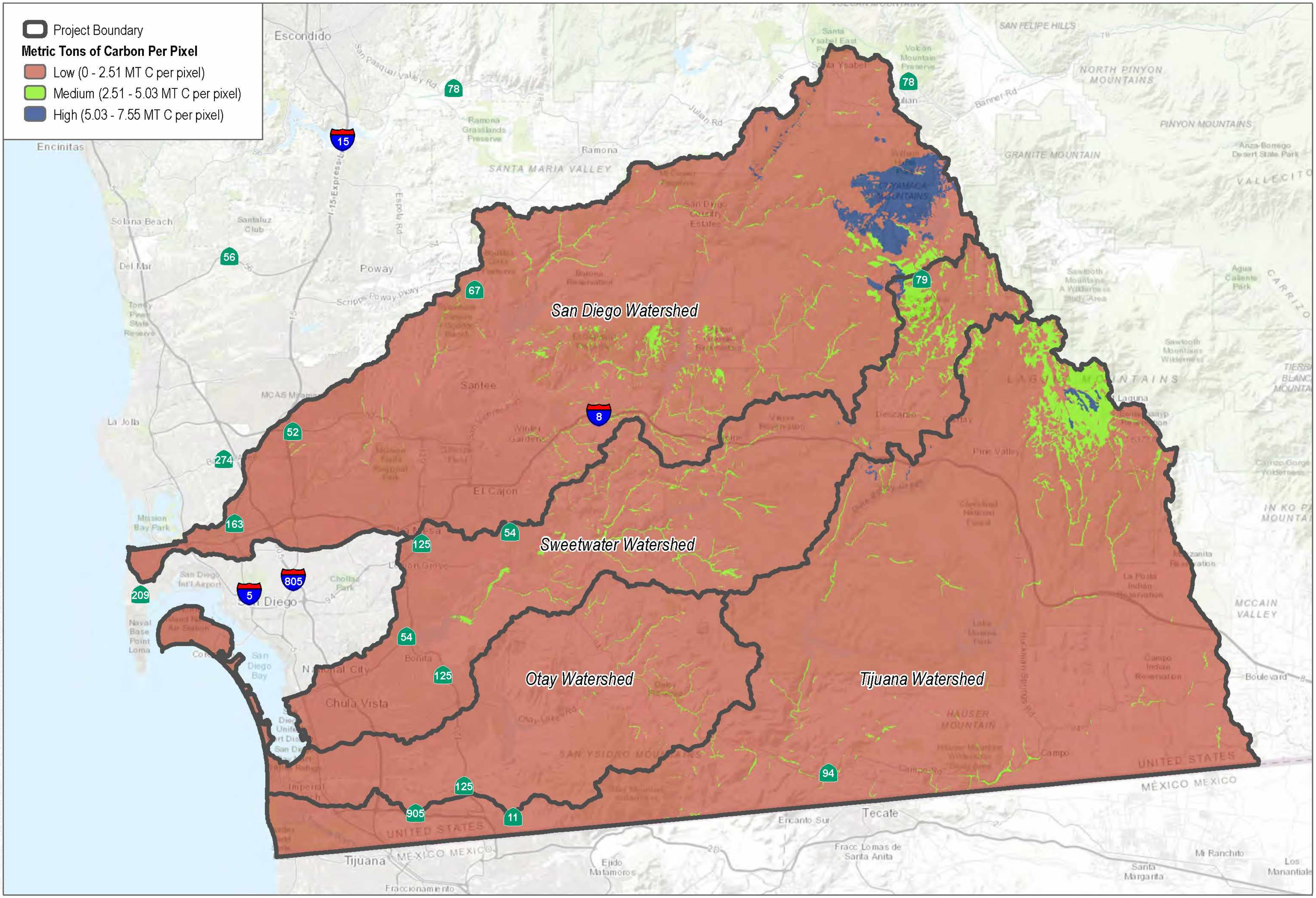

SOURCE: ESRI 2022

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FIGURE 7

Carbon Potential

Carbon Storage and Sequestration Assessment for Four Watersheds of San Diego County, California

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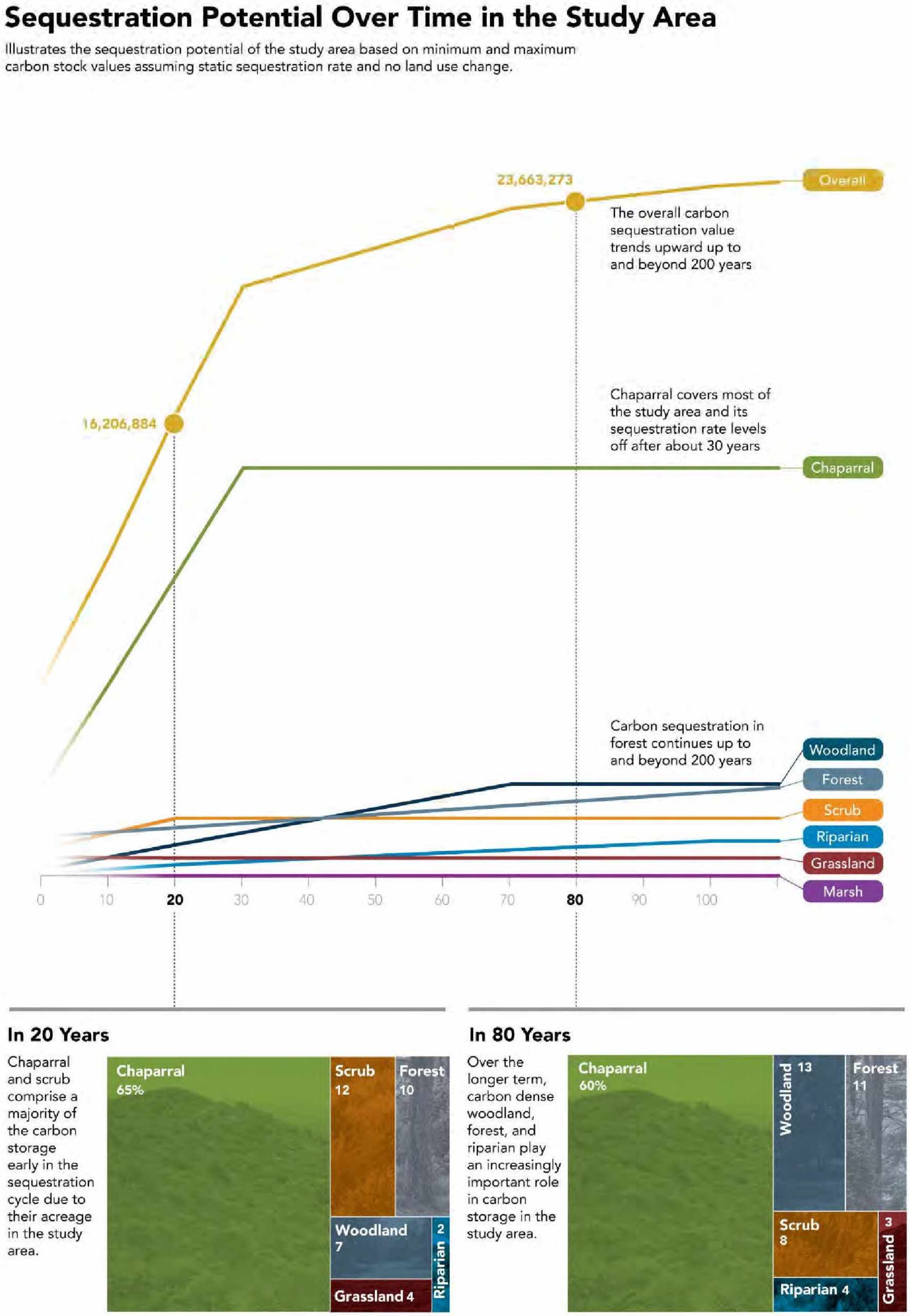

Figure 8 Sequestration Potential Over Time in the Study Area

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5 Discussion

5.1 Study Approach and Data

As described in the introduction and methods for the carbon inventory, this assessment focused on using data and methods for estimating carbon storage and sequestration that reflect the conditions and characteristics of the natural and working lands in the local watersheds of the study area. This focus dictated the selection of the land cover and soils mapping data, as well as the sources for the assigned land cover carbon stock values.

The SANDAG countywide vegetation community dataset (SanGIS 2020) was used for land cover mapping in this study because it is the authoritative land cover mapping dataset used in San Diego County and it provides relatively fine-resolution mapping and classification types at the local/watershed scale. Alternative geospatial land cover datasets were considered but not selected during study development, including U.S. Geological Survey (USGS) LANDFIRE, CAL FIRE Fire and Resource Assessment Program, and the SANDAG Vegetation of Western San Diego County. USGS LANDFIRE is a nationwide, satellite-based land cover data product with 30-meter resolution that covers the San Diego County region (USGS 2015, 2016). Because USGS LANDFIRE is a nationwide mapping product collected through remote sensing, it was not considered the most suitable source for this local/watershed focused assessment. CAL FIRE Fire and Resource Assessment Program maintains a multi-source land cover map of California from land cover data spanning a period from 1990 to 2014 and uses the relatively broad classifications of the California Wildlife Habitat Relationships (CAL FIRE 2015). This dataset was not selected for use in this study because the vegetation classifications used are fairly broad (i.e., are less specific on the vegetation types and aggregate the vegetation into broad categories) and the sources for the Southern California portion of the dataset are from 2002 and 2009, which is somewhat outdated. The SANDAG Vegetation of Western San Diego County dataset is a robust, high-resolution vegetation dataset that uses the standardized classification system based on the Manual of California and National Vegetation Classification System (SANDAG 2012). Although this dataset would be preferred for use in an assessment like this, the dataset covers only the western portion of the study area; therefore, the countywide vegetation dataset was selected in order to have a single, consistent land cover dataset for the entire study area.

The ISRIC World Soil Information SoilGrids 2.0 dataset was used for this assessment because it provided the finest resolution estimate of soil organic carbon available and is based a model that integrated field plots throughout California, including a fairly robust set of inputs from San Diego County. Other data and approaches to estimate the soil organic carbon values for the soil carbon pool were investigated during study development, including using San Diego Soil survey mapping data coupled with IPCC soil organic carbon values and the use of International Soil Carbon Network data. San Diego Soil Survey data are available countywide, which provides relatively high resolution mapping of soil types for San Diego County (USDA 2020a); however, this mapping of soil types would need to be aggregated into soil orders and the related seven IPCC soil classes (i.e., high activity clay, low activity clay, wetland, organic/spodic, sandy, volcanic, not available) with their associated soil organic carbon values (IPCC 2006). Therefore, although the San Diego Soil Survey provides detailed soil mapping for the study area, the assigned aggregated soil organic carbon values are coarse (discrete values of 0, 19, 24, 38, and 88 MT C/ha) whereas the selected ISRIC SoilGrids dataset used for this assessment includes 45 discrete values ranging from 0 to 64 MT C/ha. The International Soil Carbon Network soil network data are a collection of soil sampling dataset worldwide, including 66 locations in San Diego County (ISCN 2015). Although this dataset includes a robust set of sampling and includes soil organic carbon values for those sampling locations, it is not a comprehensive, seamless spatial dataset covering the entire study area and could not be used for our modeling purposes.

Selection of carbon density values for the vegetation types within the study area required thorough review of various sources, with a priority for values most specific to the species and environment. Specificity was particularly crucial for land cover classes that dominate the study area (e.g., chaparral). Growth and disturbance data for chaparral and shrubland communities are less understood than the well-researched forested communities, so more generalized carbon density datasets fail to capture the unique carbon dynamics of these ecosystems. Local, vegetation-specific carbon values from primary research studies were used for these landcover types, as well as for riparian, oak woodland, and grassland. USFS FIA was used for forest vegetation, and provided a similar level of specificity, as the dataset is compiled using forest monitoring surveys and is geographically specific. Where necessary, other industry-accepted data sources were used when vegetation or geographically specific sources were not available.

This assessment employed the InVEST model as a straightforward GIS-based carbon "accounting" tool for quantifying and mapping carbon storage and potential carbon sequestration in the study area. Use of the InVEST tool was prescribed by the project proponents as part of the funding agreement that supported this study. Other approaches have been used by others developing carbon storage assessments, including standard GIS-based analyses or more complex geoprocessing and analysis tools, such as the Department of Conservation TerraCount model (DOC and TNC n.d.). For the purpose and intended uses of this study as described in Chapter 1, Introduction, the InVEST model provided the best off-the-shelf tool for assessing carbon storage and sequestration; custom GIS models or more complex analysis tools were not considered necessary.

Limitations

Carbon storage and sequestration inventories at the local or regional jurisdictional level are still in their infancy, with no standardized data and methods. Given the relatively new nature of these assessments, the analysis conducted here was based on several assumptions, which present some notable limitations.

Data Inputs. Landscape carbon inventories are based on two primary data and information inputs: (1) land cover and soils mapping and (2) carbon stock values for the carbon pools. For this study, land cover mapping was obtained from the SANDAG countywide vegetation community dataset (SanGIS 2020). Compared to alternative regional mapping datasets, this San Diego-specific dataset provides fine-resolution vegetation distribution and classification of vegetation types ideal for this locally focused study; however, these data are not comprehensively updated on a regular basis and use of these data required manual assignment of carbon stock values to each vegetation type. The land cover dataset used in this study is updated periodically to reflect land use changes but is not comprehensively updated at regular time intervals like some other sources (e.g., USGS LANDFIRE); therefore, this study is based on land cover data that represent a "snapshot in time" and may not reflect all current on-the-ground land cover conditions. Additionally, finer spatial and classification resolution of the land cover data used meant that assigning carbon stock values was a manual, time-intensive process, unlike the larger, regional datasets like USGS LANDFIRE, which has CARB carbon stock values linked directly to each land cover type. The selected data and approaches were considered appropriate, despite these limitations, given the local planning priorities of this study.

Baseline Carbon Inventory. As discussed previously, the carbon storage potential of vegetation is dictated by several factors, including age-class, which in the study area region is largely governed by fire history and land use. Given that the spatial dataset for vegetation used in this study did not include age class information, age-dependent carbon density values were not used. Instead, for the baseline carbon inventory in this study, the average carbon stock values for each vegetation type were assumed. The baseline carbon inventory therefore does not account for variations in carbon density that exist in-situ for each vegetation type due to stand age.

Fire history and fire perimeter data can be used to estimate vegetation age classes for the study area; however, this approach is speculative given variabilities in fire intensities, vegetation fire response, and other factors. A review of the fire history and perimeter data revealed that approximately 48% of the study area was either unburned (i.e., no fire history) (22%) or the most recent fire was before 1990 (26%). For approximately 47% of the study area, the most recent fire was between 1990 and 2010, and the remaining 4% of the study area experienced fires in 2010 or later (CAL FIRE 2021a). Therefore, approximately 48% of the vegetation in the study area is assumed to be at least 30 years old based on fire history, and approximately 47% of the vegetation in the study area is assumed to be 10 years old or older based on fire history. For chaparral and scrub vegetation types, which are the most prevalent in the study area and the most fire prone, this review of fire history shows that these vegetation types are largely at least at their average growth potential (10–15 years) and use of average carbon stock values is representative of the current status of these vegetation types in the study area.

In addition to vegetation stand age, landscape carbon storage can be influenced by numerous other micro- and macro-scale factors, including temperature, elevation, aspect, and precipitation, that can vary across the landscape (Sharp et al. 2018). Vegetation biomass studies and associated carbon stock values are not available at sufficient resolution to quantify or model the implications all these factors on landscape carbon storage; therefore, use of average carbon stock values, based on the best available source information for each vegetation type, was considered the most appropriate approach for the baseline carbon inventory.

Sequestration Projections. Using the InVEST model, sequestration can be estimated as the difference between two discreet LULC rasters by (1) utilizing two different LULC rasters with carbon density values held constant (i.e., carbon storage changes due to changes in land use), (2) utilizing two rasters with constant LULC assumptions and changes to carbon stock values (i.e., carbon storage changes due to changes in carbon density), or (3) a combination of these two approaches. The InVEST model assumes a linear path of sequestration, when in actuality most sequestration is nonlinear and tied to age class, where higher rates of sequestration occur in early years and there is slower growth in late stages (Sharp et al. 2018).

Assessing projected land use change in the study area was outside the scope of this study, and, as described above, vegetation stand age was not part of the spatial data used in the study. Therefore, projected sequestration from the natural vegetation land cover types (excluding agricultural areas and other [e.g., urban] land covers) was presented assuming change in carbon density from a minimally stocked landscape to a landscape at capacity (the minimum to maximum carbon projection) and assuming change in carbon density from the average stocked landscape to a landscape at capacity (the baseline to maximum carbon projection). These scenarios represent sequestration potential under neutral conditions, with no influence from external influences such as wildfire or changes in land use. Additionally, as discussed in Section 5.3.1, Effects of Climate Change on Carbon Storage and Sequestration, in further detail, the capacity of the study area to sustain carbon stocks and sequester additional carbon into the future will be highly influenced by various climate change-related effects. Thus, the carbon sequestration projections in this study represent sequestration potential and not the actual carbon sequestration of the study area going forward from the current conditions that exist today.

The forecasted sequestration scenarios also did not account for potential gains or losses in soil carbon. As discussed in Section 4.1.1, Methods, it was assumed that soil carbon stock values would remain relatively constant absent disturbance or active land use or management changes per IPCC guidance, which states that soil organic carbon eventually reaches equilibrium under stable soil, climate, and land-use management conditions. However, there is evidence that the quality and quantity of carbon stocks in soil pools is influenced by aboveground litter deposits, so soil carbon storage can change in response to changes to land use and management (D'Amore and Kane 2016).

5.2 Study Findings

The carbon storage and sequestration findings presented here are important given statewide GHG emission reduction targets, carbon neutrality goals, and the increased focus on nature-based solutions for climate change mitigation. Understanding the magnitude, composition, and spatial distribution of current and future carbon stocks is a crucial first step to ensuring persistence of these stocks into the future.

Baseline carbon storage estimates indicate that the study area currently holds approximately 21.6 million metric tons (MMT) of carbon in vegetation and soils. In the absence of age class information for the landcover classes present in the study area, this baseline carbon stock was estimated using average carbon stock values from the respective sources for the existing land cover types. Most of the carbon stock is held in the chaparral and scrub vegetation communities (61% of total), which, given the relatively low carbon density of these communities, is predominantly due to their prevalence in the study area (62% of total acreage). While forests and woodland vegetation accounts for less overall carbon storage in the study area than the chaparral and scrub vegetation, these communities are vastly more carbon dense, and so account for more stored carbon than their respective acreage (i.e., 25% of carbon stock on only 10% of total acreage). As discussed further in Section 5.3.2, this suggests that forest and woodland communities represent efficient and effective targets for management and restoration investment for carbon storage. The remainder of the baseline carbon inventory (28%) is held in the grassland, marsh, riparian, agriculture, and other landcover classes. It is important to note that while riparian vegetation does not account for substantial stored carbon in the study area, like forest and woodland communities, riparian communities are also carbon dense, so it can store high amounts of carbon on relatively small areas of the landscape. This is particularly evident in the Sweetwater Watershed, where riparian vegetation accounts for 6% of the total carbon stock on only 2% of total acreage.

The estimate of sequestration potential indicates that the carbon stocks could increase by up to approximately 14.6 MMT of carbon in the study area. Given that the analysis was completed without age-specific information for the existing vegetation, this projection assumed change from minimum (approximately 11.2 MMT C) to maximum storage (25.7 MMT C) potential of the vegetation types in the study area. Assuming that a majority of the existing vegetation may be closer to average carbon storage values as opposed to minimum values, carbon sequestration potential was estimated to be approximately 5.6 MMT of carbon in the study area using a change from the baseline (20.1 MMT C) to maximum storage (25.7 MMT C)

Similar to baseline storage, the majority of the sequestration potential is attributed to carbon accumulation in the chaparral and scrub vegetation, which again is due to areal coverage of these land covers in the study area and not indicative of higher sequestration rates. In fact, as shown in Figure 8, carbon sequestration in the chaparral and scrub communities reaches carbon carrying capacity at 30 years with no additional carbon projected to accumulate beyond that period. This is due to stand senescence; according to the literature, live biomass and cover of Mediterranean-climate chaparral and shrubland species tends to peak around 25–30 years (Bohlman et al. 2018).

As with overall storage, forest and woodland communities show greatest sequestration potential and efficiency. In contrast to chaparral and scrub, this is largely due to the higher carbon carrying capacity of these vegetation types, which are able to continue sequestering and storing carbon over comparatively longer timespans before reaching maturity. As shown in Figure 8, as most vegetation types reach capacity, the forest and woodland sequestration trajectories continue a positive trend of continued carbon uptake. Once again, given the capacity of continued carbon sequestration on relatively small acreage, strategies to support sequestration in these communities would be an efficient management approach, as discussed further in Section 5.3.2.

The remainder of sequestration potential in the study area is attributed to the grassland, marsh, and riparian communities[3]. However, as discussed previously, despite the seemingly insignificant contribution to overall sequestration potential due only to the small areal coverage in the study area, the riparian community has relatively high sequestration rates with positive carbon uptake well into the future (See Figure 8).

The effects of current land cover status (i.e., vegetation stand age), possible land use and management changes, and the impact of climate change on carbon stocks and sequestration are discussed in further detail in Section 5.3.

5.3 Other Considerations

5.3.1 Effects of Climate Change on Carbon Storage and Sequestration

While the sequestration projections presented in this study assume maximum potential uptake with static sequestration rates, research clearly indicates that future climate changes will alter the carbon storage capacity of these landscapes and will have long-term implications for the success of carbon sequestration efforts (Coffield et al. 2021). There is enthusiasm for the use of California's NWLs as a natural solution to support statewide climate change mitigation; however, uncertainty remains around the future ability and magnitude of sequestration and storage in these lands in the face of climate change (Anderegg et al. 2020). In the San Diego region specifically, projected climate changes that will have the greatest impact to future carbon storage and sequestration include increased temperatures, variable precipitation, wildfire, and secondary effects of pest infestation (Kalansky et al. 2018). Each of these has the potential to affect the ability of the region's natural and working lands to sequester and store carbon in the vegetation and soils. The following is a brief summary of these climate change effects and how they will impact carbon storage in the future.

Mean temperatures in the San Diego region are projected to increase by up to 10°F by the end of the century. In addition, the frequency of heat waves, which will be longer in duration and more intense, is expected to increase (Kalansky et al. 2018). Recent climate modeling of California's ecosystems indicates that under both moderate and severe warming scenarios, aboveground live carbon stocks are anticipated to decrease substantially (Coffield et al. 2021). Similarly, carbon storage in soils declines sharply with increases to mean annual temperature (Hartley et al. 2021).

Precipitation in San Diego County is expected to remain highly variable, but will be characterized by extremes, including wetter winters, drier springs, and more frequent and severe droughts that are projected to be punctuated by more intense individual precipitation events (Kalansky et al. 2018). Drought events have considerable impacts on carbon cycling in natural and working lands, through decreased productivity and mortality-driven carbon losses (Hartmann et al. 2018). From 2011–2015 drought in California resulted in massive tree mortality resulting in a

[3] Agriculture and Other land cover classes were not included in the analysis of sequestration potential analysis. Although carbon sequestered in agricultural areas and other land covers is important, these areas were excluded from the analysis because they are largely managed and manipulated areas where carbon sequestration potential is directly influenced by human activities that are difficult to predict.

loss of approximately 600 terragrams of CO_2 equivalent (CO_2e), or the equivalent of about 10% of the state's total GHG emissions over the same period (Sleeter et al. 2019). The soil carbon cycle is also highly impacted by drought due to decreases in litter input and decomposition and reduction in root biomass production, though magnitude of response is found to be ecosystem- and vegetation community-dependent (Deng et al. 2021).

Historically, fire has been a natural and critical ecological component of California landscapes, serving to remove excess fuel, thin vegetation, and reduce competition for nutrients and water to support healthy communities that are resilient to drought and other stressors (Forest Climate Action Team 2018). However, over time, exclusion of fire from the landscape has led to biomass buildup and species change that results in increased fire severity as compared to historical levels (Mallek et al. 2013) and, particularly in Southern California, fires that occur more frequently than historic norms (Forest Climate Action Team 2018).

