Resilient Merced

A County Guide to Advance Climate Change Mitigation and Complementary Benefits through Land Management and Conservation

California Conservation

The Nature Conservancy

Table of contents

Acknowledgments

Project team

Michelle Passero, Dave Marvin, Carrie Schloss, Rodd Kelsey and Alex Leumer, The Nature Conservancy

Mark Tukman, Dylan Loudon and Rob Pedersen, Tukman Geospatial

John Nickerson and Jon Remucal, Climate Action Reserve

Jeff Onsted and Nathaniel Roth, California Department of Conservation

Steve Maxey and Tiffany Ho, Merced County

Project Contributors

Amy Swan and Mark Easter, Natural Resource Ecology Lab, Colorado State University

Louise Jackson, Emerita University of California Davis

Jean Okuye, East Merced Resources Conservation District

Andrew Plantinga, Jayme Ohlhaver and Sarah Halperin, UC Santa Barbara

Christopher Galik

Brian Murray, Duke University Energy Initiative

Kelly Graveur, Arizona State University and The Nature Conservancy

State Advisory Committee

David Bunn, Bruce Gwynne and Kathryn Lyddan, California Department of Conservation

Louise Bedsworth, Office of Planning and Research

Ashley Conrad-Saydah, California Environmental Protection Agency

Claire Jahns and Keali'i Bright, California Natural Resources Agency

Jenny Lester-Moffitt, California Department of Food and Agriculture

Anny Huang, Megan Miranda, John Dingman and Klaus Scott, California Air Resources Board

Chris Keithley, Dave Sapsis and Tadashi Moody, California Department of Forestry and Fire Protection

Merced County Stakeholder Advisory Committee

John Beam, Grassland Water District

Joshua Davis, Merced Resource Conservation District

Breanne Ramos, Merced County Farm Bureau

Ed Thompson, American Farmland Trust

Rey Leon, Valley LEAP

Maria Azevedo, California Women for Agriculture

Dave Robinson, Merced County Agricultural Commissioner

Terry Watt, land use planner

Ben Sleeter, United States Geological Survey

Jennifer Foster, Natural Resources Conservation Service, Merced

Shannon Picciano, Office of Senator Cannella

Ric Ortega, Grasslands Ecological Area

Karen Buhr, California Association of Resource Conservation Districts

Pelayo Alvarez, Carbon Cycle Institute

Michael Claiborne and Abigail Ramirez, Leadership Council for Justice and Accountability

Bob Weimer, Atwater

Renata Brillinger, California Climate and Agricultural Network

Curtis Garner, Derek Azevedo, Danny Royer and Reyn Akiona, Bowles Farming Company

Special Thanks

Jake Jacobson, Louis Blumberg and Dick Cameron, The Nature Conservancy

Rose Burroughs, Burroughs Family Farms

Bruce Orr and Amy Merrill, Stillwater Sciences

Elizabeth Vasquez, United States Bureau of Reclamation

Tom Farr, Jet Propulsion Laboratory

Varsha Gopalakrishnan, Ramboll Environ

Toby O'Geen, University of California Davis

Alan Flint, United States Geological Survey

Lorraine Flint, United States Geological Survey

Amy Yang, Mintier Harnish

Alex Steinberger, Fregonese Associates (now Cascadia Partners)

Cascadia Partners

Next 10

Barry Nickel and Aaron Cole, Focalpoint

Executive summary

The tool and methods presented in this guide help local governments, landowners, planners and land managers to understand the links between land management and conservation and greenhouse gas reductions so that they may incorporate that knowledge into planning and management decisions.

The guide describes a methodology for accounting and scenario analysis of three sets of variables related to land-based greenhouse gas reductions: **landscape carbon stocks**; **land-based emissions of the greenhouse gases methane and nitrous oxide**; and the **complementary environmental and public benefits of natural and working landscapes**. It operates at two spatial scales: the *jurisdiction* level (for example, a county) and, nested within a jurisdiction, the *activity* level (for example, an activity designed to increase landscape carbon storage—say, planting hedgerows—implemented on a parcel).