In the San Diego region specifically, wildfire risk is expected to increase in the future, with increased risk of large catastrophic fires driven by Santa Ana wind events that are also likely to increase due to drier autumns driving low antecedent precipitation preceding the height of the Santa Ana wind season (Kalansky et al. 2018). Shrublands, in particular, seem to be burning more frequently than they have historically, which risks degradation and conversion to less carbon-dense grassland environments (USDA 2020b; Bohlman et al. 2018). During wildfire events, stored carbon in live and dead aboveground biomass is converted and lost as atmospheric carbon, and during post-fire recovery, systems are at risk for becoming a sustained source of carbon if losses from decomposition exceed photosynthetic gains (Kashian et al. 2006). However, total carbon lost during fires varies across ecosystem types and is governed by the composition of fuel present (i.e., amount of live versus dead biomass), fuel moisture, fire weather, and fire intensity. Generally, grassland communities, which are less carbon dense, result in more carbon loss during fire events than do temperate forest ecosystems (Loehman et al. 2014).

The climate change impacts discussed above, including drought and increased warming, can also leave communities susceptible to infestation and to biotic disturbance (i.e., pests) (Pathak et al. 2018). When communities experience drought, host trees have decreased defenses and altered foliage quality that leave them susceptible to attack (Kolb et al. 2016). Increased oak mortality in the San Diego region has been linked to this secondary attack by pests, as was seen in Camp Pendleton with the oak ambrosia beetle during the 5-year drought (California Forest Pest Council 2017). Attack from pests cause declines in productivity and substantial carbon losses. Approximately 5% of the aboveground tree carbon stocks in the western United States were affected by bark beetle-caused tree mortality (Hicke et al. 2013).

5.3.2 Management Strategies for Maximizing Carbon Storage

As demonstrated by the sequestration projection for the study area with fixed rate assumptions, the NWLs for the region have the capacity to sequester and store carbon into the future. However, as discussed above, these lands are vulnerable to the impacts of climate change and can alternatively release more atmospheric CO_2 than they store, becoming a source and driver of future warming and climate changes. Therefore, ensuring these lands remain a sink of carbon and continue sequestering atmospheric CO_2 in the future will require climate-smart land management strategies that support healthy ecosystem function (CARB 2022). Below is an overview of these strategies specific to the land cover types present in the study area.

Natural Land Management

The natural lands in the study area include chaparral, scrub, forest, woodland, grassland, riparian, and marsh land cover types, and account for approximately 80% of the total acreage. Given that these lands make up the vast majority of the study area, climate-smart management of these lands is particularly important. Climate-smart management can limit future carbon losses, support carbon sequestration, and ensure long-term storage, while also supporting resilience through the following activities:

- **Habitat Restoration:** Implementation of active habitat restoration that converts lower-carbon-density land cover types, such as grassland, to higher-carbon-density land cover types such as shrubland, oak woodland, and riparian
- **Fire Management:** Active wildland fire management and suppression to prevent and minimize large-scale fires that convert stored carbon to atmospheric CO_2
- **Planning and Management to Avoid Natural Land Conversion:** Land use planning and policies and land management activities that avoid and minimize the conversion of higher-carbon-density land cover types such as shrubland, forest and woodland, and riparian, to lower-carbon-density land cover types such as grassland, barren, and urban.

Implementing the natural land management activities described above has the potential to increase carbon storage and sequestration when compared to that of unmanaged natural lands, as summarized below.

Habitat Restoration

- **Forest Restoration:** As in this study, forest communities in the study area are incredibly carbon dense. Forest land cover in the study area has an average carbon density of 58 MT C/ac, or the equivalent of 213 MT of atmospheric CO_2 per acre. Active reforestation efforts should be focused in areas recovering from severe wildfire damage, where regeneration is slow, to prevent conversion to less-dense communities (i.e., grasslands) (CNRA 2022).
- **Oak Woodland Restoration:** Oak woodlands in the study area are also relatively carbon dense and account for carbon storage values that far exceed the acreage they occupy. Woodland land cover in the study area has an average carbon density of approximately 42 MT C/ac, or the equivalent of 153 MT of atmospheric CO_2 per acre.
- **Riparian Restoration:** While riparian communities do not account for a lot of acreage or carbon storage when compared to the other vegetative communities in the study area, this is community also has a relatively high carbon density, with an average carbon density of approximately 36 MT C/ac, or the equivalent of 131 MT of atmospheric CO_2 per acre.
- **Chaparral and Shrubland Restoration:** While not as carbon dense as forest, woodland, or riparian communities, native chaparral and scrub land cover make up the vast majority of the study area, occupying over 62% of the landscape. Due to the expanse of these vegetation types, restoration of these communities could be an important tool in securing carbon stocks and future sequestration potential in the region. The average chaparral and scrub carbon densities are approximately 13 and 4 MT C/ac, respectively. These densities are the equivalent of sequestering 49 and 16 MT of atmospheric CO_2 per acre from chaparral and scrub vegetation, respectively. Restoring degraded chaparral and shrubland communities can increase habitat connectivity and enhance system resilience to reduce permanent loss of carbon from the landscape (CNRA 2022).

In addition to the carbon storage and sequestration benefits, habitat restoration can result in numerous complementary benefits, such as improved air quality, scenic value, flood risk, water quality, and watershed integrity, as well as numerous biodiversity benefits (terrestrial connectively, natural habitat areas, priority conservation areas, terrestrial habitat value, and aquatic biodiversity).

Fire Management

As discussed above, wildland fires present a significant challenge in maintaining carbon stocks and retaining carbon persistence in natural lands. Wildfires occur through multiple interacting factors including weather, land use, and human activity, which makes predicting future wildfires difficult (Forest Management Task Force 2021). Natural lands of the San Diego region are fire prone, as illustrated by the region's fire history as described in Section 5.1. Of the 20 largest fires on record in California, 2 occurred in San Diego County: the 2003 Cedar Fire (over 273,000 acres) and the 2007 Witch Fire (nearly 200,000 acres) (CAL FIRE 2021b).

The age classes of the vegetation types in the study area are influenced by fire history and affect the current carbon storage and the potential to sequester carbon over time. Further, as mentioned above, the effect of wildfire on storage and sequestration differs by vegetation type; scrub, chaparral, and grassland communities tend to burn more completely, whereas wildfires in riparian, wetland, and oak woodlands tend to burn less intensely, leaving more live and dead aboveground carbon on the landscape in these communities (Loehman et al. 2014).

Carbon storage and sequestration potential for this analysis were estimated absent of age-class information for the vegetation communities within the study area, and therefore do not directly account for the impact of fire. In general, areas with more recent fires are likely to be less carbon dense than estimated in this study but will accumulate carbon at a higher rate as they regenerate. Older age class areas with less recent fire activity are likely to be more carbon dense than estimated here but will also accumulate carbon at a slower rate. See discussion in Section 5.1 on the limitations of the landscape carbon storage related to vegetation stand age.

Managing wildland fires, such as through wildfire planning and fire suppression, is an important factor in maintaining the persistence of the carbon storage in natural lands going forward. There is consensus within the literature that management strategies to reduce stand density and restore beneficial fire patterns can support climate resilience, reduce likelihood of severe wildfires, and minimize losses from long-term forest carbon stocks (Bedsworth et al. 2018). In the study area, forest thinning can be achieved through prescribed burns and natural wildfire management to reduce the risk of catastrophic wildfires, which can increase carbon sequestration rates and stabilize carbon stocks. Proper thinning can also increase resilience to future drought. In chaparral and shrubland communities, fire management strategies include creation of buffer zones and managed grazing for fuel management by establishing fuel breaks (CNRA 2022).

Planning and Management to Avoid Natural Land Conversion

Avoided conversion refers to retaining and gaining carbon and achieving other complementary benefits by maintaining the NWLs in the landscape. Land use planning and policies implemented by local municipalities and other entities within the study area influence land use and the amount of conversion of natural lands to lower-carbon-storage land covers. Further, entities with responsibilities for land management in natural lands implement measures, such as invasive plant species management and access control, that can prevent and minimize the conversion of higher-carbon land cover types to lower-carbon land cover types. In addition to maintaining carbon in the natural landscape, avoiding conversion to urban activities or other uses results in numerous positive outcomes across complementary benefits associated with agricultural quality, water quality, biodiversity, and human wellbeing and resilience.

Working Land Management

Based on the land cover class summary provided in Table 1, agricultural lands cover approximately 3%, or 25,274 acres, of the study area. Most strategies in working lands are related to the management of soils and, as the largest terrestrial organic carbon pool (carbon stored in the top 2 meters of the world's soils accounts for almost three times the amount of carbon in the atmosphere) (Paustian et al. 2016), even though agricultural lands don't represent a large percentage of total acreage in the study area, investment in working land management strategies to manage soils presents a promising opportunity for carbon sequestration.

Working land management activities known to have the potential to increase carbon storage or decrease GHG emissions as compared to unmanaged agricultural lands are summarized below.[4]

- Improved Nitrogen Fertilizer Management: Adjusting the application rate, source, method, and timing of synthetic nitrogen fertilizers to more accurately align with the needs of a crop can reduce N_2O emissions (Paustian et al. 2016). Improved nitrogen fertilizer management has the potential to remove 0.01 to 0.03 MT CO_2e[5] per acre per year. If implemented over the total agricultural acreage in the study area, this could remove approximately 253 to 759 MT CO_2 from the atmosphere per year. This is the equivalent of storing 69 to 207 MT of carbon in these lands.
- Use of Alternative Soil Amendments: Replacing or augmenting synthetic nitrogen fertilizers with manure, compost, biochar, or other organic byproducts can increase the residence time of carbon in the soil as a result of slowed decomposition (Paustian et al. 2016). Application of organic amendments has also proved to be a long-term solution; a single application of compost to rangelands in California was found to increase sequestration for up to 30 years (Bedsworth et al. 2018). Use of alternative soil amendments has the potential to remove 0.13 to 4.49 MT CO_2e per acre per year. If implemented over the total agricultural acreage in the study area, this could remove approximately 3,286 to 113,481 MT CO_2 from the atmosphere per year, or the equivalent of storing 895 to 30,921 MT of carbon.
- Use of Cover Crops: Planting and rotating cover crops such as grasses and forbs,[6] together with maximizing the depth of deposition by planting crops with longer roots and reducing soil disruption from methods such as tillage (Paustian et al. 2016), also has carbon sequestration benefits. Use of cover crops has the potential to remove 0.18 to 0.25 MT CO_2e per acre per year. If implemented over the total agricultural acreage, this would amount to approximately 4,550 to 6,319 MT CO_2 from the atmosphere per year, or the equivalent of storing 1,240 to 1,722 MT of carbon in these lands.

4 Annual CO_2e reduction/removal rates for these working land management activities have been developed by the U.S. Department of Agriculture for the carbon and GHG evaluation of Natural Resources Conservation Service conservation practice planning (COMET-Planner, USDA 2021; DOC and TNC n.d.).

5 Because reductions from strategies here include N_2O emissions, the metric is presented in units of CO_2 "equivalents" (CO_2e), which is used to compare emissions from various GHGs based on global warming potential (i.e., the GHG's ability to trap heat in the atmosphere relative to another gas).

6 CO_2 removals are the result of planting seasonal leguminous cover crops that provide natural resource protection or improvement and supply partial fertilizer demand to areas managed for irrigated annual row crops.

- **Uses of Mulches:** Adding crop and other residues.[7] Use of mulches has the potential to remove 0.21 MT CO_2e per acre per year. If implemented over the agricultural acreage in the study area, this would amount to removing 5,308 MT CO_2 from the atmosphere per year, or the equivalent of storing 1,446 MT of carbon.
- **Planting Hedgerows:** Planting hedgerow trees[8] has the potential to remove 8.29 MT CO_2e per acre per year. If implemented over the total agricultural acreage in the study area, this could remove 208,005 MT CO_2e per year, or the equivalent of storing 56,677 MT of carbon.

In addition to the carbon storage and sequestration benefits, implementation of the above working land strategies can result in complementary benefits including improved air and water quality, scenic value, and watershed integrity, as well as numerous biodiversity related benefits (e.g., terrestrial connectivity).

Urban Land Management

Urban forests can include urban parks, street trees, landscaped boulevards, gardens, coastal promenades, greenways, and wetlands. In addition to the carbon storage potential, urban trees provide a multitude of ancillary benefits, including providing shade that can reduce building heating and cooling needs, providing wildlife habitat, and sequestering criteria air pollutants. Managing urban forests, specifically the planting and maintenance care of trees, can increase stored carbon within the region. The benefit of such plantings is discussed in further detail below.

Trees sequester CO_2 while they are actively growing. The amount of CO_2 sequestered depends on the type of tree, density of tree plantings, and other factors. Thereafter, the accumulation of carbon in biomass slows with age and is assumed to be offset by losses from clipping, pruning, and death. Active growing periods are subject to, among other things, species, climate regime, and planting density. In addition, trees are subject to mortality and other types of losses, and therefore may need to be replaced or relocated to ensure carbon is stored and continues to be sequestered over time.

The California Emissions Estimator Model includes a method for estimating carbon gain from tree planting on a per-tree basis. The gain of sequestered carbon resulting from planting and growth of trees is estimated based on the carbon sequestration rate for the tree species, the number of new trees, and the growing period. The California Emissions Estimator Model has default carbon content values (in units of MT CO_2 per tree per year) for 10 different general tree species plus a miscellaneous tree category.[9] The miscellaneous tree species category CO_2 sequestration rate, which represents the average carbon content across the 10 tree species, is 0.0354 MT CO_2 per tree per year. Accordingly, planting one tree would generate a net gain in carbon of 0.71 MT CO_2e over the assumed active growing period of 20 years, consistent with the Intergovernmental Panel on Climate Change's assumption.[10] To scale, planting 1,000 miscellaneous trees would result in the removal of approximately 708 MT CO_2e from the atmosphere over the growing period, or the equivalent of approximately 193 MT of carbon stored in the urban forest environment.

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7 CO_2 removals are based on the application of plant residues or other suitable materials produced off site to the land surface on irrigated pasture.

8 Establishment of dense vegetation in a linear design to achieve a natural resource conservation purpose on areas managed as vineyards.

9 Aspen, soft maple, mixed hardwood, hardwood maple, juniper, cedar/larch, Douglas fir, true fir/hemlock, pine, spruce, and miscellaneous.

10 The sequestered carbon from new trees modeling does not include CO_2 emissions estimates associated with planting, care, and maintenance activities (e.g., tree planting and care vehicle travel and maintenance equipment operation).

While urban tree plantings do suggest opportunity for carbon storage and sequestration, it should be noted that maintenance of planted urban trees can also have a negative impact on the overall carbon budget, given the carbon emissions associated with maintenance activities at the nursery, materials needed for staking, nutrients used to amend soils, and material transport, among others (Kendall and McPherson 2012). Therefore, other considerations and strategies to supplement tree plantings and ensure carbon storage and sequestration in urban forest environments are recommended, including protecting against habitat loss and fragmentation, adopting integrated pest management practices, increasing soil health, utilizing place-based tree and plant selection, and reusing water and using recycled water in urban green spaces (CNRA 2022).

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6 Conclusion

This assessment provides an estimate of baseline carbon storage and carbon sequestration potential of the natural and working lands within four watersheds of San Diego County, including the Otay River, San Diego River, Sweetwater River, and Tijuana River Watersheds. The results of this assessment have important implications for policy and decision makers who aim to use nature-based solutions for climate change mitigation.

In these watersheds, chaparral and scrub vegetation stores a majority of landscape carbon due primarily to the extensive acreage they cover, and the carbon storage in these vegetation communities is accumulated over a relatively shorter timeframe. Protection and management of the chaparral and scrub on the landscape is critical to ensure that these carbon stores are maintained. Forest, woodland, and riparian vegetation covers considerably less acreage in these watersheds; however, these vegetation communities are carbon dense and continue sequestering carbon over long periods. Therefore, in addition to the importance of protecting and managing forests, woodlands, and riparian communities on the landscape, active restoration and enhancement of these vegetation types offers the highest potential and most efficient means of increasing carbon storage and sequestration in the natural lands.

In addition to the carbon storage and sequestration provided by these vegetation communities, their protection, management, restoration, and enhancement provides a myriad of complementary benefits, including habitat for plants and wildlife, habitat connectivity for wildlife movement, hydrological and water quality benefits, climate change resiliency, and scenic and passive recreation value. These complementary benefits are particularly important in these four watersheds of San Diego County where urban, agricultural, and rural land uses have resulted in habitat fragementation and stressors on biodiversity that can be ameliorated through carbon storage and sequestration management actions.

Agricultural lands and other land covers including urban areas also store carbon in these watersheds; however, the carbon offset and sequestration potential of these lands is strongly reliant upon active human interventions. Emissions reductions can be realized in agricultural lands through changes in farmland fertilizer, soil, and crop management. Urban tree planting can increase carbon storage and sequestration but should be done in consideration of overall carbon and water budgets.

As this study illustrates, the natural and working lands within these four watersheds of San Diego County play an important role in providing nature-based solutions for climate change mitigation in the region. Actions to maintain and enhance the carbon storage and sequestration in these lands is critical for building resilience and charting our trajectory towards carbon neutrality.

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7 Acknowledgements and Preparers

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Appendix A

Watershed Summaries

The following provides summaries and mapping for each of the watersheds (i.e., San Diego River, Sweetwater River, Otay River, and Tijuana River) in the study area for the Carbon Storage and Sequestration Assessment for Four Watersheds of San Diego County, California.

Watershed Summaries

San Diego River Watershed

Table A-1. Land Cover Class and Type for the San Diego River Watershed

Land Cover Class/Type	Acreage
Chaparral	**103,675**
Chamise Chaparral	8,258
Chaparral	16,592
Coastal Sage-Chaparral Transition	5,856
Granitic Chamise Chaparral	2,205
Granitic Northern Mixed Chaparral	18,367
Granitic Southern Mixed Chaparral	4,751
Interior Live Oak Chaparral	644
Mafic Chamise Chaparral	257
Mafic Northern Mixed Chaparral	2,870
Mafic Southern Mixed Chaparral	1,338
Mixed Montane Chaparral	58
Montane Chaparral	764
Montane Scrub Oak Chaparral	164
Northern Mixed Chaparral	8,159
Scrub Oak Chaparral	305
Southern Mixed Chaparral	33,085
Forest	**16,343**
Canyon Live Oak Forest	419
Coulter Pine Forest	31
Jeffrey Pine Forest	1,207
Mixed Evergreen Forest	351
Mixed Oak/Coniferous/Bigcone/Coulter Forest	5,382
Oak Forest	40
Sierran Mixed Coniferous Forest	8,913
Grassland	**12,269**
Dry Montane Meadows	1,031
Foothill/Mountain Perennial Grassland	2,231
Freshwater Seep	334
Montane Meadow	69
Native Grassland	67
Non-Native Grassland	2,310

Table A-1. Land Cover Class and Type for the San Diego River Watershed

Land Cover Class/Type	Acreage
Valley and Foothill Grassland	4,904
Valley Needlegrass Grassland	254
Wet Montane Meadow	882
Wildflower Field	186
Marsh	**211**
Cismontane Alkali Marsh	3
Coastal and Valley Freshwater Marsh	56
Freshwater Marsh	71
Southern Coastal Salt Marsh	44
Transmontane Freshwater Marsh	37
Riparian	**6,498**
Mule Fat Scrub	7
Riparian and Bottomland Habitat	35
Riparian Scrubs	4
Riparian Woodlands	34
Southern Arroyo Willow Riparian Forest	22
Southern Coast Live Oak Riparian Forest	3,551
Southern Cottonwood-Willow Riparian Forest	315
Southern Riparian Forest	1,418
Southern Riparian Scrub	877
Southern Sycamore-Alder Riparian Woodland	106
Southern Willow Scrub	59
Tamarisk Scrub	4
White Alder Riparian Forest	63
Scrub	**44,858**
Alluvial Fan Scrub	3
Big Sagebrush Scrub	36
Diegan Coastal Sage Scrub	44,318
Diegan Coastal Sage Scrub: Coastal form	9
Diegan Coastal Sage Scrub: Inland form	10
Montane Buckwheat Scrub	482
Woodland	**20,010**
Black Oak Woodland	1,994
Coast Live Oak Woodland	314
Dense Coast Live Oak Woodland	6,389
Dense Engelmann Oak Woodland	2,772
Engelmann Oak Woodland	196
Mixed Oak Woodland	3,288
Non-Native Woodland	192
Open Coast Live Oak Woodland	1,238
Open Engelmann Oak Woodland	3,258
Undifferentiated Open Woodland	354

Table A-1. Land Cover Class and Type for the San Diego River Watershed

Land Cover Class/Type	Acreage
Woodland	14
Agriculture	**5,128**
Extensive Agriculture - Field/Pasture, Row Crops	3,389
Field/Pasture	706
General Agriculture	43
Intensive Agriculture - Dairies, Nurseries, Chicken Ranches	152
Orchards and Vineyards	553
Row Crops	284
Other	**69,778**
Beach	28
Disturbed Habitat	4,362
Disturbed Wetland	45
Emergent Wetland	—
Estuarine	26
Eucalyptus Woodland	173
Freshwater	2,499
Non-Native Vegetation	85
Non-Vegetated Channel or Floodway	434
Open Water	277
Shallow Bay	2
Urban/Developed	61,847
Total	**278,770**

Table A-2. Soil Organic Carbon for the San Diego River Watershed

Soil Organic Carbon in Metric Tons Carbon per Hectare (Metric Tons Carbon per Acre in parentheses)	Acreage
n.d.	54,809
21–30 (8.5-12.1)	12,190
31–40 (12.5-16.2)	169,147
41–50 (16.6-20.2)	40,593
51–60 (20.6-24.3)	1,942
61–64 (24.7-25.9)	89

Table A-3. Total Baseline Landscape Carbon Storage for the San Diego River Watershed

Land Cover Class	Metric Tons of Carbon
Chaparral	2,956,314
Forest	1,533,565
Grassland	201,658

Table A-3. Total Baseline Landscape Carbon Storage for the San Diego River Watershed

Land Cover Class	Metric Tons of Carbon
Marsh	2,942
Riparian	333,991
Scrub	795,208
Woodland	1,136,292
Agriculture	86,165
Other	522,458
Total	**7,568,594**

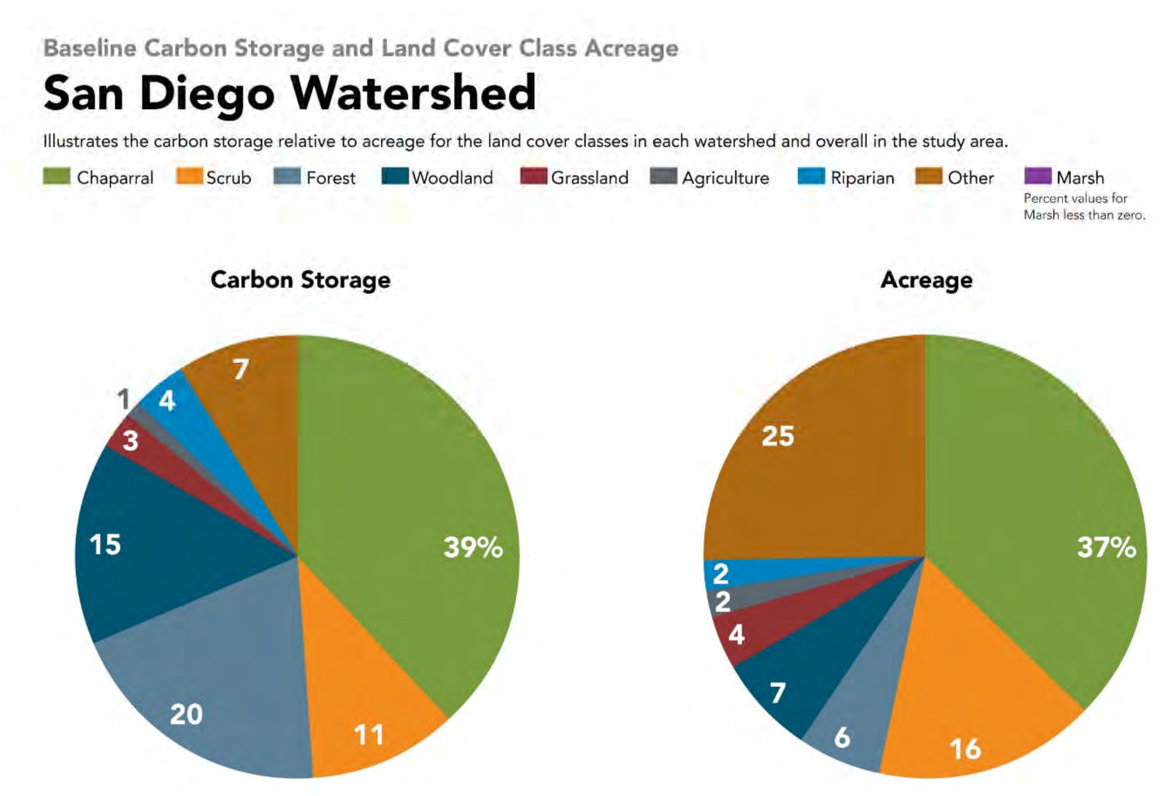

Exhibit A-1. Carbon Storage and Acreage for the San Diego River Watershed

Sweetwater River Watershed

Table A-4. Land Cover Class and Type for the Sweetwater River Watershed

Land Cover Class/Type	Acreage
Chaparral	63,192
Chamise Chaparral	3,048
Chaparral	13,531
Coastal Sage-Chaparral Transition	1,791
Granitic Chamise Chaparral	2,432
Granitic Northern Mixed Chaparral	11,360
Granitic Southern Mixed Chaparral	11,778
Interior Live Oak Chaparral	8
Mafic Chamise Chaparral	1,091
Mafic Northern Mixed Chaparral	2,033
Mafic Southern Mixed Chaparral	390
Montane Chaparral	302
Montane Manzanita Chaparral	460
Montane Scrub Oak Chaparral	772
Northern Mixed Chaparral	6,985
Scrub Oak Chaparral	14
Southern Mixed Chaparral	7,198
Forest	4,501
Black Oak Forest	121
Canyon Live Oak Forest	7
Coast Live Oak Forest	224
Jeffrey Pine Forest	3,483
Mixed Oak/Coniferous/Bigcone/Coulter Forest	419
Sierran Mixed Coniferous Forest	214
Southern Interior Cypress Forest	33
Grassland	6,106
Alkali Seep	44
Dry Montane Meadows	8
Foothill/Mountain Perennial Grassland	278
Freshwater Seep	58
Montane Meadow	567
Non-Native Grassland	1,866
Valley and Foothill Grassland	2,401
Valley Sacaton Grassland	46
Wildflower Field	838
Marsh	308
Coastal and Valley Freshwater Marsh	45
Freshwater Marsh	7
Southern Coastal Salt Marsh	255

Table A-4. Land Cover Class and Type for the Sweetwater River Watershed

Land Cover Class/Type	Acreage
Riparian	**3,647**
Mule Fat Scrub	5
Riparian Woodlands	458
Southern Coast Live Oak Riparian Forest	1,968
Southern Cottonwood-Willow Riparian Forest	312
Southern Riparian Forest	422
Southern Riparian Scrub	438
Southern Willow Scrub	36
White Alder Riparian Forest	9
Scrub	**17,730**
Big Sagebrush Scrub	50
Diegan Coastal Sage Scrub	17,527
Diegan Coastal Sage Scrub: Coastal form	1
Maritime Succulent Scrub	4
Montane Buckwheat Scrub	134
Riversidian Upland Sage Scrub	5
Sagebrush Scrub	10
Woodland	**5,587**
Black Oak Woodland	382
Coast Live Oak Woodland	36
Dense Coast Live Oak Woodland	3,099
Dense Engelmann Oak Woodland	181
Mixed Oak Woodland	3
Oak Woodland	39
Open Coast Live Oak Woodland	10
Open Engelmann Oak Woodland	1,790
Undifferentiated Open Woodland	39
Woodland	8
Agriculture	**3,919**
Extensive Agriculture - Field/Pasture, Row Crops	2,445
Field/Pasture	158
General Agriculture	1,021
Intensive Agriculture - Dairies, Nurseries, Chicken Ranches	179
Orchards and Vineyards	115
Other	**41,677**
Disturbed Habitat	2,745
Disturbed Wetland	51
Eucalyptus Woodland	50
Freshwater	193
Non-Native Vegetation	1
Non-Vegetated Channel or Floodway	184
Open Water	1,307

Table A-4. Land Cover Class and Type for the Sweetwater River Watershed

Land Cover Class/Type	Acreage
Shallow Bay	32
Urban/Developed	37,113
Total	**146,668**

Table A-5. Soil Organic Carbon for the Sweetwater River Watershed

Soil Organic Carbon in Metric Tons Carbon per Hectare (Metric Tons Carbon per Acre in parentheses)	Acreage
n.d.	33,112
21–30 (8.5-12.1)	4,917
31–40 (12.5-16.2)	82,697
41–50 (16.6-20.2)	25,653
51–60 (20.6-24.3)	289
61–64 (24.7-25.9)	0

Table A-6. Total Baseline Landscape Carbon Storage for the Sweetwater River Watershed

Land Cover Class	Metric Tons of Carbon
Chaparral	1,835,794
Forest	339,290
Grassland	90,832
Marsh	4,258
Riparian	190,949
Scrub	310,643
Woodland	323,438
Agriculture	41,629
Other	320,996
Total	**3,457,830**

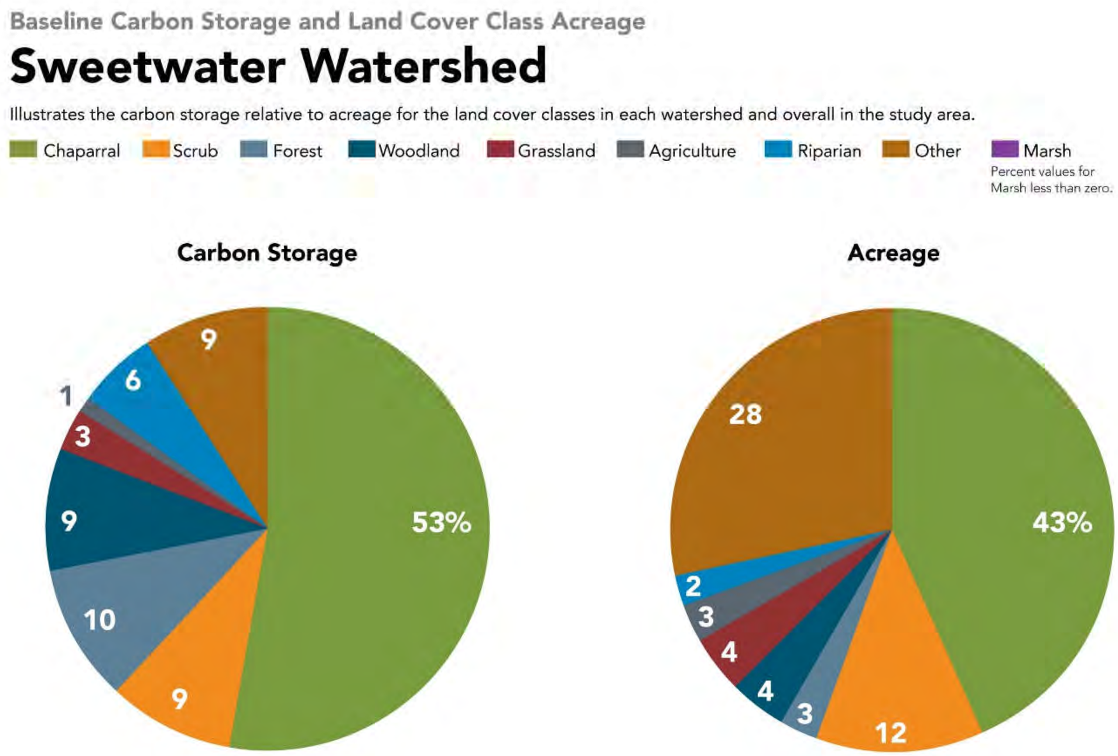

Exhibit A-2. Carbon Storage and Acreage for the Sweetwater River Watershed

Otay River Watershed

Table A-7. Land Cover Class and Type for the Otay River Watershed

Land Cover Class/Type	Acreage
Chaparral	**22,959**
Chamise Chaparral	1,679
Chaparral	12,654
Coastal Sage-Chaparral Transition	1,749
Granitic Northern Mixed Chaparral	1,325
Mafic Northern Mixed Chaparral	151
Northern Mixed Chaparral	2,275
Scrub Oak Chaparral	46
Southern Mixed Chaparral	3,079
Forest	**3,976**
Southern Interior Cypress Forest	3,976

Table A-7. Land Cover Class and Type for the Otay River Watershed

Land Cover Class/Type	Acreage
Grassland	**7,397**
Native Grassland	160
Non-Native Grassland	1,751
San Diego Mesa Vernal Pool	456
Valley and Foothill Grassland	4,767
Valley Needlegrass Grassland	263
Marsh	**439**
Cismontane Alkali Marsh	149
Coastal and Valley Freshwater Marsh	91
Freshwater Marsh	125
Southern Coastal Salt Marsh	74
Riparian	**1,561**
Arundo donax Dominant/Southern Willow Scrub	15
Mule Fat Scrub	72
Riparian and Bottomland Habitat	3
Riparian Forests	1
Southern Coast Live Oak Riparian Forest	633
Southern Riparian Forest	52
Southern Riparian Scrub	51
Southern Riparian Woodland	53
Southern Sycamore-Alder Riparian Woodland	8
Southern Willow Scrub	253
Tamarisk Scrub	420
Scrub	**29,300**
Diegan Coastal Sage Scrub	28,846
Maritime Succulent Scrub	454
Woodland	**2,074**
Coast Live Oak Woodland	214
Dense Coast Live Oak Woodland	1,458
Engelmann Oak Woodland	1
Non-Native Woodland	3
Open Engelmann Oak Woodland	393
Woodland	5
Agriculture	**8,421**
Extensive Agriculture - Field/Pasture, Row Crops	8,067
General Agriculture	7
Intensive Agriculture - Dairies, Nurseries, Chicken Ranches	155
Orchards and Vineyards	192
Other	**22,182**
Beach	441
Disturbed Habitat	3,821
Disturbed Wetland	81

Table A-7. Land Cover Class and Type for the Otay River Watershed

Land Cover Class/Type	Acreage
Estuarine	4
Eucalyptus Woodland	118
Freshwater	981
Non-Native Vegetation	139
Non-Vegetated Channel or Floodway	50
Open Water	10
Saltpan/Mudflats	132
Shallow Bay	68
Southern Foredunes	87
Subtidal	3
Urban/Developed	16,247
Total	**98,309**

Table A-8. Soil Organic Carbon for the Otay River Watershed

Soil Organic Carbon in Metric Tons Carbon per Hectare (Metric Tons Carbon per Acre in parentheses)	Acreage
n.d.	19,888
21–30 (8.5-12.1)	17,992
31–40 (12.5-16.2)	57,362
41–50 (16.6-20.2)	3,068
51–60 (20.6-24.3)	0
61–64 (24.7-25.9)	0

Table A-9. Total Baseline Landscape Carbon Storage for the Otay River Watershed

Land Cover Class	Metric Tons of Carbon
Chaparral	645,070
Forest	242,109
Grassland	104,325
Marsh	5,214
Riparian	69,602
Scrub	516,399
Woodland	121,260
Agriculture	83,830
Other	167,355
Total	**1,955,165**

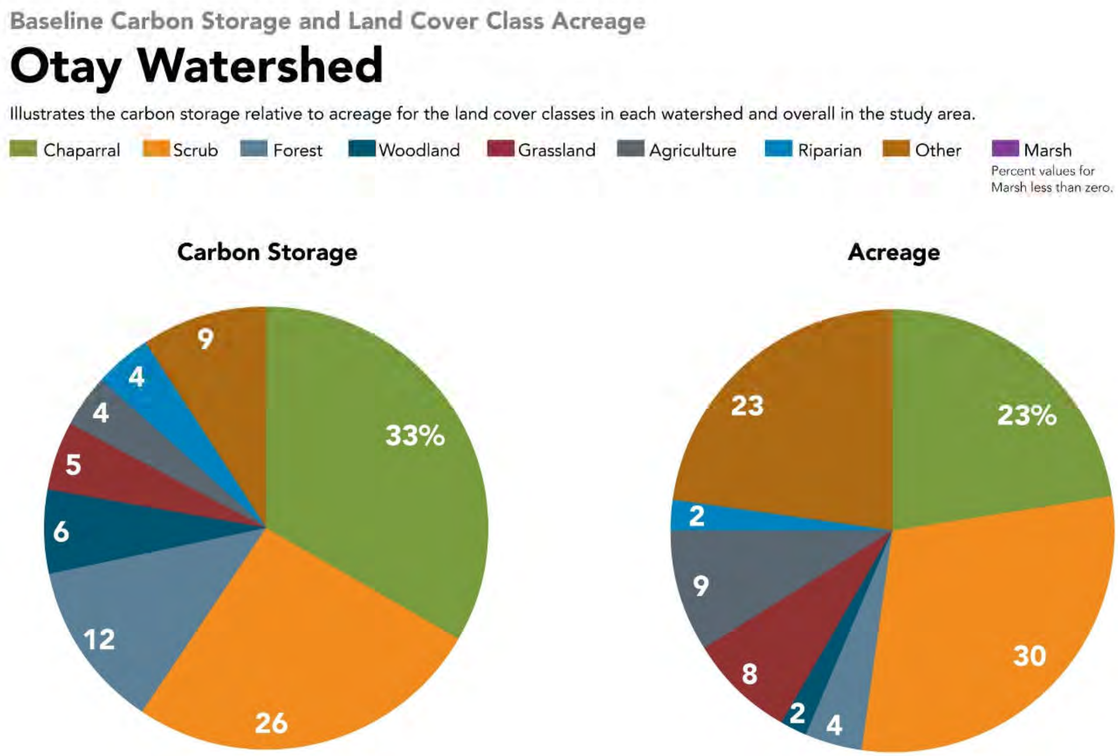

Exhibit A-3. Carbon Storage and Acreage for the Otay River Watershed

Tijuana River Watershed

Table A-10. Land Cover Class and Type for the Tijuana River Watershed

Land Cover Class/Type	Acreage
Chaparral	213,201
Chamise Chaparral	11,671
Chaparral	15,508
Coastal Sage-Chaparral Transition	4,302
Granitic Chamise Chaparral	20,007
Granitic Northern Mixed Chaparral	95,803
Granitic Southern Mixed Chaparral	59
Interior Live Oak Chaparral	506
Mafic Chamise Chaparral	792
Mafic Northern Mixed Chaparral	10,511

Table A-10. Land Cover Class and Type for the Tijuana River Watershed

Land Cover Class/Type	Acreage
Mafic Southern Mixed Chaparral	4
Montane Ceanothus Chaparral	170
Montane Manzanita Chaparral	2,421
Montane Scrub Oak Chaparral	5,057
Northern Mixed Chaparral	30,787
Red Shank Chaparral	4,467
Scrub Oak Chaparral	6,726
Semi-Desert Chaparral	1,074
Southern Mixed Chaparral	3,336
Forest	14,191
Black Oak Forest	919
Canyon Live Oak Forest	94
Coast Live Oak Forest	346
Jeffrey Pine Forest	8,508
Mixed Oak/Coniferous/Bigcone/Coulter Forest	2,053
Sierran Mixed Coniferous Forest	488
Southern Interior Cypress Forest	1,784
Grassland	10,807
Alkali Seep	418
Dry Montane Meadows	120
Foothill/Mountain Perennial Grassland	1,359
Freshwater Seep	1,326
Montane Meadow	207
Native Grassland	48
Non-Native Grassland	4,775
Valley and Foothill Grassland	1,158
Valley Needlegrass Grassland	2
Valley Sacaton Grassland	324
Wet Montane Meadow	845
Wildflower Field	224
Marsh	791
Cismontane Alkali Marsh	5
Coastal and Valley Freshwater Marsh	12
Freshwater Marsh	137
Southern Coastal Salt Marsh	636
Riparian	5,558
Mule Fat Scrub	5
Riparian Forests	5
Riparian Scrubs	2
Southern Arroyo Willow Riparian Forest	29
Southern Coast Live Oak Riparian Forest	2,669
Southern Cottonwood-Willow Riparian Forest	226

Table A-10. Land Cover Class and Type for the Tijuana River Watershed

Land Cover Class/Type	Acreage
Southern Riparian Forest	406
Southern Riparian Scrub	2,080
Southern Willow Scrub	84
Tamarisk Scrub	5
White Alder Riparian Forest	47
Scrub	**17,100**
Alluvial Fan Scrub	58
Big Sagebrush Scrub	352
Coastal Scrub	7
Diegan Coastal Sage Scrub	11,019
Diegan Coastal Sage Scrub: Inland form	7
Maritime Succulent Scrub	51
Mojavean Desert Scrub	90
Montane Buckwheat Scrub	3,935
Sagebrush Scrub	1,524
Upper Sonoran Subshrub Scrub	57
Woodland	**12,121**
Black Oak Woodland	74
Coast Live Oak Woodland	60
Dense Coast Live Oak Woodland	7,741
Dense Engelmann Oak Woodland	129
Mixed Oak Woodland	46
Oak Woodland	16
Open Coast Live Oak Woodland	3,056
Open Engelmann Oak Woodland	795
Peninsular Pinon Woodland	8
Undifferentiated Open Woodland	138
Woodland	58
Agriculture	**7,807**
Extensive Agriculture - Field/Pasture, Row Crops	4,275
Field/Pasture	2,037
General Agriculture	983
Intensive Agriculture - Dairies, Nurseries, Chicken Ranches	454
Orchards and Vineyards	58
Other	**17,370**
Beach	94
Disturbed Habitat	3,070
Disturbed Wetland	195
Estuarine	83
Eucalyptus Woodland	42
Freshwater	1,286
Non-Vegetated Channel or Floodway	240

Table A-10. Land Cover Class and Type for the Tijuana River Watershed

Land Cover Class/Type	Acreage
Saltpan/Mudflats	94
Southern Foredunes	86
Urban/Developed	12,180
Total	**298,944**

Table A-11. Soil Organic Carbon for the Tijuana River Watershed

Soil Organic Carbon in Metric Tons Carbon per Hectare (Metric Tons Carbon per Acre in parentheses)	Acreage
n.d.	9,494
21–30 (8.5-12.1)	65,453
31–40 (12.5-16.2)	178,187
41–50 (16.6-20.2)	45,066
51–60 (20.6-24.3)	730
61–64 (24.7-25.9)	14

Table A-12. Total Baseline Landscape Carbon Storage for the Tijuana River Watershed

Land Cover Class	Metric Tons of Carbon
Chaparral	5,860,253
Forest	1,014,279
Grassland	163,994
Marsh	15,622
Riparian	273,731
Scrub	310,976
Woodland	705,032
Agriculture	100,656
Other	203,489
Total	**8,648,031**

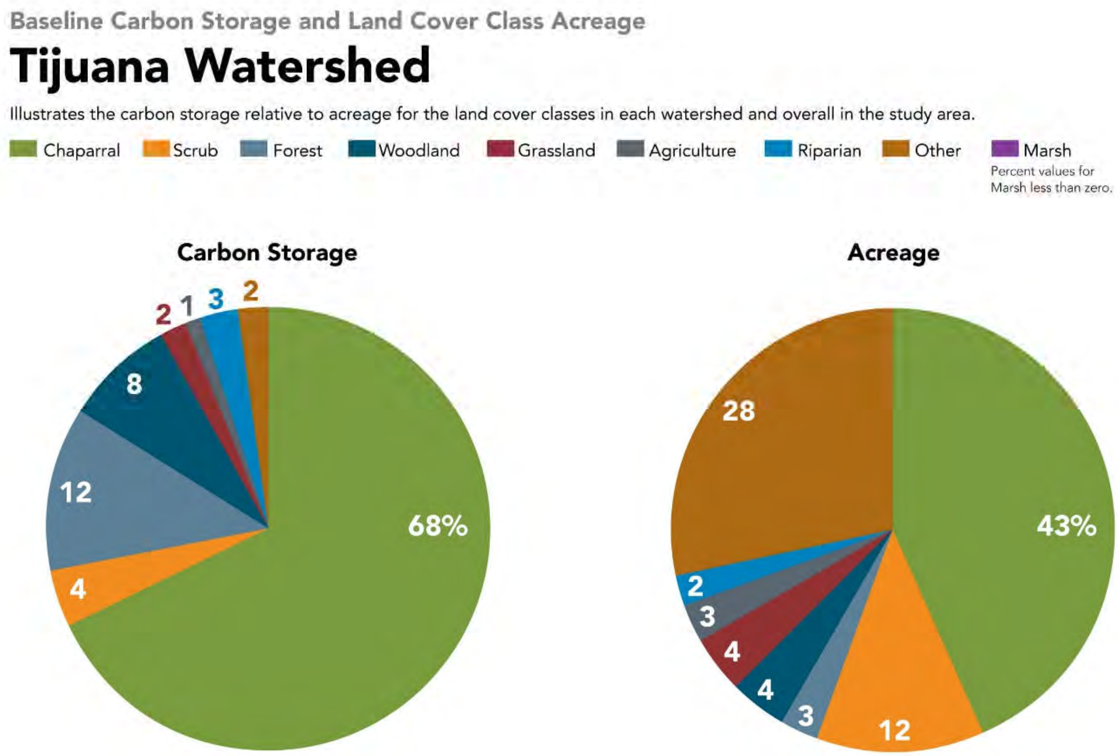

Exhibit A-4. Carbon Storage and Acreage for the Tijuana River Watershed

Watershed Maps

Table A-13. Watershed Map Figure Numbers

San Diego River	Sweetwater River	Otay River	Tijuana River
A-1 Land Cover	A-2 Land Cover	A-3 Land Cover	A-4 Land Cover
A-5 Soils	A-6 Soils	A-7 Soils	A-8 Soils
A-9 Baseline Carbon Storage	A-10 Baseline Carbon Storage	A-11 Baseline Carbon Storage	A-12 Baseline Carbon Storage
A-13 Minimum Carbon Storage	A-14 Minimum Carbon Storage	A-15 Minimum Carbon Storage	A-17 Minimum Carbon Storage
A-17 Maximum Carbon Storage	A-18 Maximum Carbon Storage	A-19 Maximum Carbon Storage	A-20 Maximum Carbon Storage
A-21 Carbon Potential	A-22 Carbon Potential	A-23 Carbon Potential	A-24 Carbon Potential

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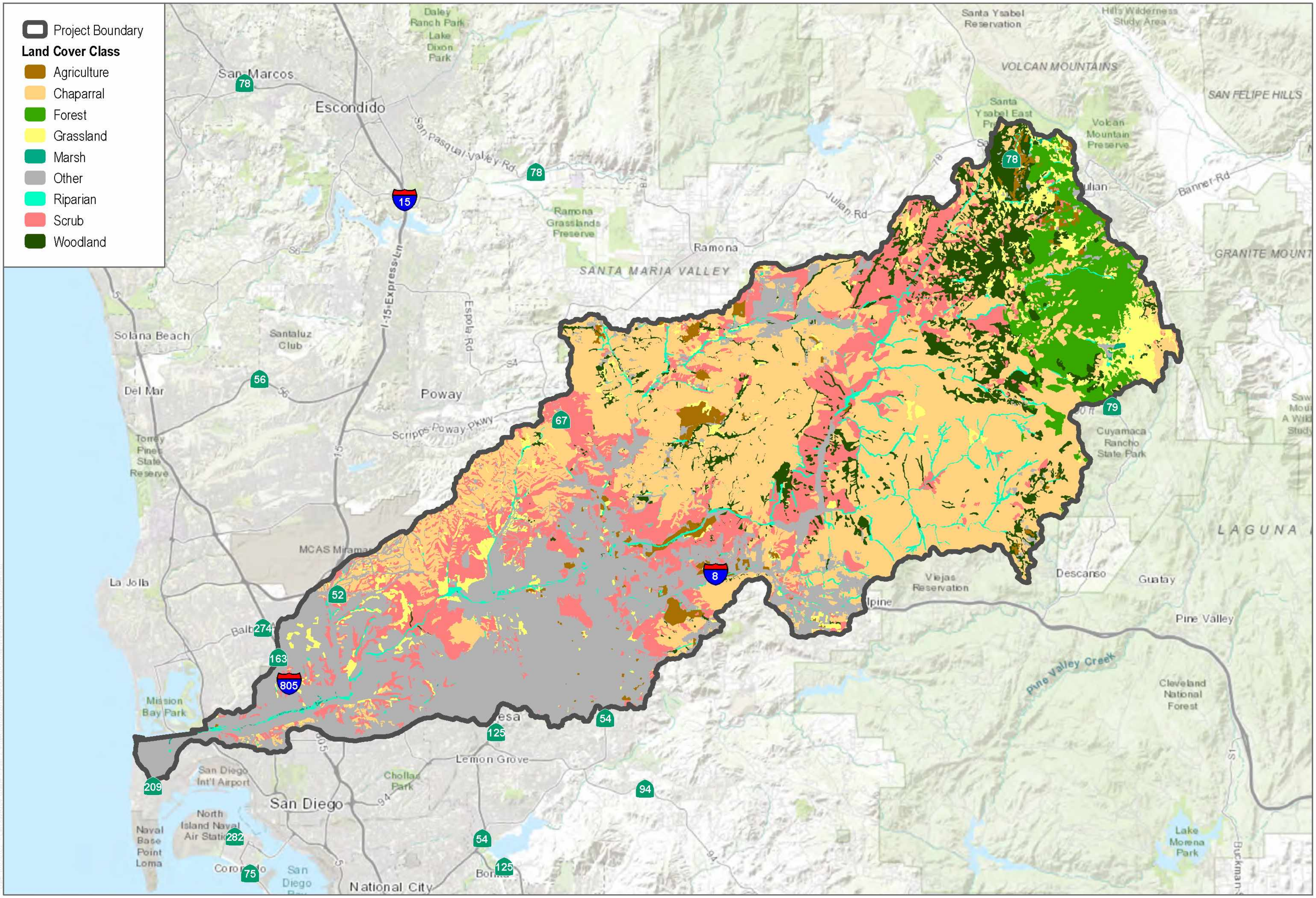


SOURCE: SANDAG 2022

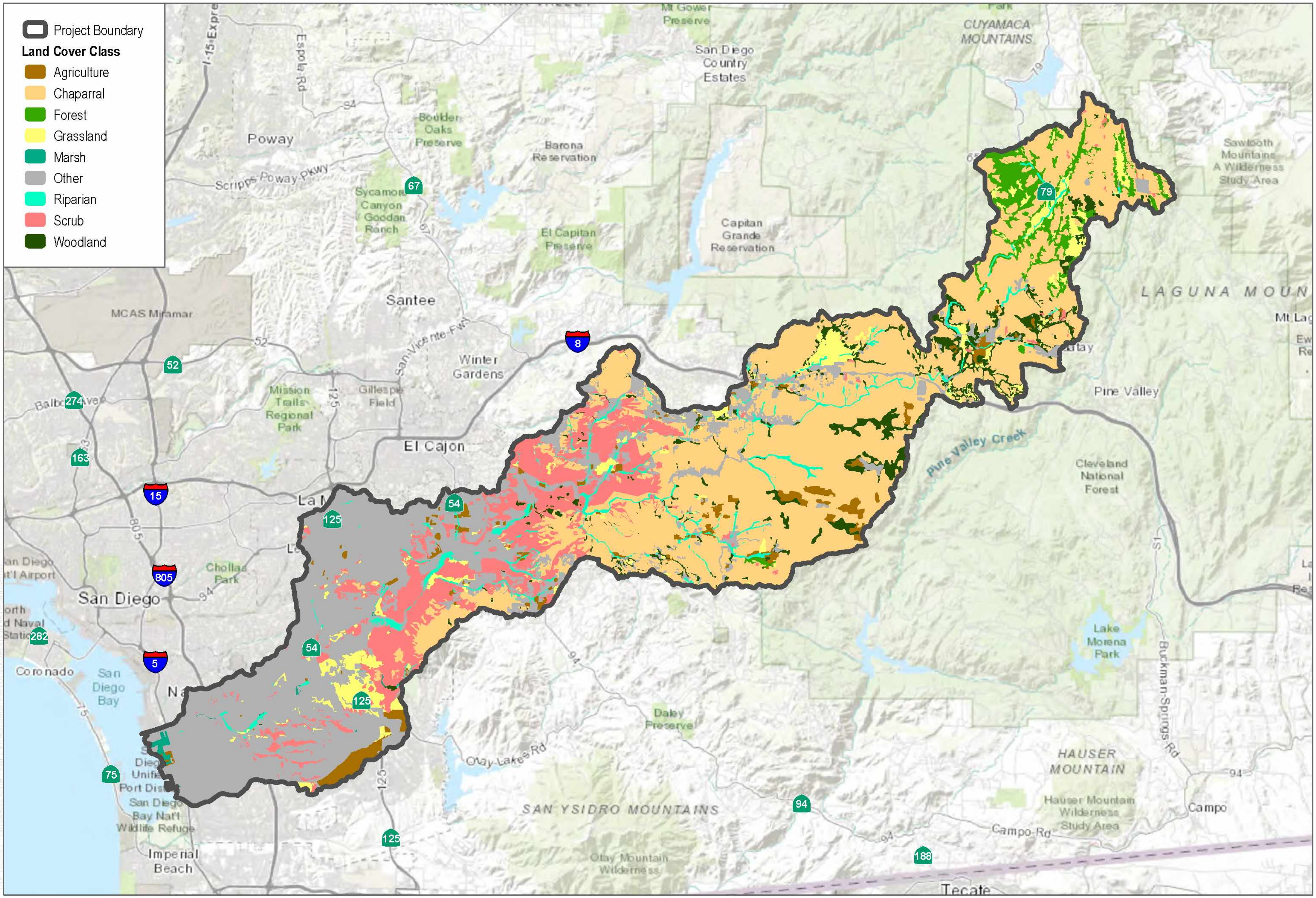
DUDEK

0 5 10 Miles

FIGURE A-1

Land Cover - San Diego Watershed

Carbon Storage and Sequestration Assessment for Four Watersheds of San Diego County, California



SOURCE: SANDAG 2022

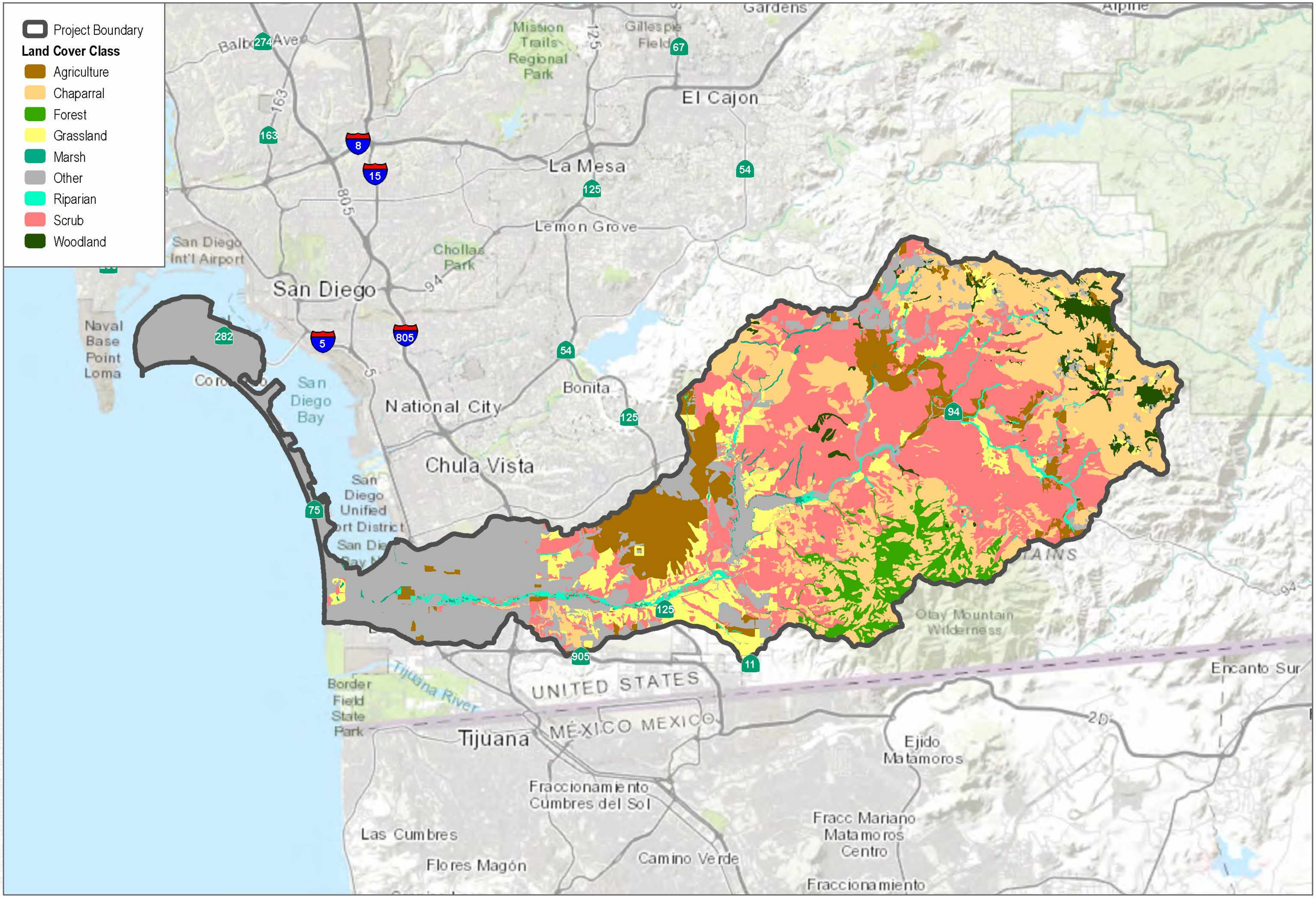
DUDEK

0 5 10 Miles

FIGURE A-2

Land Cover - Sweetwater Watershed

Carbon Storage and Sequestration Assessment for Four Watersheds of San Diego County, California



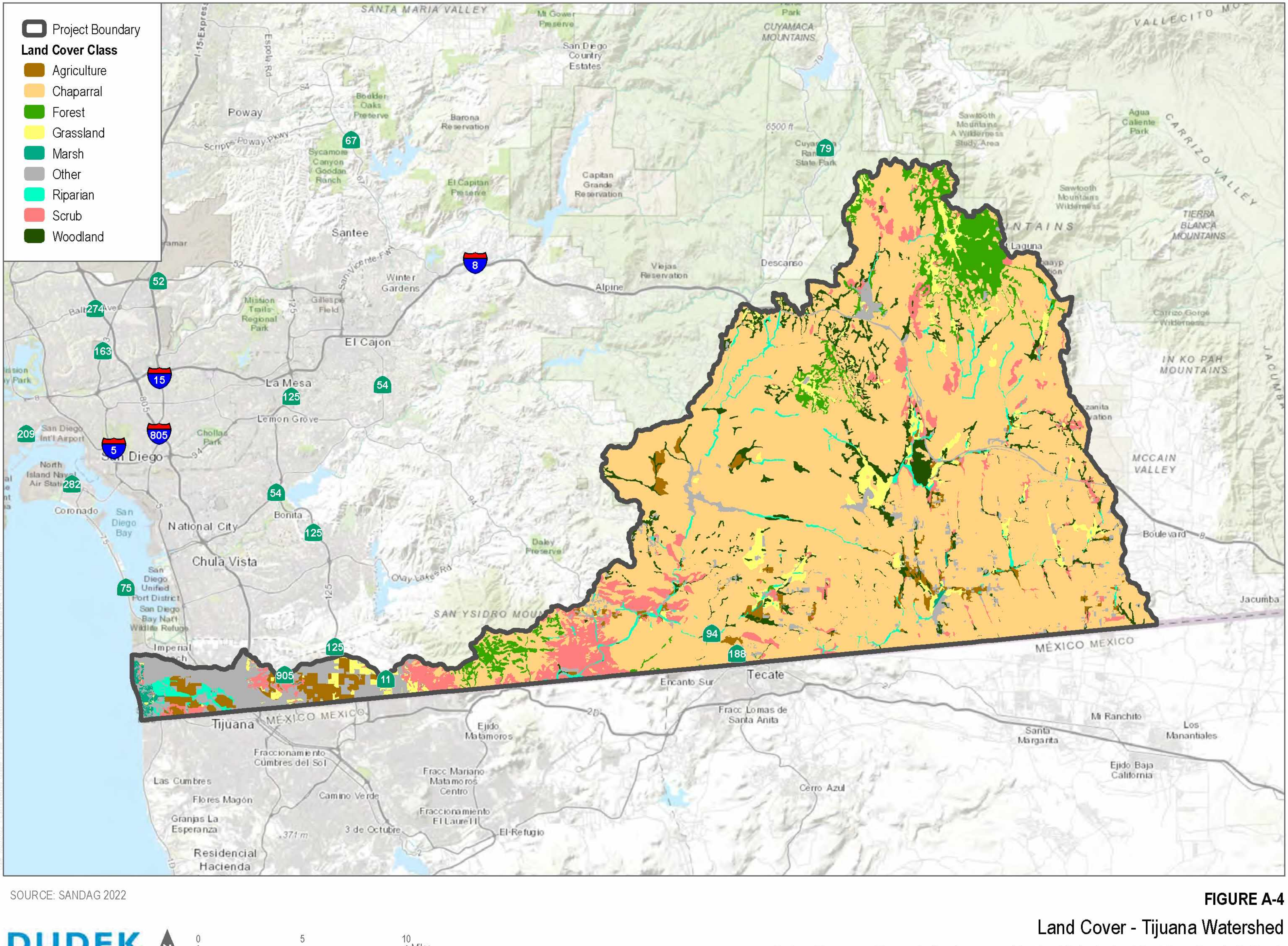
SOURCE: SANDAG 2022

DUDEK

0 5 10 Miles

FIGURE A-3

Land Cover - Otay Watershed



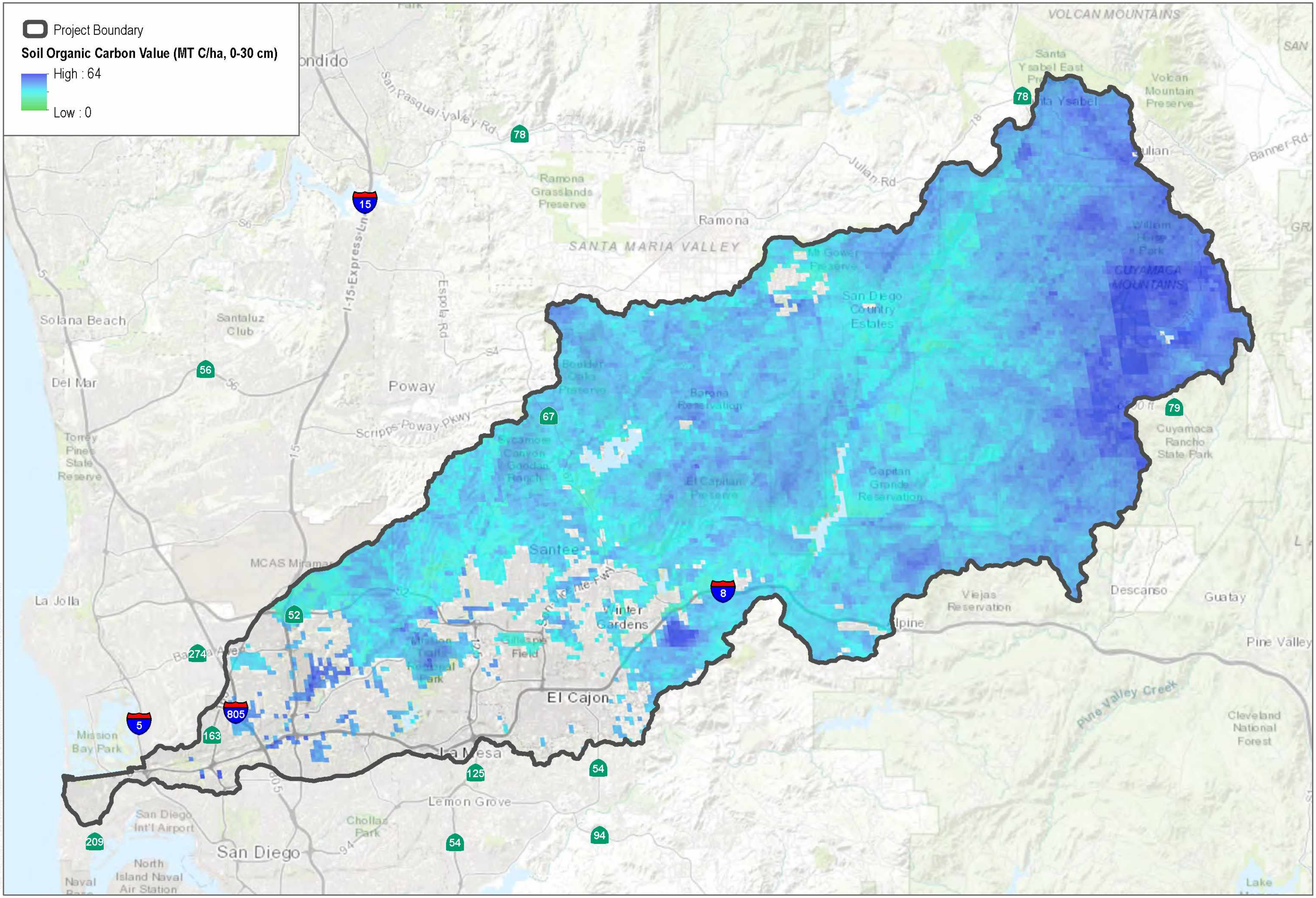
SOURCE: SANDAG 2022

DUDEK

FIGURE A-4

Land Cover - Tijuana Watershed

Carbon Storage and Sequestration Assessment for Four Watersheds of San Diego County, California

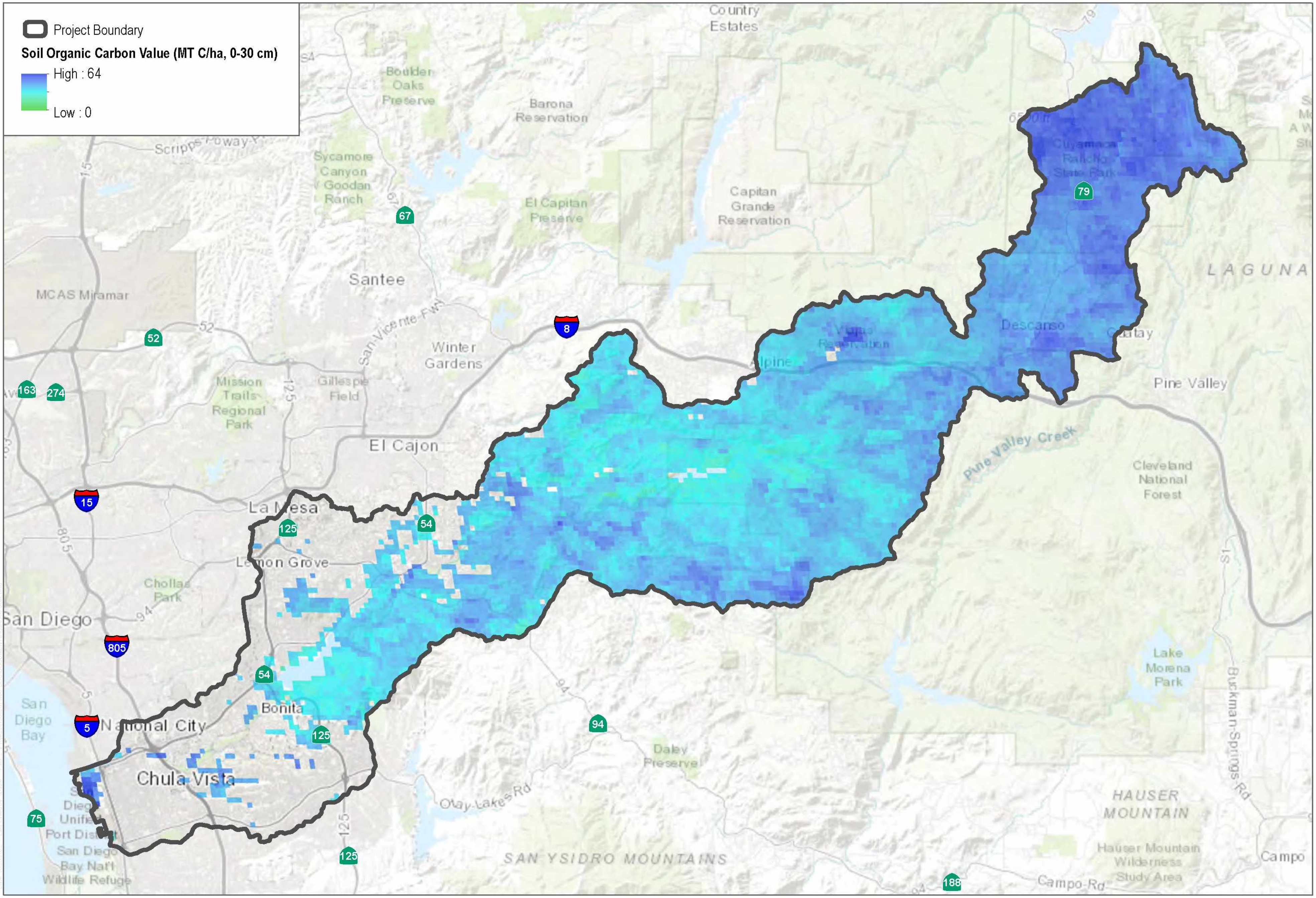


SOURCE: ISIRC 2022

FIGURE A-5

Soils - San Diego Watershed

Carbon Storage and Sequestration Assessment for Four Watersheds of San Diego County, California



SOURCE: ISIRC 2022

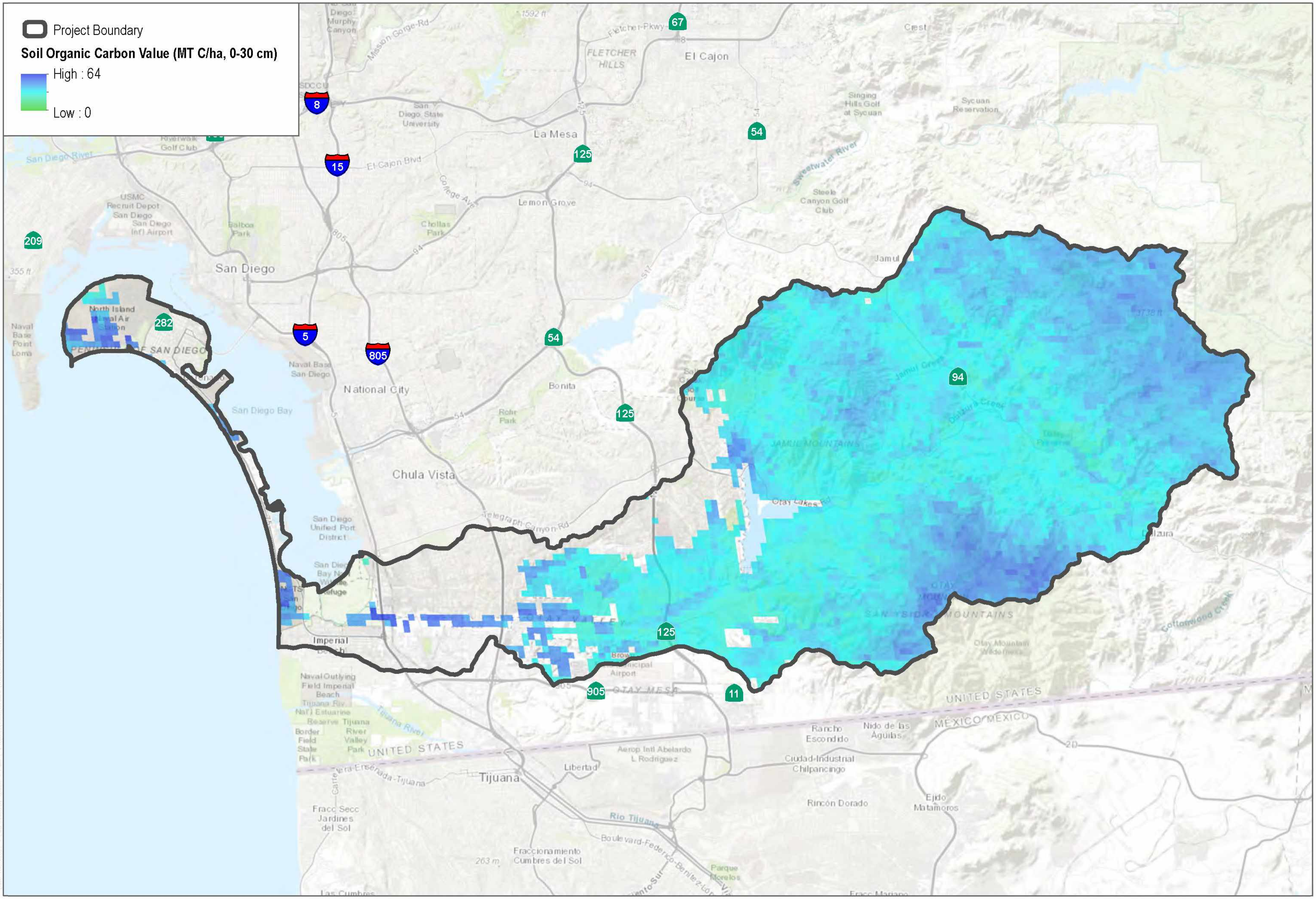
DUDEK

0 5 10 Miles

FIGURE A-6

Soils - Sweetwater Watershed

Carbon Storage and Sequestration Assessment for Four Watersheds of San Diego County, California



SOURCE: ISIRC 2022

DUDEK

0 5 10 Miles

FIGURE A-7

Soils - Otay Watershed

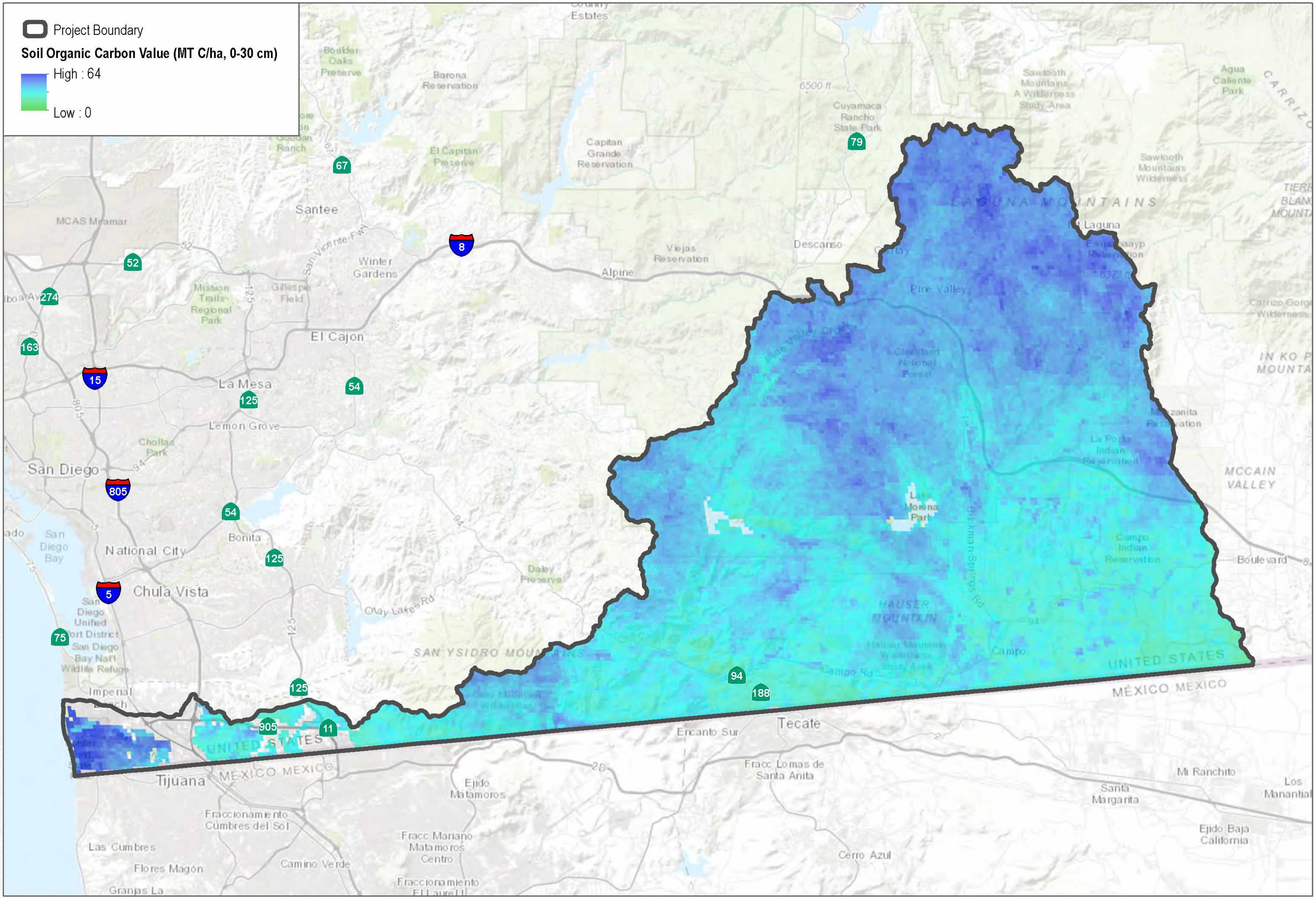
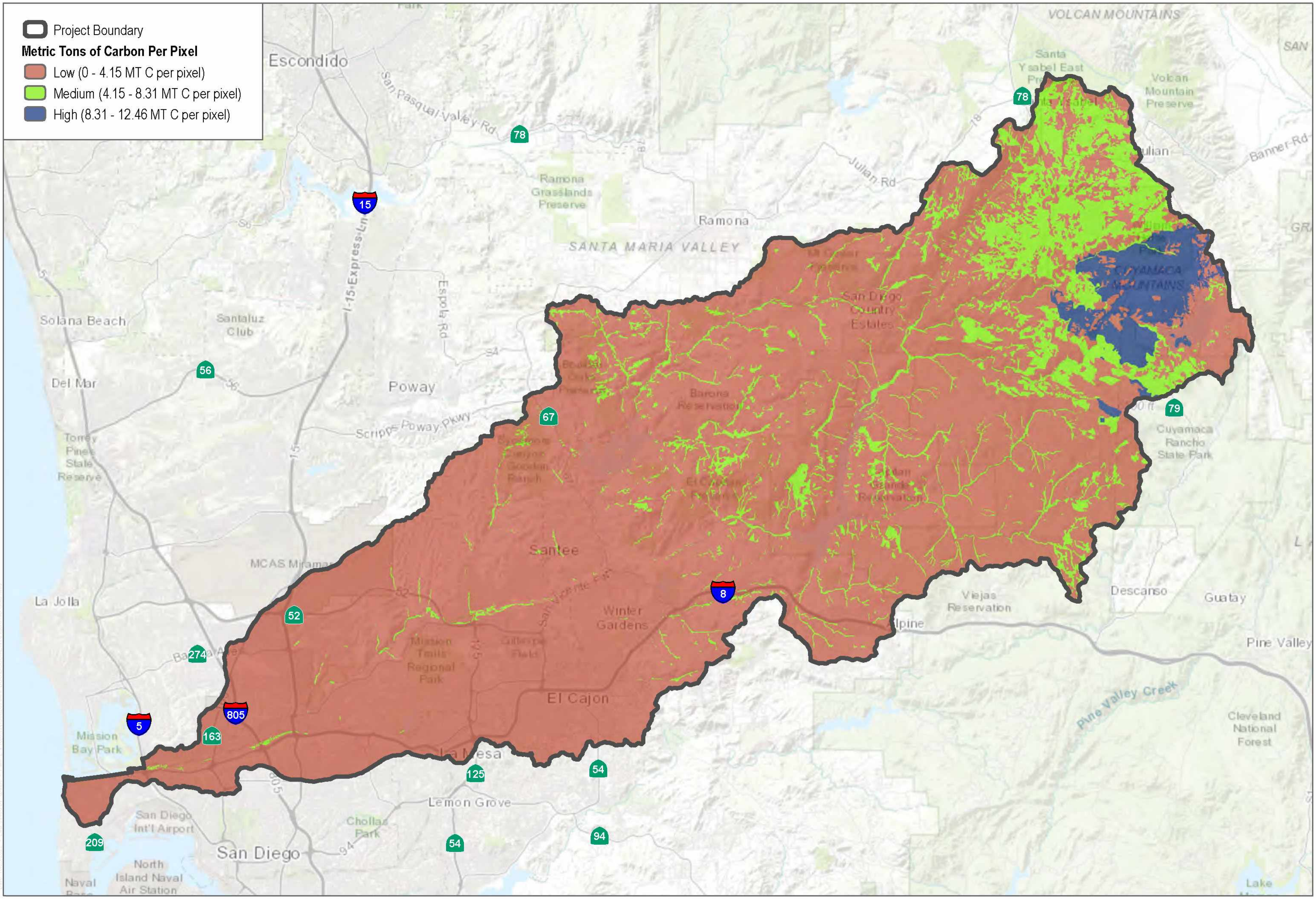


FIGURE A-8

Soils - Tijuana Watershed

Carbon Storage and Sequestration Assessment for Four Watersheds of San Diego County, California



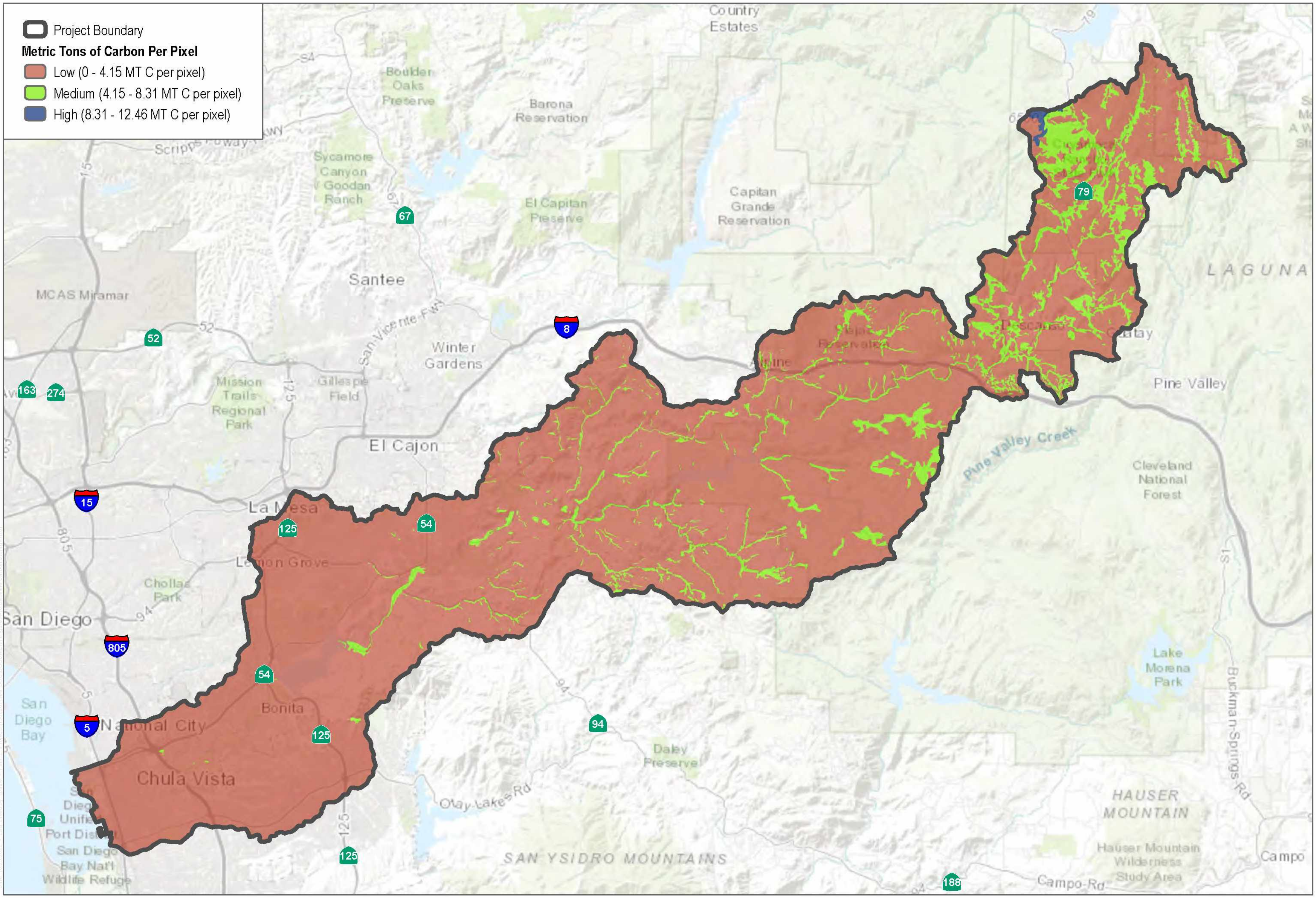
SOURCE: ESRI 2022

DUDEK

FIGURE A-9

Total Baseline Carbon Storage - San Diego Watershed

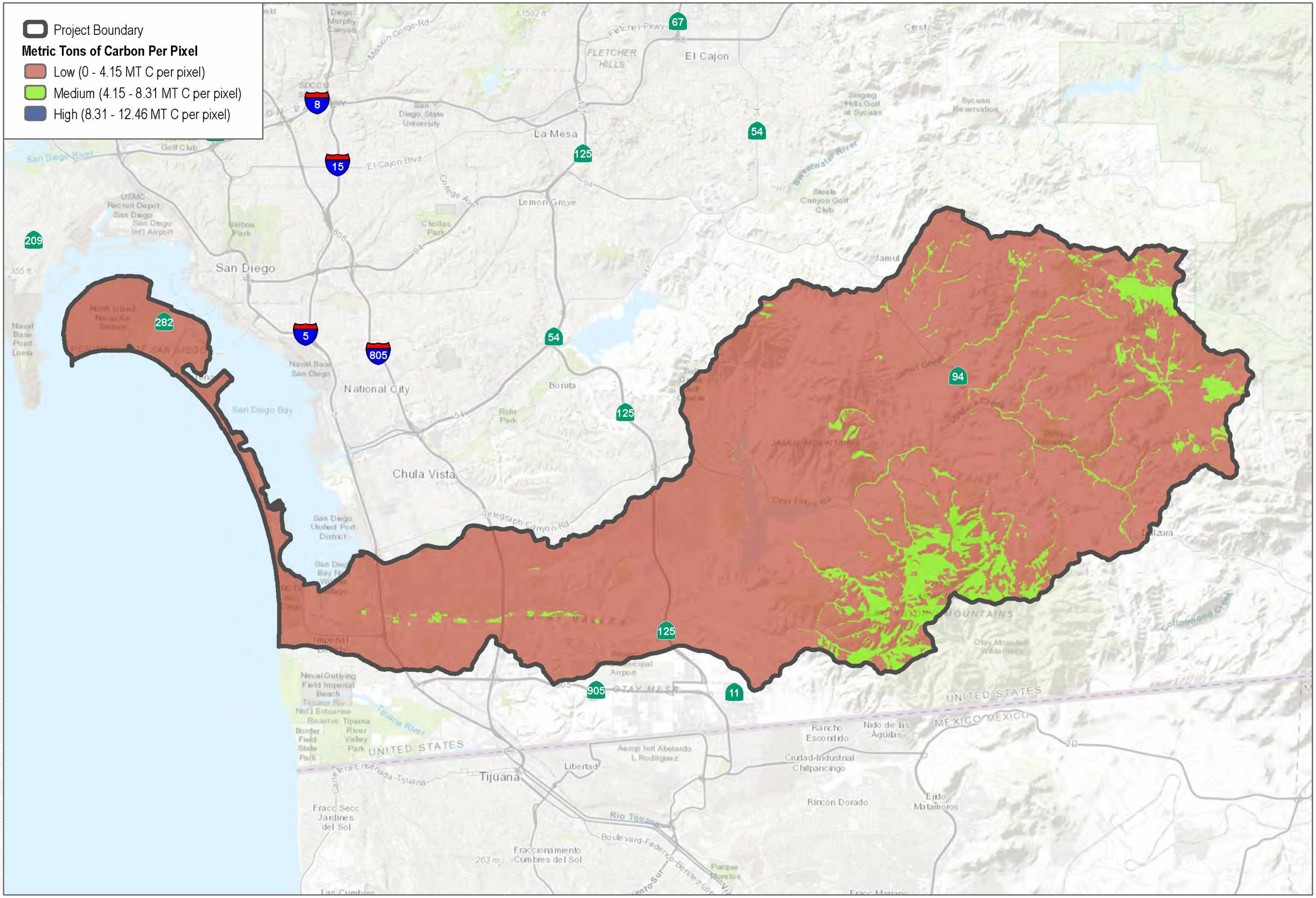
Carbon Storage and Sequestration Assessment for Four Watersheds of San Diego County, California



SOURCE: ESRI 2022

FIGURE A-10

Total Baseline Carbon Storage - Sweetwater Watershed



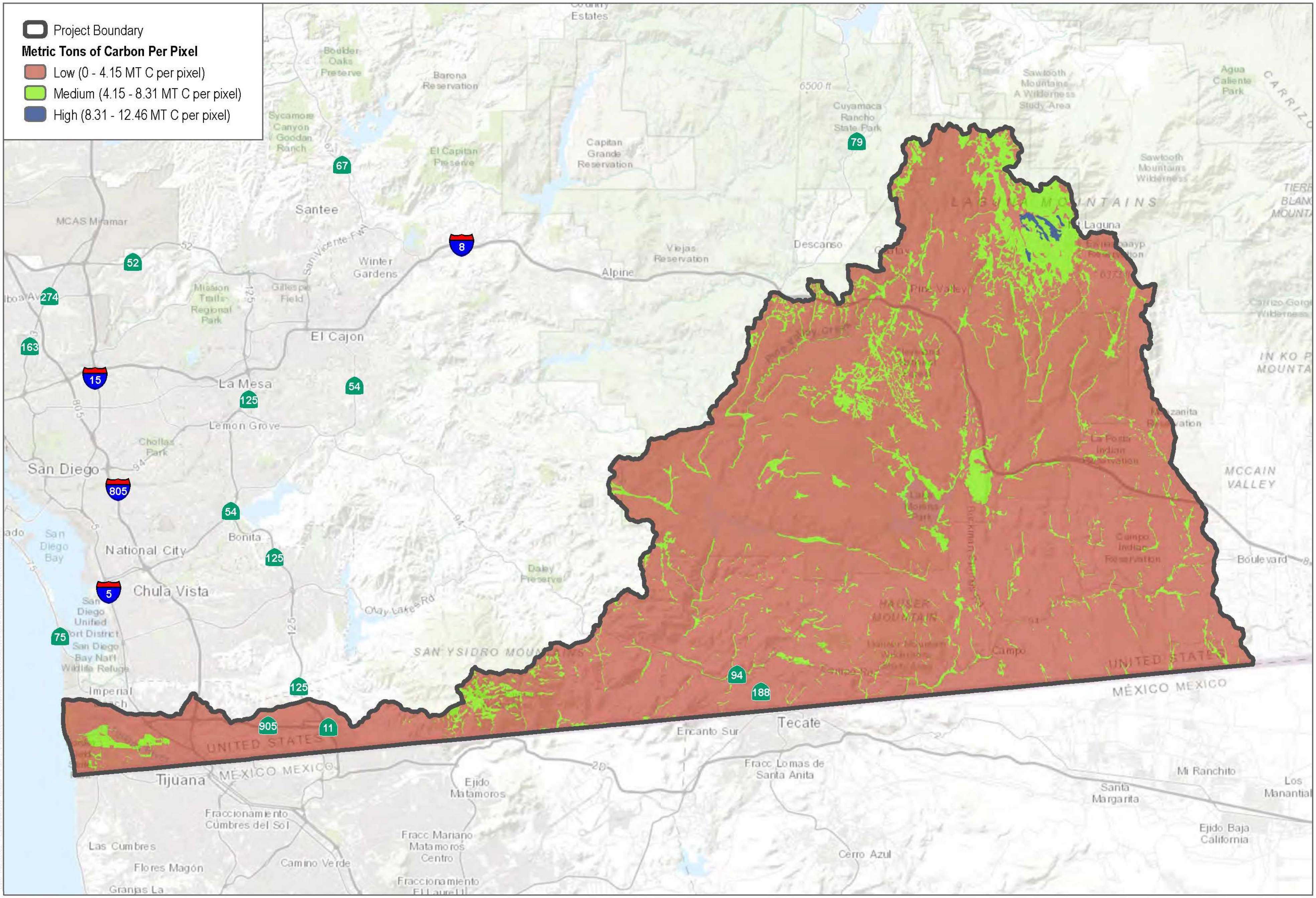
SOURCE: ESRI 2022

DUDEK

FIGURE A-11

Total Baseline Carbon Storage - Otay Watershed

Carbon Storage and Sequestration Assessment for Four Watersheds of San Diego County, California



SOURCE: ESRI 2022

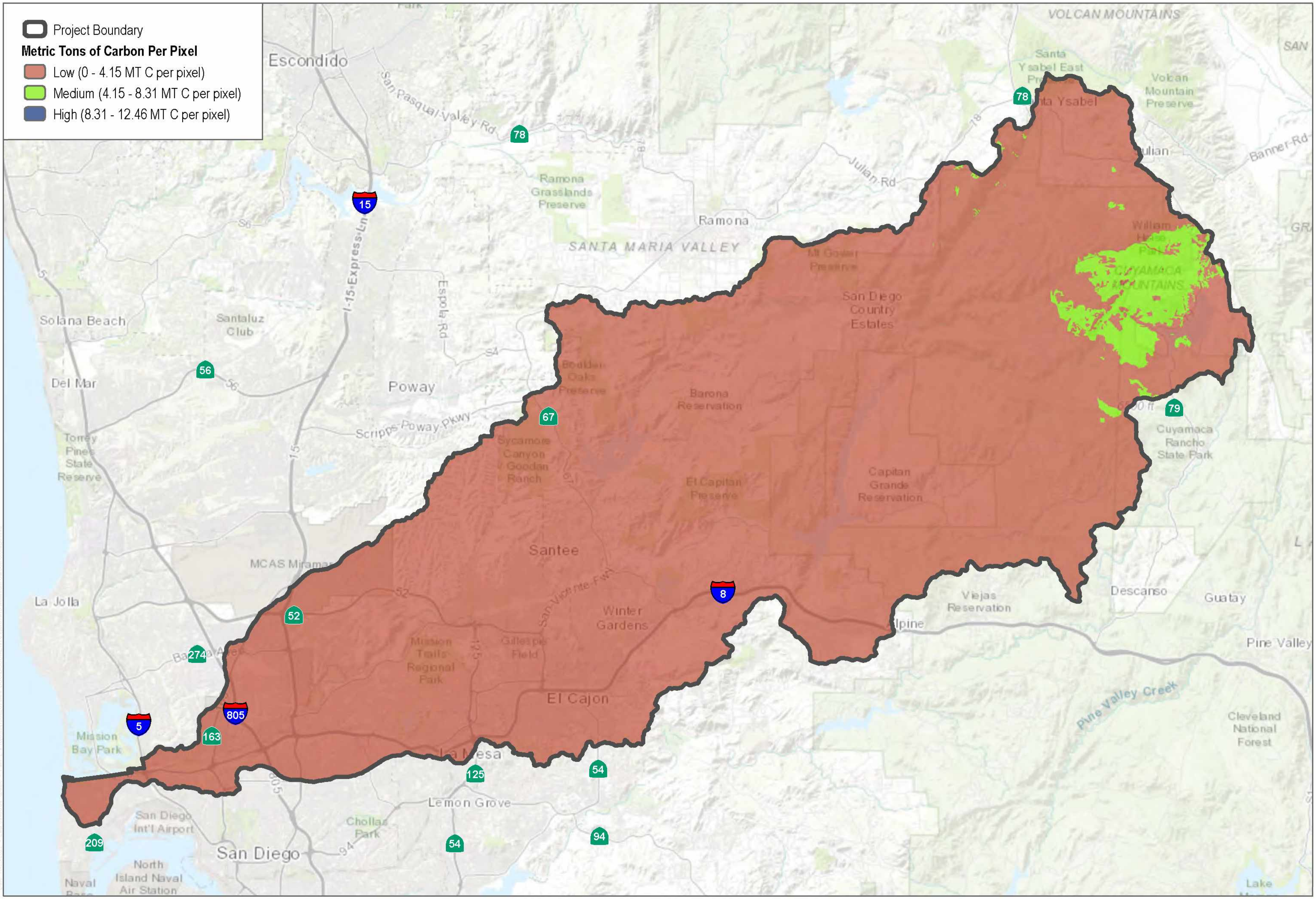
DUDEK

0 5 10 Miles

FIGURE A-12

Total Baseline Carbon Storage - Tijuana Watershed

Carbon Storage and Sequestration Assessment for Four Watersheds of San Diego County, California



SOURCE: ESRI 2022

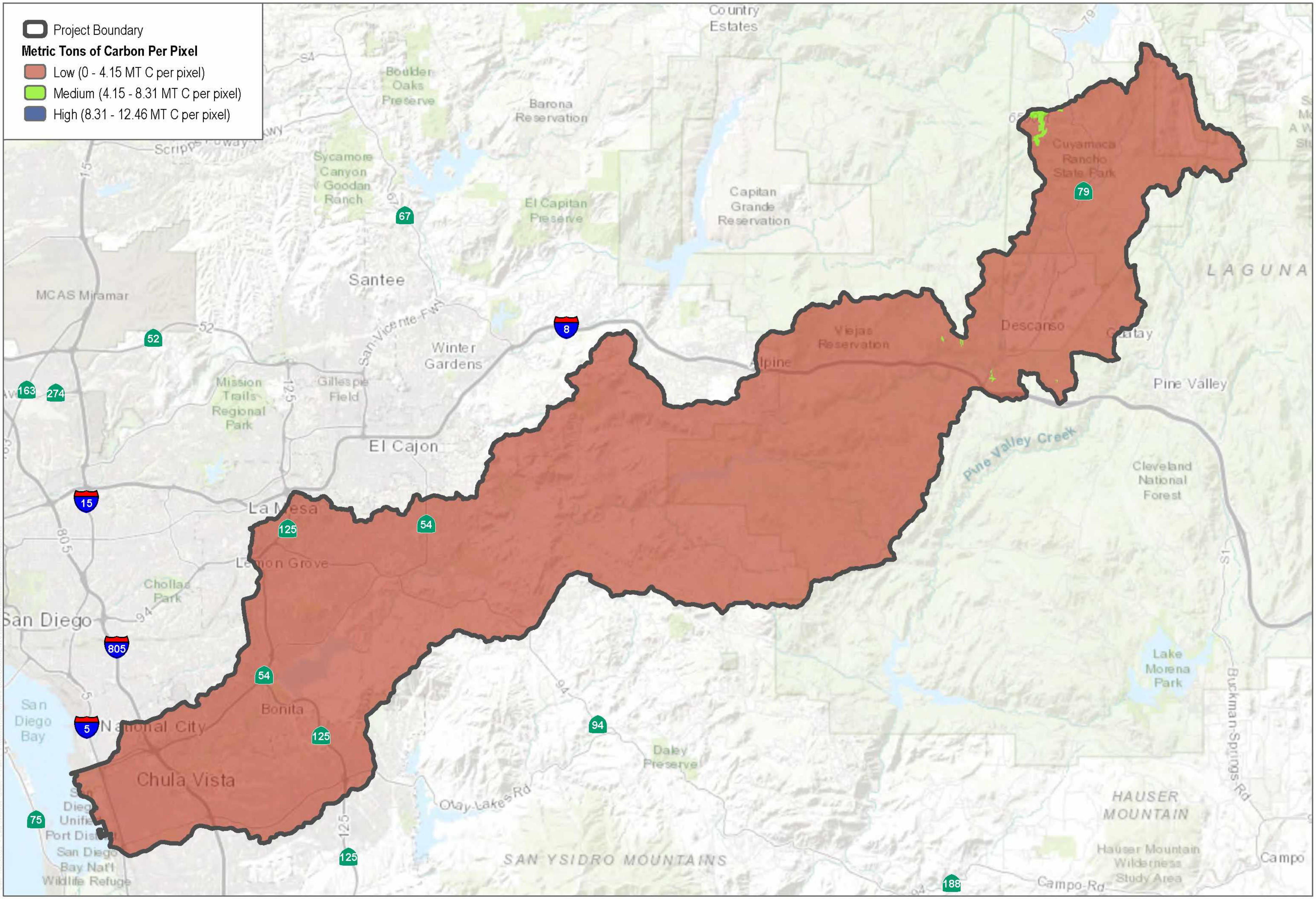
DUDEK

0 5 10 Miles

FIGURE A-13

Total Minimum Carbon Storage - San Diego Watershed

Carbon Storage and Sequestration Assessment for Four Watersheds of San Diego County, California



SOURCE: ESRI 2022

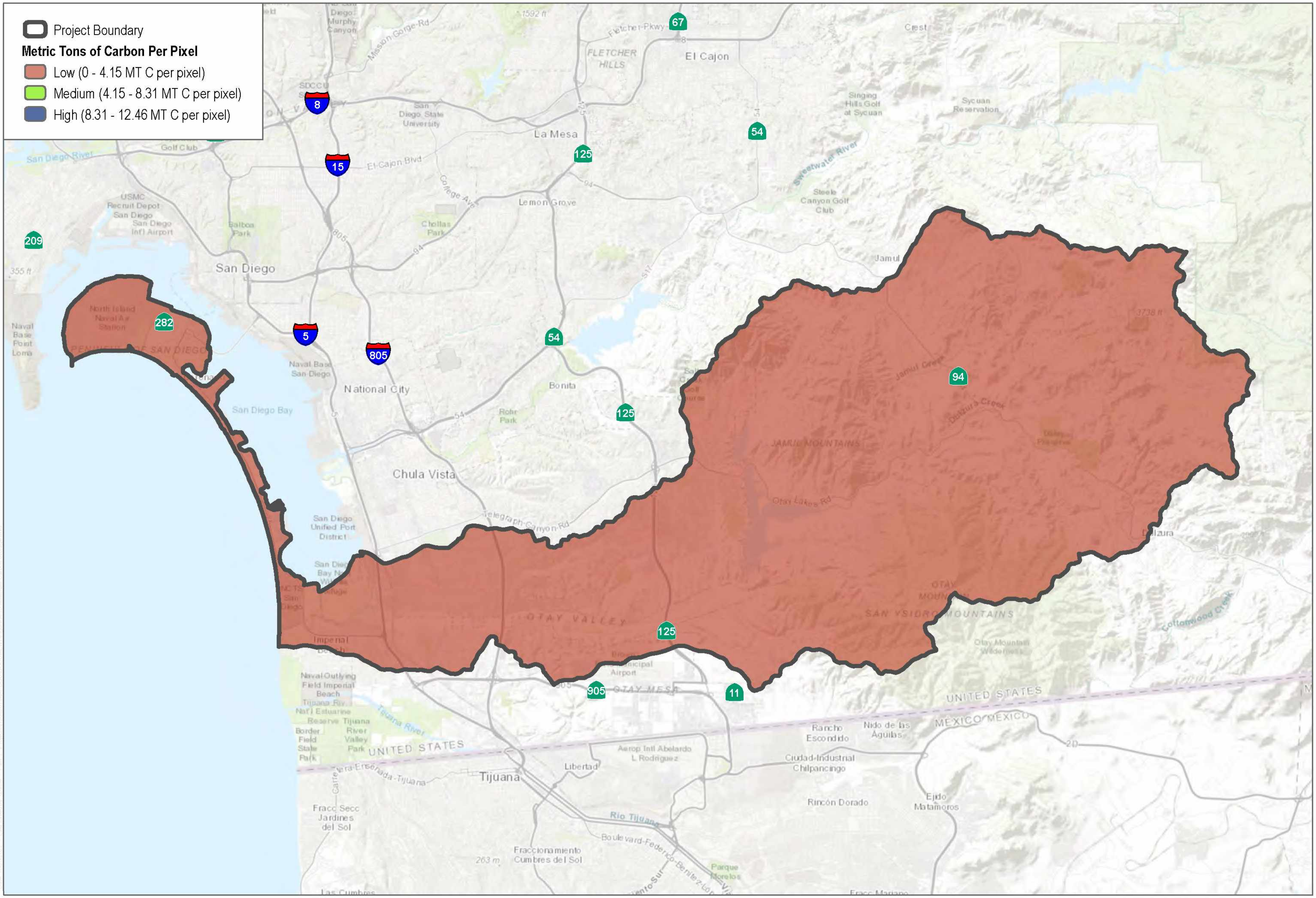
DUDEK

0 5 10 Miles

FIGURE A-14

Total Minimum Carbon Storage - Sweetwater Watershed

Carbon Storage and Sequestration Assessment for Four Watersheds of San Diego County, California



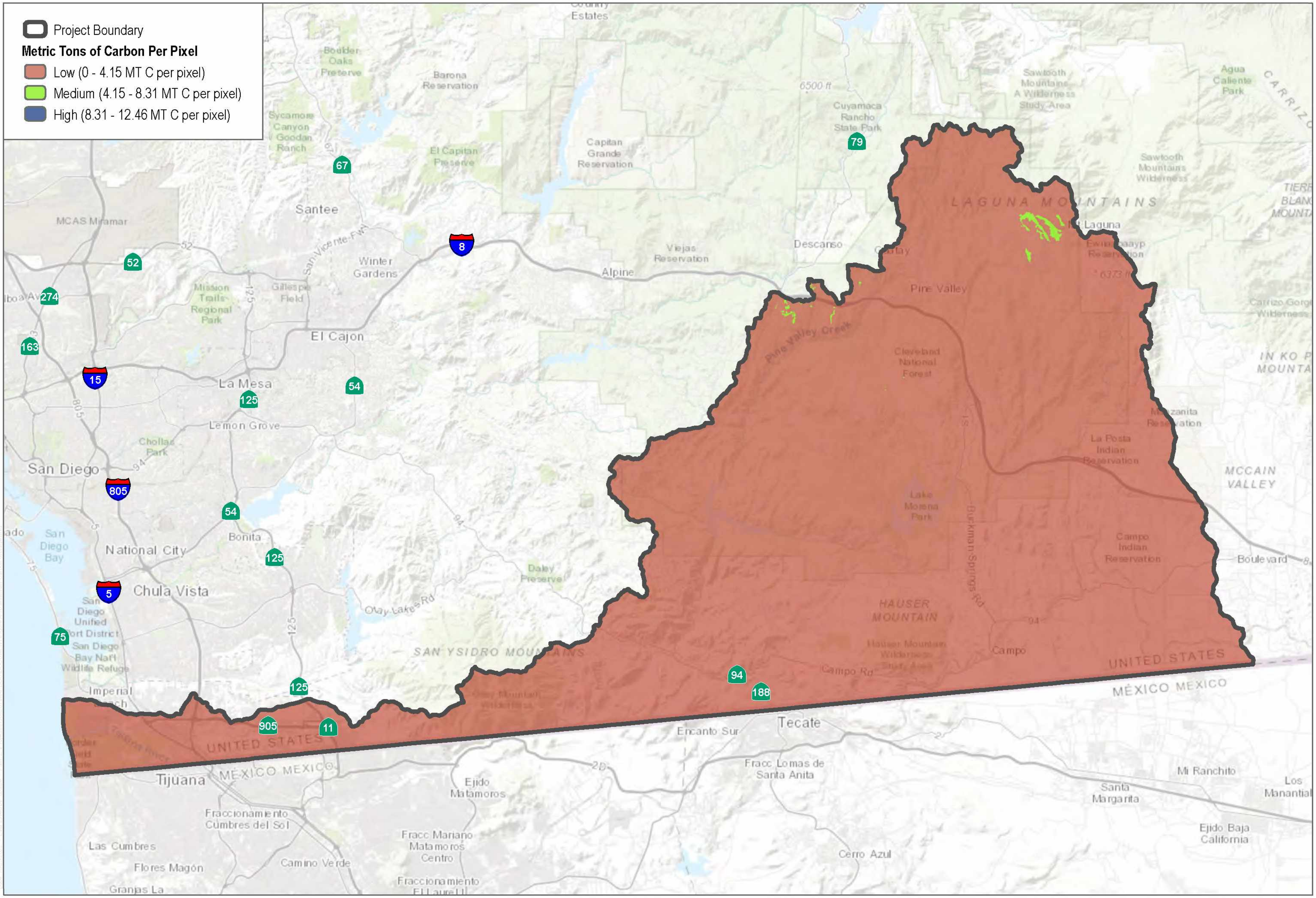
SOURCE: ESRI 2022

DUDEK

FIGURE A-15

Total Minimum Carbon Storage - Otay Watershed

Carbon Storage and Sequestration Assessment for Four Watersheds of San Diego County, California



SOURCE: ESRI 2022

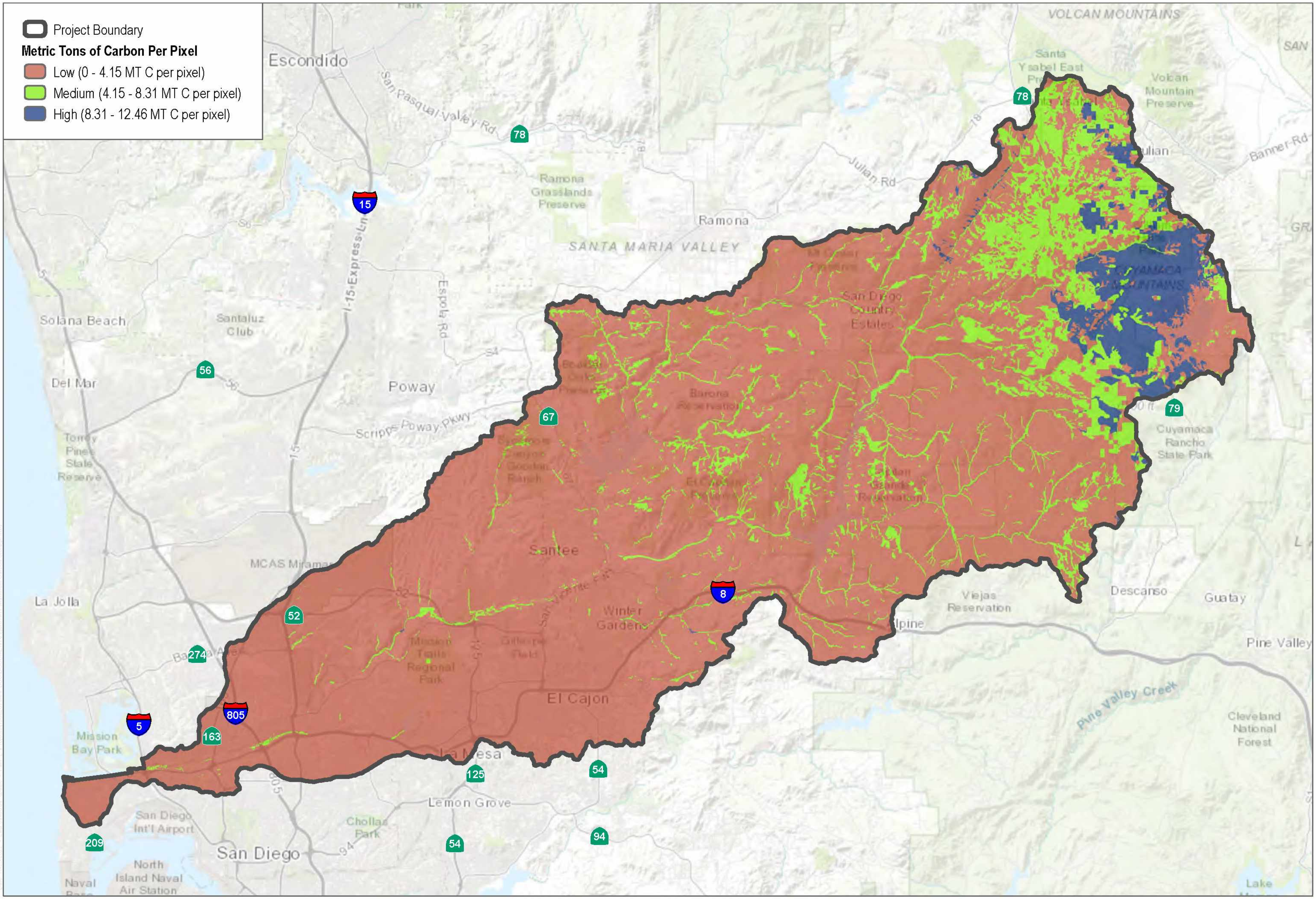
DUDEK

0 5 10 Miles

FIGURE A-16

Total Minimum Carbon Storage - Tijuana Watershed

Carbon Storage and Sequestration Assessment for Four Watersheds of San Diego County, California



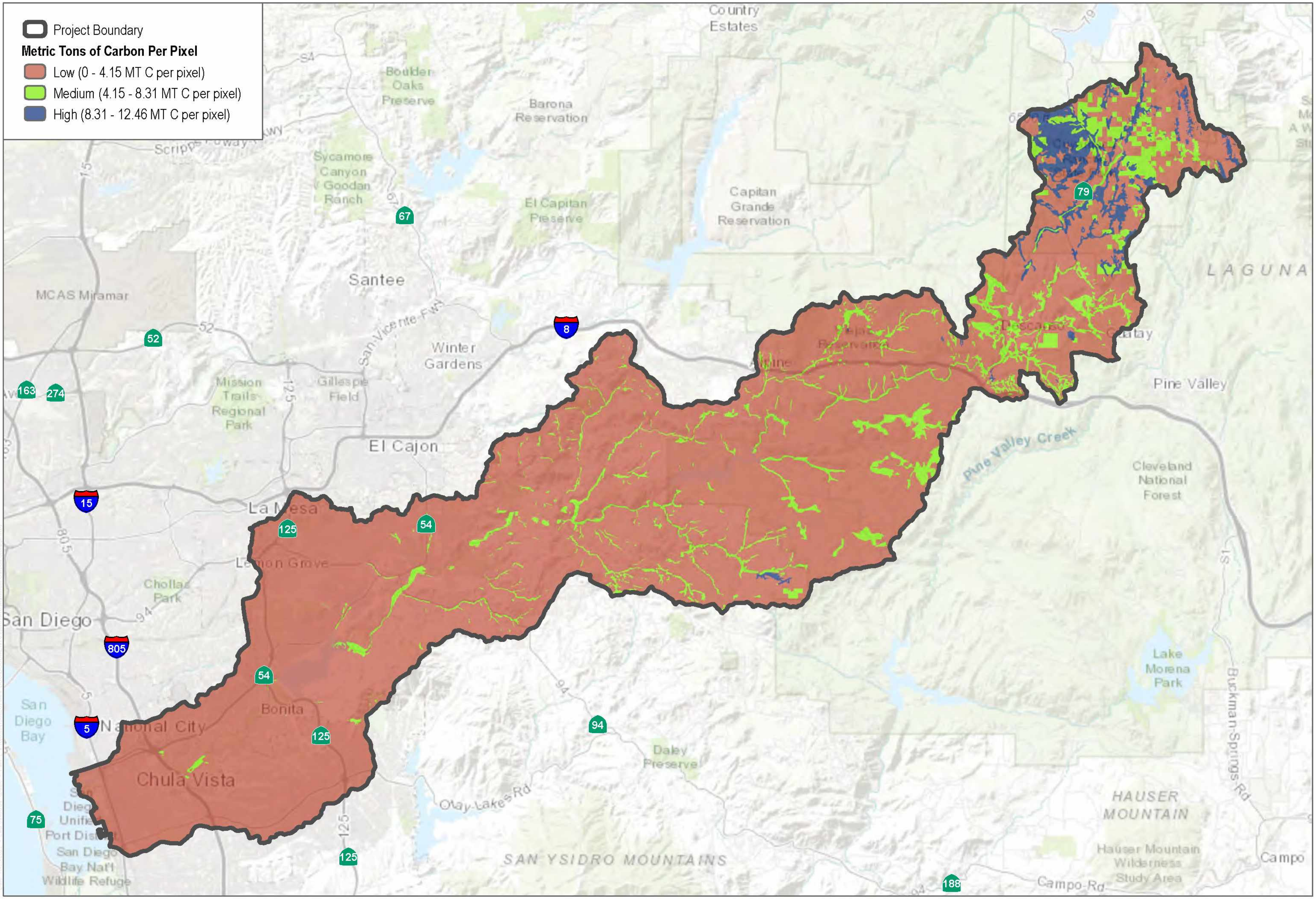
SOURCE: ESRI 2022

DUDEK

FIGURE A-17

Total Maximum Carbon Storage - San Diego Watershed

Carbon Storage and Sequestration Assessment for Four Watersheds of San Diego County, California



SOURCE: ESRI 2022

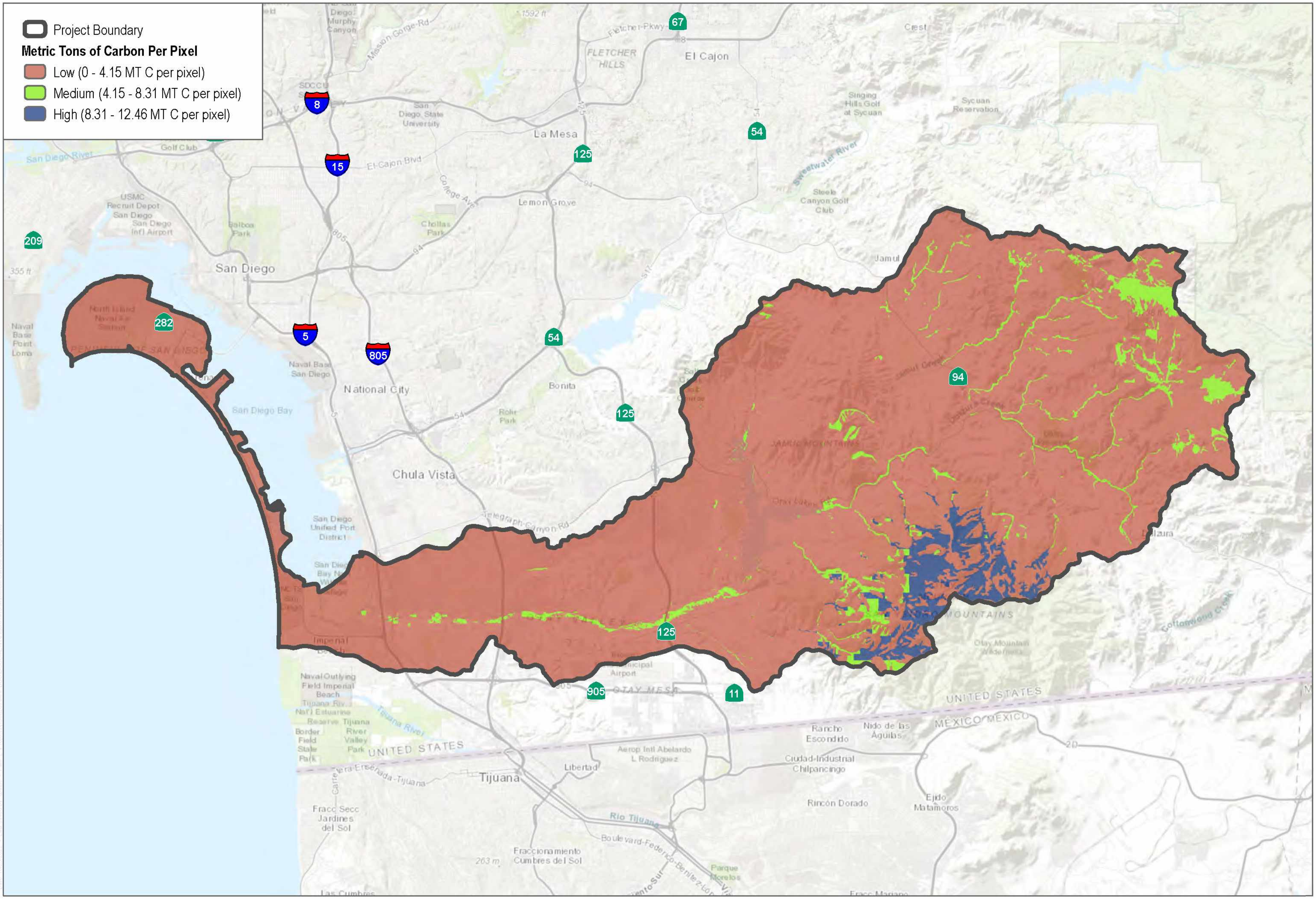
DUDEK

0 5 10 Miles

FIGURE A-18

Total Maximum Carbon Storage - Sweetwater Watershed

Carbon Storage and Sequestration Assessment for Four Watersheds of San Diego County, California



SOURCE: ESRI 2022

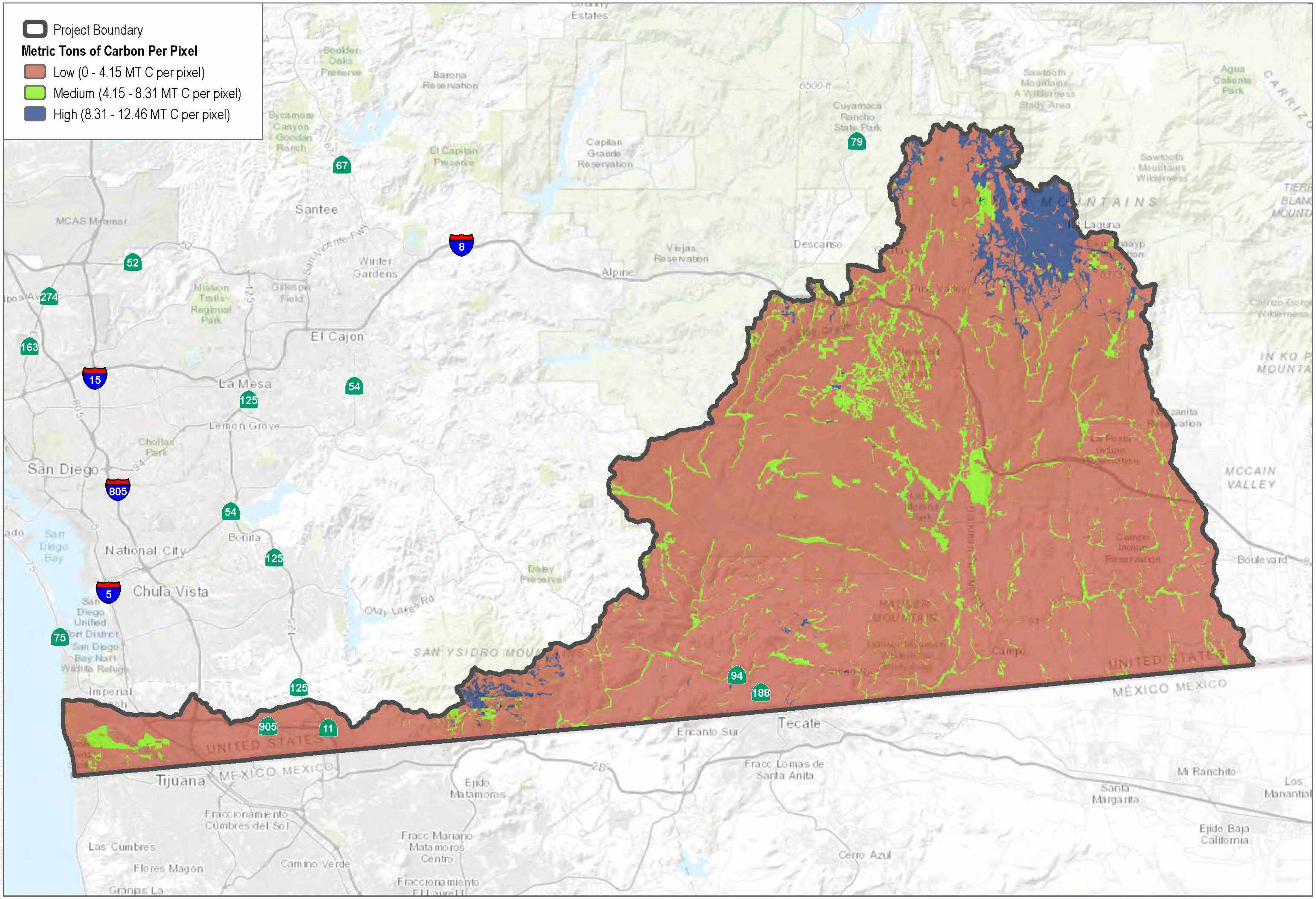
DUDEK

0 5 10 Miles

FIGURE A-19

Total Maximum Carbon Storage - Otay Watershed

Carbon Storage and Sequestration Assessment for Four Watersheds of San Diego County, California



SOURCE: ESRI 2022

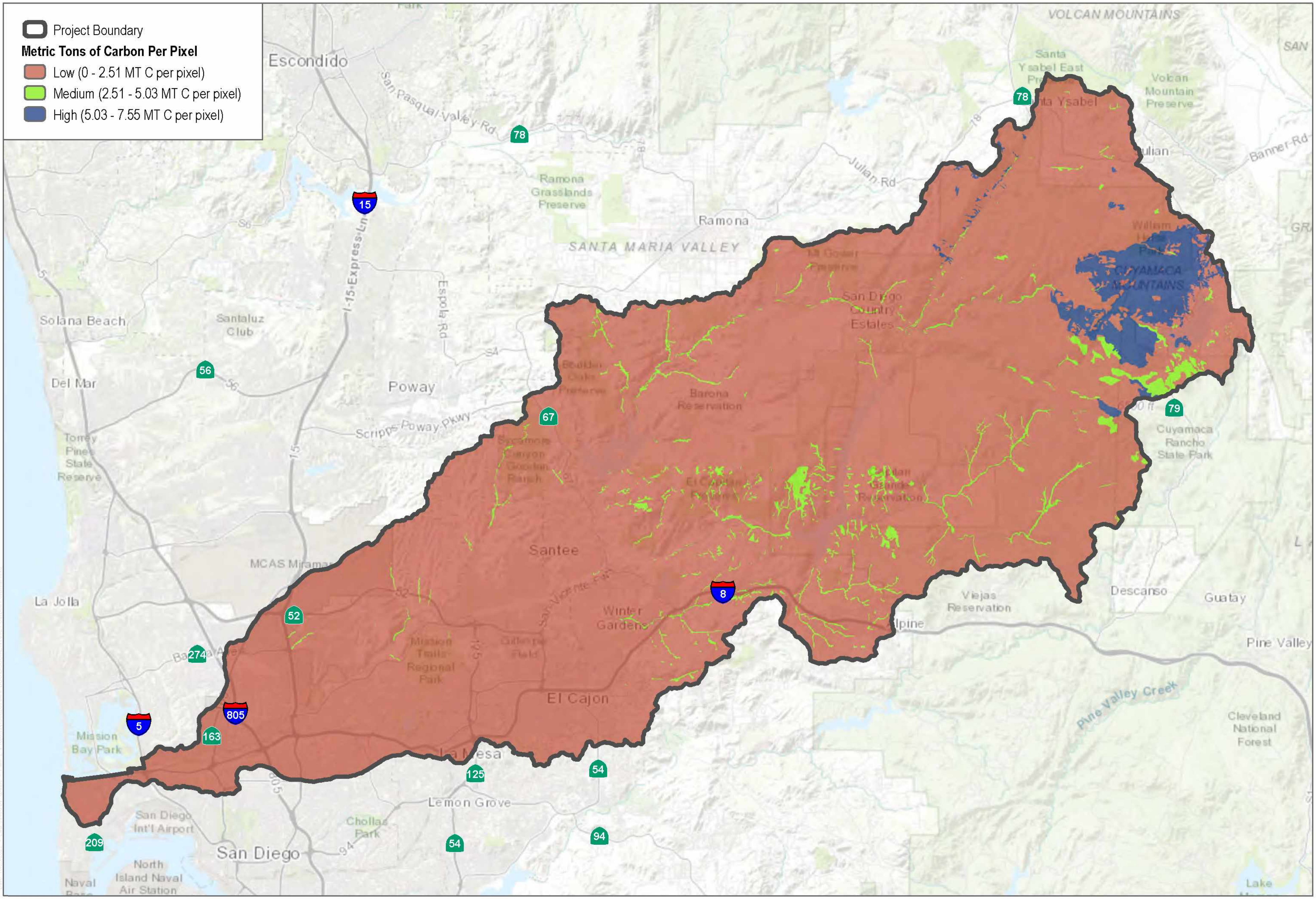
DUDEK

0 5 10 Miles

FIGURE A-20

Total Maximum Carbon Storage - Tijuana Watershed

Carbon Storage and Sequestration Assessment for Four Watersheds of San Diego County, California



SOURCE: ESRI 2022

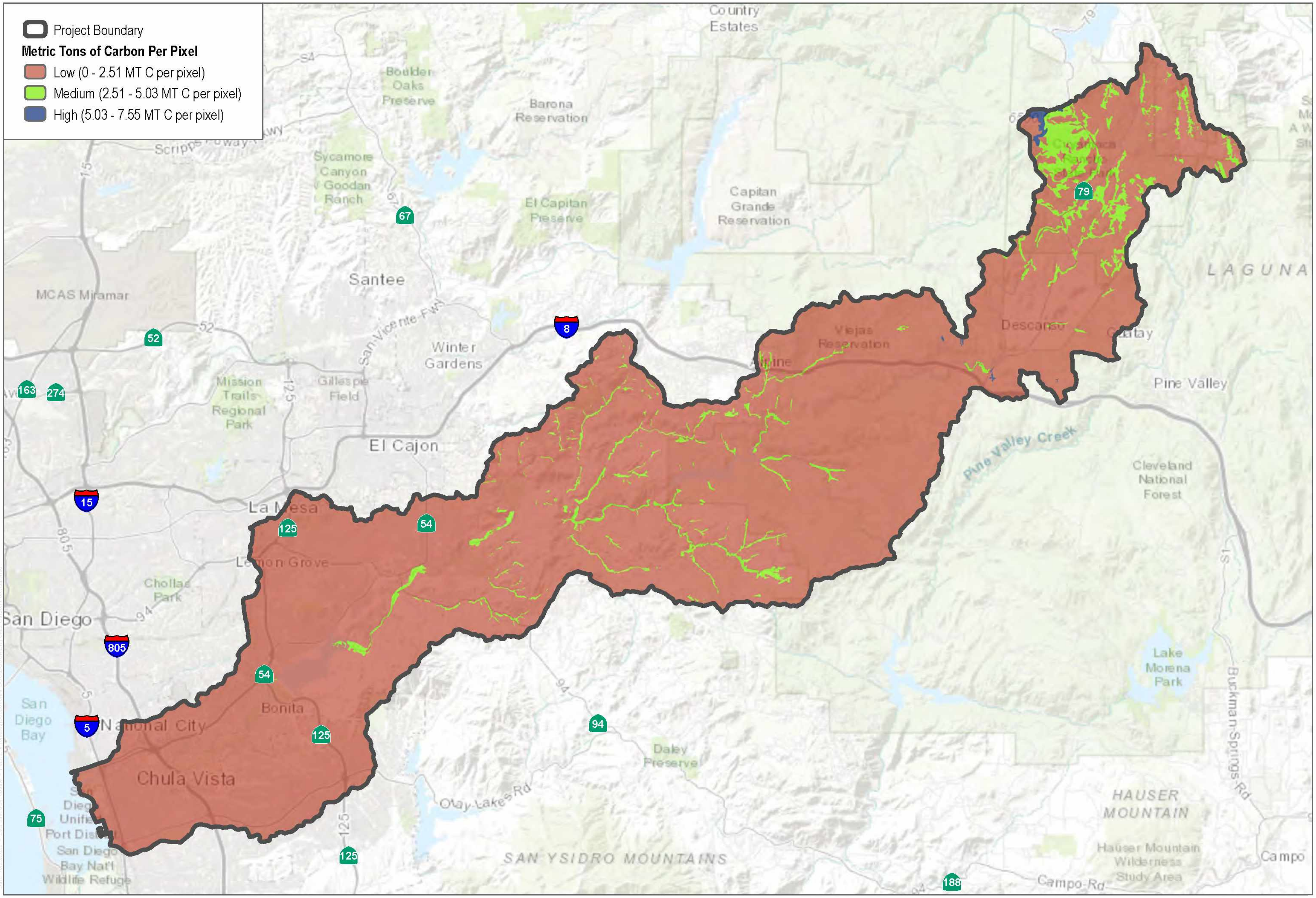
DUDEK

0 5 10 Miles

FIGURE A-21

Carbon Potential - San Diego Watershed

Carbon Storage and Sequestration Assessment for Four Watersheds of San Diego County, California



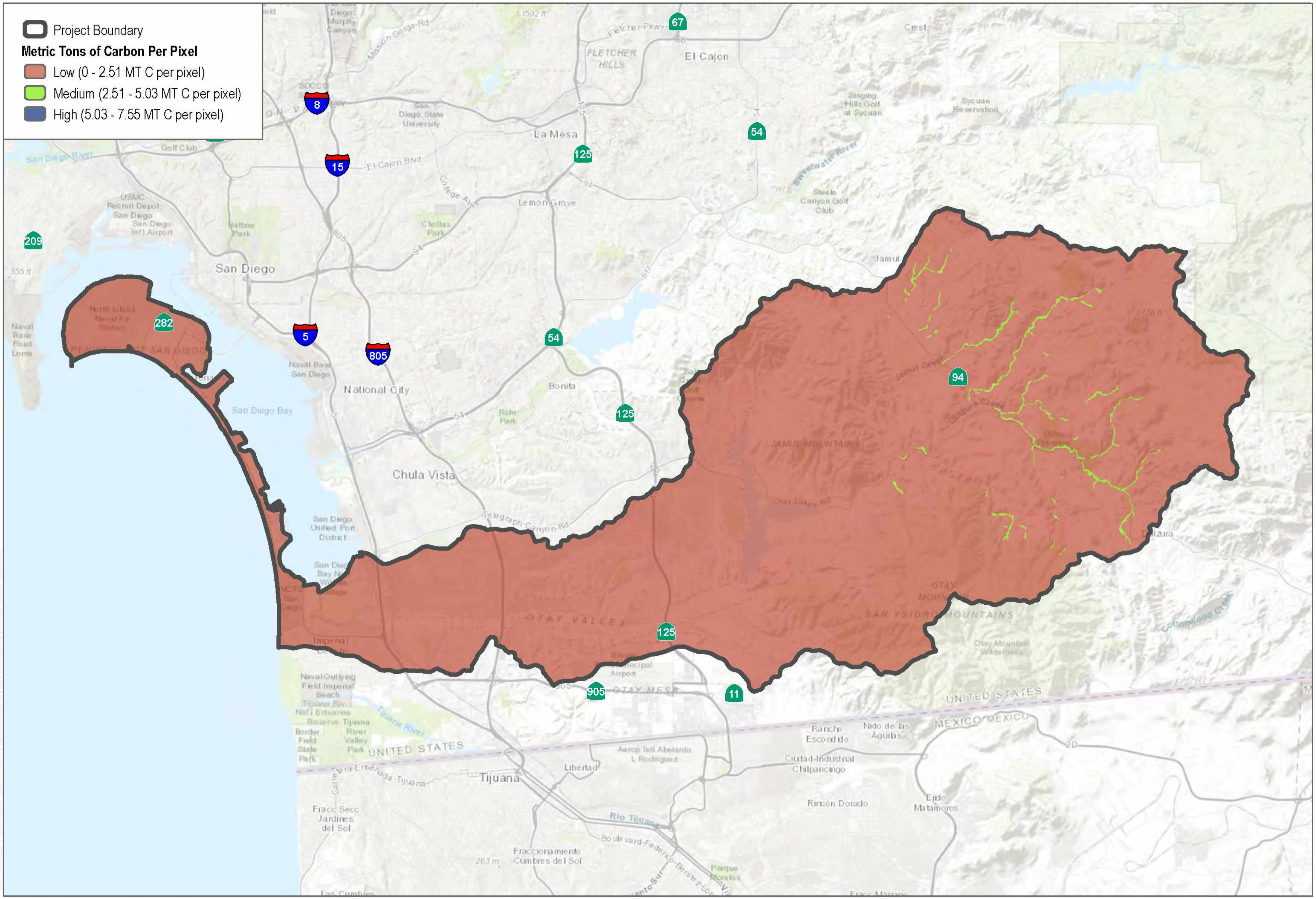
SOURCE: ESRI 2022

0 5 10 Miles

FIGURE A-22

Carbon Potential - Sweetwater Watershed

Carbon Storage and Sequestration Assessment for Four Watersheds of San Diego County, California



SOURCE: ESRI 2022

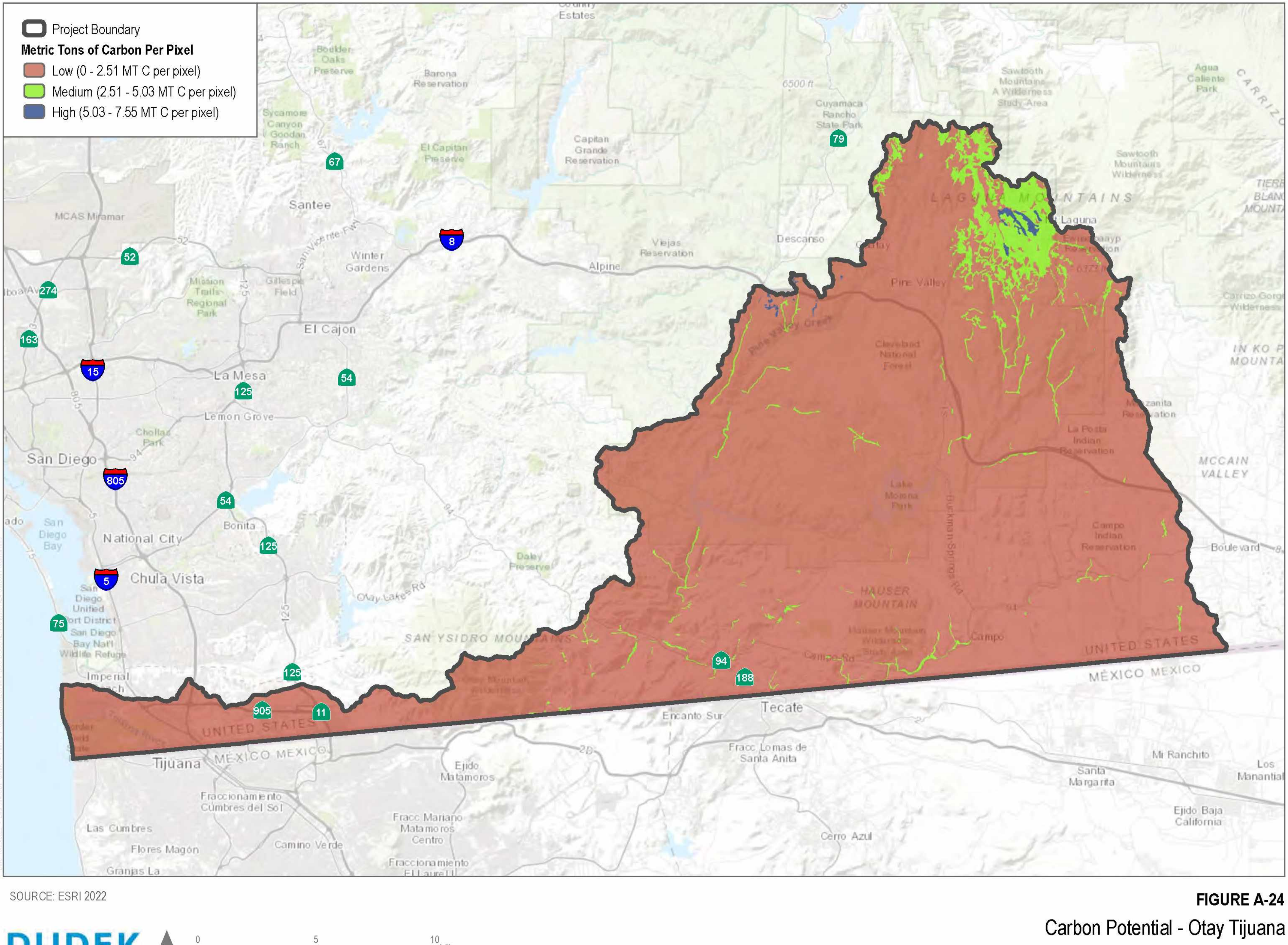
DUDEK

0 5 10 Miles

FIGURE A-23

Carbon Potential - Otay Watershed

Carbon Storage and Sequestration Assessment for Four Watersheds of San Diego County, California



SOURCE: ESRI 2022

DUDEK

FIGURE A-24

Carbon Potential - Otay Tijuana

Carbon Storage and Sequestration Assessment for Four Watersheds of San Diego County, California

Appendix B
Itemized Carbon Inventories

Land Cover Carbon Stock Values

Vegetation Grouping	Vegetation Type (SanGIS)	Metric Tons Carbon per Acre (MT C/ac)											
		Average				Min				Max			
		ABOVE	BELOW	DEAD	Total	ABOVE	BELOW	DEAD	Total	ABOVE	BELOW	DEAD	Total
Scrub	34000 Mojavean Desert Scrub	0.08	0.13	0.03	0.24	0.03	0.06	0.02	0.11	0.16	0.28	0.06	0.50
Scrub	39000 Upper Sonoran Subshrub Scrub	0.08	0.13	0.03	0.24	0.13	0.23	0.03	0.40	0.66	1.10	0.31	2.07
Scrub	32400 Maritime Succulent Scrub	1.26	0.00	3.82	5.08	0.78	0.00	0.00	0.78	1.89	0.00	3.66	5.56
Scrub	32510 Diegan Coastal Sage Scrub: Coastal form	1.26	0.00	3.82	5.08	0.78	0.00	0.00	0.78	1.89	0.00	3.66	5.56
Scrub	32520 Diegan Coastal Sage Scrub: Inland form	1.26	0.00	3.82	5.08	0.78	0.00	0.00	0.78	1.89	0.00	3.66	5.56
Scrub	32710 Riversidian Upland Sage Scrub	1.26	0.00	3.82	5.08	0.78	0.00	0.00	0.78	1.89	0.00	3.66	5.56
Scrub	32720 Alluvial Fan Scrub	1.26	0.00	3.82	5.08	0.78	0.00	0.00	0.78	1.89	0.00	3.66	5.56
Scrub	35200 Sagebrush Scrub	1.26	0.00	3.82	5.08	0.78	0.00	0.00	0.78	1.89	0.00	3.66	5.56
Scrub	37K00 Montane Buckwheat Scrub	1.26	0.00	3.82	5.08	0.78	0.00	0.00	0.78	1.89	0.00	3.66	5.56
Scrub	32000 Coastal Scrub	1.26	0.00	3.82	5.08	0.78	0.00	0.00	0.78	1.89	0.00	3.66	5.56
Scrub	32500 Diegan Coastal Sage Scrub	1.26	0.00	3.82	5.08	0.78	0.00	0.00	0.78	1.89	0.00	3.66	5.56
Scrub	32520 Diegan Coastal Sage Scrub: Inland form	1.26	0.00	3.82	5.08	0.78	0.00	0.00	0.78	1.89	0.00	3.66	5.56
Scrub	37K00 Montane Buckwheat Scrub	1.26	0.00	3.82	5.08	0.78	0.00	0.00	0.78	1.89	0.00	3.66	5.56
Scrub	35210 Big Sagebrush Scrub	3.20	1.92	0.00	5.12	0.09	0.17	0.04	0.30	6.87	12.53	1.58	20.99
Chaparral	37210 Granitic Chamise Chaparral	3.21	0.00	3.65	6.86	1.28	0.00	3.29	4.56	4.05	0.00	3.78	7.83
Chaparral	37220 Mafic Chamise Chaparral	3.21	0.00	3.65	6.86	1.28	0.00	3.29	4.56	4.05	0.00	3.78	7.83
Chaparral	37200 Chamise Chaparral	3.21	0.00	3.65	6.86	1.28	0.00	3.29	4.56	4.05	0.00	3.78	7.83
Chaparral	37210 Granitic Chamise Chaparral	3.21	0.00	3.65	6.86	1.28	0.00	3.29	4.56	4.05	0.00	3.78	7.83
Chaparral	37122 Mafic Southern Mixed Chaparral	6.02	2.53	6.14	14.70	1.51	0.00	0.57	2.08	7.61	2.53	13.08	23.21
Chaparral	37130 Northern Mixed Chaparral	6.02	2.53	6.14	14.70	1.51	0.00	0.57	2.08	7.61	2.53	13.08	23.21
Chaparral	37132 Mafic Northern Mixed Chaparral	6.02	2.53	6.14	14.70	1.51	0.00	0.57	2.08	7.61	2.53	13.08	23.21
Chaparral	37400 Semi-Desert Chaparral	6.02	2.53	6.14	14.70	1.51	0.00	0.57	2.08	7.61	2.53	13.08	23.21
Chaparral	37500 Montane Chaparral	6.02	2.53	6.14	14.70	1.51	0.00	0.57	2.08	7.61	2.53	13.08	23.21
Chaparral	37510 Mixed Montane Chaparral	6.02	2.53	6.14	14.70	1.51	0.00	0.57	2.08	7.61	2.53	13.08	23.21
Chaparral	37520 Montane Manzanita Chaparral	6.02	2.53	6.14	14.70	1.51	0.00	0.57	2.08	7.61	2.53	13.08	23.21
Chaparral	37530 Montane Ceanothus Chaparral	6.02	2.53	6.14	14.70	1.51	0.00	0.57	2.08	7.61	2.53	13.08	23.21
Chaparral	37540 Montane Scrub Oak Chaparral	6.02	2.53	6.14	14.70	1.51	0.00	0.57	2.08	7.61	2.53	13.08	23.21
Chaparral	37A00 Interior Live Oak Chaparral	6.02	2.53	6.14	14.70	1.51	0.00	0.57	2.08	7.61	2.53	13.08	23.21
Chaparral	37G00 Coastal Sage-Chaparral Transition	6.02	2.53	6.14	14.70	1.51	0.00	0.57	2.08	7.61	2.53	13.08	23.21
Chaparral	37000 Chaparral	6.02	2.53	6.14	14.70	1.51	0.00	0.57	2.08	7.61	2.53	13.08	23.21
Chaparral	37120 Southern Mixed Chaparral	6.02	2.53	6.14	14.70	1.51	0.00	0.57	2.08	7.61	2.53	13.08	23.21
Chaparral	37121 Granitic Southern Mixed Chaparral	6.02	2.53	6.14	14.70	1.51	0.00	0.57	2.08	7.61	2.53	13.08	23.21
Chaparral	37130 Northern Mixed Chaparral	6.02	2.53	6.14	14.70	1.51	0.00	0.57	2.08	7.61	2.53	13.08	23.21
Chaparral	37131 Granitic Northern Mixed Chaparral	6.02	2.53	6.14	14.70	1.51	0.00	0.57	2.08	7.61	2.53	13.08	23.21
Chaparral	37132 Mafic Northern Mixed Chaparral	6.02	2.53	6.14	14.70	1.51	0.00	0.57	2.08	7.61	2.53	13.08	23.21
Chaparral	37300 Red Shank Chaparral	6.02	2.53	6.14	14.70	1.51	0.00	0.57	2.08	7.61	2.53	13.08	23.21
Chaparral	37900 Scrub Oak Chaparral	6.02	2.53	6.14	14.70	1.51	0.00	0.57	2.08	7.61	2.53	13.08	23.21
Woodland	70000 Woodland	30.35	0.00	9.24	39.59	0.49	0.00	0.30	0.78	50.23	0.00	15.36	65.58
Woodland	72310 Peninsular Pinon Woodland	9.13	1.36	31.52	42.01	3.09	0.34	21.06	24.49	18.83	3.10	50.42	72.35
Woodland	78000 Undifferentiated Open Woodland	24.01	3.62	27.69	55.32	3.89	0.08	24.09	28.06	79.27	15.25	37.31	131.83
Woodland	79000 Undifferentiated Dense Woodland	15.78	0.00	24.69	40.47	0.45	0.00	0.00	0.45	64.07	0.00	0.00	64.07
Woodland	71000 Cismontane Woodland	15.78	0.00	24.69	40.47	0.45	0.00	0.00	0.45	64.07	0.00	0.00	64.07
Woodland	71100 Oak Woodland	15.78	0.00	24.69	40.47	0.45	0.00	0.00	0.45	64.07	0.00	0.00	64.07
Woodland	77000 Mixed Oak Woodland	15.78	0.00	24.69	40.47	0.45	0.00	0.00	0.45	64.07	0.00	0.00	64.07
Woodland	71120 Black Oak Woodland	4.45	0.00	25.50	29.95	0.45	0.00	0.00	0.45	64.07	0.00	0.00	64.07
Woodland	71160 Coast Live Oak Woodland	14.16	0.00	29.95	44.11	0.45	0.00	0.00	0.45	64.07	0.00	0.00	64.07
Woodland	71161 Open Coast Live Oak Woodland	14.16	0.00	29.95	44.11	0.45	0.00	0.00	0.45	64.07	0.00	0.00	64.07
Woodland	71162 Dense Coast Live Oak Woodland	14.16	0.00	29.95	44.11	0.45	0.00	0.00	0.45	64.07	0.00	0.00	64.07
Woodland	71182 Dense Engelmann Oak Woodland	12.95	0.00	28.33	41.28	0.45	0.00	0.00	0.45	64.07	0.00	0.00	64.07
Woodland	71180 Engelmann Oak Woodland	12.95	0.00	28.33	41.28	0.45	0.00	0.00	0.45	64.07	0.00	0.00	64.07
Woodland	71181 Open Engelmann Oak Woodland	12.95	0.00	28.33	41.28	0.45	0.00	0.00	0.45	64.07	0.00	0.00	64.07
Forest	81100 Mixed Evergreen Forest	6.71	1.23	24.58	32.52	3.96	0.00	6.97	10.94	41.11	0.00	9.02	50.13
Forest	81300 Oak Forest	14.10	2.69	25.93	42.72	5.21	0.00	9.16	14.37	54.01	0.00	11.85	65.86
Forest	81310 Coast Live Oak Forest	20.38	3.83	27.42	51.63	6.29	0.00	11.07	17.36	65.27	0.00	14.32	79.59
Forest	81320 Canyon Live Oak Forest	30.13	5.99	27.63	63.75	7.77	0.00	13.67	21.44	80.59	0.00	17.69	98.28
Forest	81340 Black Oak Forest	25.56	5.08	27.04	57.68	7.03	0.00	12.37	19.40	72.92	0.00	16.00	88.92
Forest	83230 Southern Interior Cypress Forest	7.06	1.39	37.48	45.93	5.60	0.00	9.85	15.45	58.06	0.00	12.74	70.81
Forest	84000 Lower Montane Coniferous Forest	41.79	9.25	49.18	100.22	12.22	0.00	21.49	33.71	126.70	0.00	27.81	154.51
Forest	84140 Coulter Pine Forest	10.95	2.26	29.79	43.00	5.24	0.00	9.22	14.46	54.36	0.00	11.93	66.29
Forest	84230 Sierran Mixed Coniferous Forest	41.79	9.25	49.18	100.22	12.22	0.00	21.49	33.71	126.70	0.00	27.81	154.51
Forest	84500 Mixed Oak/Coniferous/Bigcone/Coulter Forest	10.95	2.26	29.79	43.00	5.24	0.00	9.22	14.46	54.36	0.00	11.93	66.29
Forest	85100 Jeffrey Pine Forest	20.07	4.42	32.28	56.77	6.92	0.00	12.17	19.09	71.77	0.00	15.75	87.52
Grassland	45100 Montane Meadow	0.61	0.00	0.00	0.61	0.00	0.00	0.00	0.00	0.61	0.00	0.00	0.61
Grassland	45110 Wet Montane Meadow	0.61	0.00	0.00	0.61	0.00	0.00	0.00	0.00	0.61	0.00	0.00	0.61
Grassland	45120 Dry Montane Meadows	0.61	0.00	0.00	0.61	0.00	0.00	0.00	0.00	0.61	0.00	0.00	0.61
Grassland	42100 Native Grassland	0.51	1.90	0.00	2.41	0.41	1.46	0.00	1.87	0.72	2.86	0.00	3.57
Grassland	42120 Valley Sacaton Grassland	0.51	1.90	0.00	2.41	0.41	1.46	0.00	1.87	0.72	2.86	0.00	3.57
Grassland	42300 Wildflower Field	0.51	1.90	0.00	2.41	0.41	1.46	0.00	1.87	0.72	2.86	0.00	3.57
Grassland	42400 Foothill/Mountain Perennial Grassland	0.51	1.90	0.00	2.41	0.41	1.46	0.00	1.87	0.72	2.86	0.00	3.57
Grassland	44000 Vernal Pool	0.51	1.90	0.00	2.41	0.41	1.46	0.00	1.87	0.72	2.86	0.00	3.57
Grassland	45320 Alkali Seep	0.51	1.90	0.00	2.41	0.41	1.46	0.00	1.87	0.72	2.86	0.00	3.57
Grassland	45400 Freshwater Seep	0.51	1.90	0.00	2.41	0.41	1.46	0.00	1.87	0.72	2.86	0.00	3.57
Grassland	42000 Valley and Foothill Grassland	0.51	1.90	0.00	2.41	0.41	1.46	0.00	1.87	0.72	2.86	0.00	3.57
Grassland	42110 Valley Needlegrass Grassland	0.51	1.90	0.00	2.41	0.41	1.46	0.00	1.87	0.72	2.86	0.00	3.57
Grassland	44320 San Diego Mesa Vernal Pool	0.51	1.90	0.00	2.41	0.41	1.46	0.00	1.87	0.72	2.86	0.00	3.57
Grassland	42200 Non-Native Grassland	0.54	2.06	0.00	2.60	0.41	1.46	0.00	1.87	0.72	2.86	0.00	3.57
Riparian	61000 Riparian Forests	30.70	0.00	9.36	40.06	1.14	0.00	0.34	1.48	38.06	0.00	14.59	52.66
Riparian	61300 Southern Riparian Forest	30.70	0.00	9.36	40.06	1.14	0.00	0.34	1.48	38.06	0.00	14.59	52.66
Riparian	63000 Riparian Scrubs	17.38	0.00	8.62	26.01	1.13	0.00	0.34	1.47	19.33	0.00	13.57	32.91
Riparian	63300 Southern Riparian Scrub	17.38	0.00	8.62	26.01	1.13	0.00	0.34	1.47	19.33	0.00	13.57	32.91
Riparian	63310 Mule Fat Scrub	17.38	0.00	8.62	26.01	1.13	0.00	0.34	1.47	19.33	0.00	13.57	32.91
Riparian	63320 Southern Willow Scrub	17.38	0.00	8.62	26.01	1.13	0.00	0.34	1.47	19.33	0.00	13.57	32.91
Riparian	63321 Arundo donnax Dominant/Southern Willow Scrub	17.38	0.00	8.62	26.01	1.13	0.00	0.34	1.47	19.33	0.00	13.57	32.91
Riparian	63810 Tamarisk Scrub	17.38	0.00	8.62	26.01	1.13	0.00	0.34	1.47	19.33	0.00	13.57	32.91
Riparian	62000 Riparian Woodlands	30.35	0.00	9.24	39.59	0.49	0.00	0.30	0.78	50.23	0.00	15.36	65.58
Riparian	62500 Southern Riparian Woodland	30.35	0.00	9.24	39.59	0.49	0.00	0.30	0.78	50.23	0.00	15.36	65.58
Riparian	61310 Southern Coast Live Oak Riparian Forest	30.35	0.00	9.24	39.59	0.49	0.00	0.30	0.78	50.23	0.00	15.36	65.58
Riparian	62400 Southern Sycamore-alder Riparian Woodland	30.35	0.00	9.24	39.59	0.49	0.00	0.30	0.78	50.23	0.00	15.36	65.58
Riparian	60000 Riparian and Bottomland Habitat	19.92	0.00	8.76	28.68	1.77	0.00	0.38	2.14	20.95	0.00	13.66	34.60
Riparian	61320 Southern Arroyo Willow Riparian Forest	38.46	0.00	9.88	48.34	1.83	0.00	0.39	2.22	45.24	0.00	15.09	60.33
Riparian	61330 Southern Cottonwood-willow Riparian Forest	38.46	0.00	9.88	48.34	1.83	0.00	0.39	2.22	45.24	0.00	15.09	60.33
Riparian	61510 White Alder Riparian Forest	38.46	0.00	9.88	48.34	1.83	0.00	0.39	2.22	45.24	0.00	15.09	60.33
Marsh	52120 Southern Coastal Salt Marsh	0.53	2.00	0.00	2.53	0.41	1.46	0.00	1.87	0.72	2.86	0.00	3.57
Marsh	52310 Cismontane Alkali Marsh	0.53	1.99	0.00	2.52	0.41	1.46	0.00	1.87	0.72	2.86	0.00	3.57
Marsh	52400 Freshwater Marsh	0.53	1.99	0.00	2.52	0.41	1.46	0.00	1.87	0.72	2.86	0.00	3.57
Marsh	52410 Coastal and Valley Freshwater Marsh	0.53	1.99	0.00	2.52	0.41	1.46	0.00	1.87	0.72	2.86	0.00	3.57
Agriculture	18100 Orchards and Vineyards	7.45	0.00	0.00	7.45	7.45	0.00	0.00	7.45	7.45	0.00	0.00	7.45
Agriculture	18000 General Agriculture	1.71	0.00	0.00	1.71	1.71	0.00	0.00	1.71	1.71	0.00	0.00	1.71
Agriculture	18200 Intensive Agriculture - Dairies, Nurseries, Chicken Ranches	1.71	0.00	0.00	1.71	1.71	0.00	0.00	1.71	1.71	0.00	0.00	1.71
Agriculture	18300 Extensive Agriculture - Field/Pasture, Row Crops	1.71	0.00	0.00	1.71	1.71	0.00	0.00	1.71	1.71	0.00	0.00	1.71
Agriculture	18320 Row Crops	1.71	0.00	0.00	1.71	1.71	0.00	0.00	1.71	1.71	0.00	0.00	1.71
Agriculture	18310 Field/Pasture	2.55	0.00	0.00	2.55	2.55	0.00	0.00	2.55	2.55	0.00	0.00	2.55

Land Cover Carbon Stock Values

Vegetation Grouping	Vegetation Type (SanGIS)	Metric Tons Carbon per Acre (MT C/ac)											
		Average				Min				Max			
		ABOVE	BELOW	DEAD	Total	ABOVE	BELOW	DEAD	Total	ABOVE	BELOW	DEAD	Total
Other	64100 Open Water	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Other	64111 Subtidal	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Other	64121 Deep Bay	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Other	64122 Intermediate Bay	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Other	64123 Shallow Bay	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Other	64130 Estuarine	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Other	64140 Freshwater	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Other	13100 Open Water	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Other	13140 Freshwater	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Other	64200 Non-Vegetated Channel or Floodway	0.15	-0.13	0.00	0.03	0.15	-0.13	0.00	0.03	0.15	-0.13	0.00	0.03
Other	64300 Saltpan/Mudflats	0.15	-0.13	0.00	0.03	0.15	-0.13	0.00	0.03	0.15	-0.13	0.00	0.03
Other	64400 Beach	0.15	-0.13	0.00	0.03	0.15	-0.13	0.00	0.03	0.15	-0.13	0.00	0.03
Other	13200 Non-Vegetated Channel, Floodway, Lakeshore Fringe	0.15	-0.13	0.00	0.03	0.15	-0.13	0.00	0.03	0.15	-0.13	0.00	0.03
Other	12000 Urban/Developed	3.10	0.00	0.00	3.10	0.00	0.00	0.00	0.00	3.10	0.00	0.00	3.10
Other	11000 Non-Native Vegetation	0.54	2.06	0.00	2.60	0.41	1.46	0.00	1.87	0.72	2.86	0.00	3.57
Other	11300 Disturbed Habitat	0.54	2.06	0.00	2.60	0.41	1.46	0.00	1.87	0.72	2.86	0.00	3.57
Other	52440 Emergent Wetland	0.53	1.99	0.00	2.52	0.41	1.46	0.00	1.87	0.72	2.86	0.00	3.57
Other	11200 Disturbed Wetland	0.53	2.00	0.00	2.53	0.41	1.46	0.00	1.87	0.72	2.86	0.00	3.57
Other	21230 Southern Foredunes	0.14	0.16	0.05	0.35	0.14	0.16	0.05	0.35	0.14	0.16	0.05	0.35
Other	79100 Eucalyptus Woodland	2.28	0.31	24.00	26.58	3.24	0.00	5.70	8.94	33.61	0.00	7.38	40.98

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Baseline Carbon Storage - Total Carbon (MT C) by Watershed

Vegetation Type	Watershed				Grand Total
	Otay	San Diego	Sweetwater	Tijuana	
Chaparral					
Chamise Chaparral	32,632	174,129	65,741	240,240	512,742
Chaparral	365,063	470,219	388,069	439,525	1,662,875
Coastal Sage-Chaparral Transition	50,544	167,028	49,202	115,377	382,150
Granitic Chamise Chaparral	-	47,108	53,089	414,679	514,876
Granitic Northern Mixed Chaparral	38,394	546,750	348,432	2,720,287	3,653,863
Granitic Southern Mixed Chaparral	-	139,506	340,139	1,813	481,458
Interior Live Oak Chaparral	-	21,843	249	16,843	38,935
Mafic Chamise Chaparral	-	5,642	23,195	17,018	45,855
Mafic Northern Mixed Chaparral	4,485	90,701	64,264	321,079	480,529
Mafic Southern Mixed Chaparral	-	40,565	11,075	111	51,752
Mixed Montane Chaparral	-	1,769	-	-	1,769
Montane Ceanothus Chaparral	-	-	-	5,481	5,481
Montane Chaparral	-	25,566	10,151	-	35,717
Montane Manzanita Chaparral	-	-	14,892	76,894	91,786
Montane Scrub Oak Chaparral	-	5,550	25,229	157,758	188,537
Northern Mixed Chaparral	66,669	249,508	226,276	892,005	1,434,458
Red Shank Chaparral	-	-	-	125,092	125,092
Scrub Oak Chaparral	1,382	9,632	452	191,041	202,508
Semi-Desert Chaparral	-	-	-	31,224	31,224
Southern Mixed Chaparral	85,901	960,797	215,339	93,786	1,355,823
Chaparral Total	*645,070*	*2,956,314*	*1,835,794*	*5,860,253*	*11,297,431*
Forest					
Black Oak Forest	-	-	9,102	68,774	77,876
Canyon Live Oak Forest	-	34,455	588	7,666	42,708
Coast Live Oak Forest	-	-	15,259	23,268	38,527
Coulter Pine Forest	-	1,865	-	-	1,865
Jeffrey Pine Forest	-	90,080	261,045	629,060	980,185
Lower Montane Coniferous Forest	-	46	-	-	46
Mixed Evergreen Forest	-	17,842	-	-	17,842
Mixed Oak/Coniferous/Bigcone/Coulter Forest	-	325,461	25,621	121,110	472,192
Oak Forest	-	2,400	-	-	2,400
Sierran Mixed Coniferous Forest	-	1,061,416	25,606	57,310	1,144,332
Southern Interior Cypress Forest	242,109	-	2,069	107,091	351,269
Forest Total	*242,109*	*1,533,565*	*339,290*	*1,014,279*	*3,129,243*
Grassland					
Alkali Seep	-	-	815	6,118	6,933
Dry Montane Meadows	-	18,468	153	2,056	20,678
Foothill/Mountain Perennial Grassland	-	43,126	5,388	24,614	73,129
Freshwater Seep	-	6,498	1,119	22,111	29,728
Montane Meadow	-	1,377	10,432	3,606	15,416
Native Grassland	2,193	1,078	-	701	3,971
Non-Native Grassland	24,507	37,025	27,094	65,538	154,164
San Diego Mesa Vernal Pool	6,304	-	-	-	6,304
Valley and Foothill Grassland	67,335	70,015	28,267	15,418	181,035
Valley Needlegrass Grassland	3,985	3,826	-	4	7,815
Valley Sacaton Grassland	-	-	758	5,181	5,939
Vernal Pool	1	-	-	-	1
Wet Montane Meadow	-	16,371	-	14,315	30,686
Wildflower Field	-	3,874	16,806	4,331	25,011
Grassland Total	*104,325*	*201,658*	*90,832*	*163,994*	*560,809*
Marsh					
Cismontane Alkali Marsh	2,281	22	-	79	2,382
Coastal and Valley Freshwater Marsh	1,269	542	382	224	2,417
Freshwater Marsh	1,058	1,567	81	2,082	4,789
Southern Coastal Salt Marsh	605	111	3,794	13,237	17,747
Transmontane Freshwater Marsh	-	701	-	-	701
Marsh Total	*5,214*	*2,942*	*4,258*	*15,622*	*28,036*
Riparian					
Arundo donax Dominant/Southern Willow Scrub	492	-	-	-	492
Mule Fat Scrub	2,814	257	184	222	3,477
Riparian and Bottomland Habitat	128	1,070	-	-	1,198

Baseline Carbon Storage - Total Carbon (MT C) by Watershed

Vegetation Type	Watershed				Grand Total
	Otay	San Diego	Sweetwater	Tijuana	
Riparian Forests	31	-	-	285	316
Riparian Scrubs	-	178	-	60	238
Riparian Woodlands	-	1,807	24,367	-	26,174
Southern Arroyo Willow Riparian Forest	-	1,216	-	1,864	3,080
Southern Coast Live Oak Riparian Forest	33,634	192,034	106,414	143,902	475,984
Southern Cottonwood-Willow Riparian Forest	-	17,046	19,858	14,305	51,208
Southern Riparian Forest	2,733	77,198	22,465	22,092	124,489
Southern Riparian Scrub	1,917	31,729	15,657	84,274	133,577
Southern Riparian Woodland	2,794	-	-	-	2,794
Southern Sycamore-Alder Riparian Woodland	409	5,220	-	-	5,629
Southern Willow Scrub	8,509	1,947	1,434	3,422	15,312
Tamarisk Scrub	16,141	177	-	181	16,498
White Alder Riparian Forest	-	4,112	570	3,124	7,807
Riparian Total	*69,602*	*333,991*	*190,949*	*273,731*	*868,273*
Scrub					
Alluvial Fan Scrub	-	14	-	1,078	1,091
Big Sagebrush Scrub	-	793	1,114	7,213	9,121
Coastal Scrub	-	-	-	111	111
Diegan Coastal Sage Scrub	509,842	784,309	306,403	193,146	1,793,701
Diegan Coastal Sage Scrub: Coastal form	-	45	12	-	57
Diegan Coastal Sage Scrub: Inland form	-	183	-	143	327
Maritime Succulent Scrub	6,556	-	18	908	7,483
Mojavean Desert Scrub	-	-		1,565	1,565
Montane Buckwheat Scrub	-	9,865	2,768	78,265	90,897
Riversidian Upland Sage Scrub	-	-	122	-	122
Sagebrush Scrub	-	-	206	27,842	28,047
Upper Sonoran Subshrub Scrub	-	-	-	706	706
Scrub Total	*516,399*	*795,208*	*310,643*	*310,976*	*1,933,227*
Woodland					
Black Oak Woodland	-	88,862	16,675	3,390	108,927
Cismontane Woodland	-	-	23	-	23
Coast Live Oak Woodland	12,352	18,660	2,077	3,431	36,519
Dense Coast Live Oak Woodland	86,315	381,445	186,334	452,763	1,106,858
Dense Engelmann Oak Woodland	-	157,077	10,469	7,366	174,913
Engelmann Oak Woodland	72	11,298	27	-	11,398
Mixed Oak Woodland	-	185,312	165	2,730	188,206
Non-Native Woodland	141	10,642	-	-	10,783
Oak Woodland	-	28	2,144	903	3,075
Open Coast Live Oak Woodland	-	73,131	591	176,098	249,819
Open Engelmann Oak Woodland	22,098	184,281	101,706	44,995	353,080
Peninsular Pinon Woodland	-	-	-	442	442
Undifferentiated Open Woodland	-	24,777	2,779	9,853	37,408
Woodland	282	779	448	3,062	4,571
Woodland Total	*121,260*	*1,136,292*	*323,438*	*705,032*	*2,286,022*
Agriculture					
Extensive Agriculture - Field/Pasture, Row Crops	78,044	52,067	18,273	46,715	195,099
Field/Pasture	-	12,954	2,626	30,040	45,620
General Agriculture	12	679	16,940	15,694	33,324
Intensive Agriculture - Dairies, Nurseries, Chicken Ranches	1,605	2,233	1,633	6,999	12,469
Orchards and Vineyards	4,169	12,857	2,158	1,208	20,391
Row Crops	-	5,377	-	-	5,377
Agriculture Total	*83,830*	*86,165*	*41,629*	*100,656*	*312,280*
Other					
Beach	1,709	1	-	862	2,571
Deep Bay	-	-	-	-	-
Disturbed Habitat	40,127	52,228	31,704	38,541	162,601
Disturbed Wetland	1,081	452	523	3,437	5,492
Emergent Wetland	-	-	-	-	-
Estuarine	44	-	-	1,304	1,348
Eucalyptus Woodland	4,011	6,147	1,810	1,637	13,604
Freshwater	3,135	15,690	1,684	11,376	31,886
Intermediate Bay	-	-	-	-	-

Baseline Carbon Storage - Total Carbon (MT C) by Watershed

Vegetation Type	Watershed				Grand Total
	Otay	San Diego	Sweetwater	Tijuana	
Non-Native Vegetation	1,818	1,281	6	-	3,106
Non-Vegetated Channel or Floodway	644	3,859	2,156	3,034	9,693
Open Water	94	2,231	8,005	-	10,331
Saltpan/Mudflats	770	-	-	1,675	2,445
Shallow Bay	1	-	297	-	298
Southern Foredunes	645	-	-	897	1,542
Subtidal	11	-	-	-	11
Urban/Developed	113,266	440,569	274,811	140,725	969,371
Other Total	*167,355*	*522,458*	*320,996*	*203,489*	*1,214,299*
Grand Total	**1,955,165**	**7,568,594**	**3,457,830**	**8,648,031**	**21,629,620**