- The **landscape carbon stock** is the total amount of carbon stored in soils and in woody and herbaceous vegetation. Some land management and agricultural activities can increase these stocks, drawing carbon dioxide out of the atmosphere; others, such as the development of natural lands for agriculture or urban uses, can result in a net release of carbon from soils and vegetation to the atmosphere.
- Several sources of **land-based emissions of the greenhouse gases methane and nitrous oxide** are evaluated in this guide: methane emissions from wetlands and rice fields, and nitrous oxide emissions from croplands and grasslands. Both methane and nitrous oxide are potent greenhouse gases, and their emission rates are influenced by land management and agricultural practices and the type of land use.
- The **complementary benefits** of natural and working landscapes are a collection of quantifiable values provided by the land and what it supports. Activities designed to increase landscape carbon stocks or reduce land-based greenhouse gas emissions can affect these complementary benefits. The guide evaluates 18 benefits, such as pollution mitigation, wildlife habitat and groundwater recharge.

To demonstrate the application of the methodology to a specific jurisdiction, the guide uses Merced County, California, as a case study. More than 95% of the county's 1.27 million acres are devoted to food and fiber production, with 2016 agricultural revenues totaling $3.45 billion.[1] Merced County is also developing rapidly; its population is expected to increase 50% by 2040. Given this rate of growth, county and local governments and landowners will face important land use decisions regarding residential and industrial development and natural and working lands.

The methods and findings presented in this guide are designed to support the development of jurisdiction-level climate and land use plans and greenhouse gas accounting by identifying the potential greenhouse gas reductions and complementary benefits that could be achieved through land management, conservation and land use decisions. Likewise, landowners can also benefit from this information.

This guide is organized around the seven elements of the methodology (Figure ES.1). The methodology is designed such that it can be readily adapted to other jurisdictions. The "Using this guide" section summarizes the resources and expertise required to implement the methodology in another jurisdiction.

© Erika Nortemann/The Nature Conservancy

1 2016 Report on Agriculture, Merced County Department of Agriculture, available at https://www.co.merced.ca.us/151/Crop-Statistics-Reports.

Inventory
Develop jurisdiction-level estimates for landscape carbon stocks and land-based greenhouse gas emissions

Baseline reference scenario
Extrapolate past rates of change for landscape carbon stocks and land-based emissions to provide basis for estimating greenhouse gas reduction potential

Complementary benefits assessment
Quantify the per-acre benefits provided by natural and working lands

Forecasting
With the TerraCount scenario analysis tool, develop scenarios of changes in land use and land management, and evaluate impacts on landscape carbon stocks, land-based emissions and complementary benefit values; evaluate indirect effects including leakage and potential changes to vehicle miles traveled

Implementation
With "activity sheets," support the implementation and documentation of the climate benefits of "nested activities"—changes to land-management and agricultural practices

Monitoring and reporting
Over time, monitor jurisdictional changes by updating the inventory and the complementary benefits assessment; track the climate benefits of nested activities

Recording information
Develop a database of all of the above information, providing transparency and facilitating analysis

▲ **Figure ES.1:** The seven elements of the methodology developed in this guide.

Section 1: Inventory

The first step is to estimate landscape carbon stocks and land-based greenhouse gas emissions across the entire jurisdiction—in this case, Merced County. These carbon stocks and emissions flows are estimated from publicly available, regularly updated spatial data sets on land cover, land use, crop type, climate zone and soil type, combined with well-documented conversion factors that relate these parameters to carbon concentrations and greenhouse gas emission rates. The data sets used allow for the inventory to be conducted at multiple points in time, which supports the second step in the process, the development of the baseline reference scenario.

In Merced County, the inventory process estimated total landscape carbon stocks at 49,567,396 metric tons of carbon dioxide equivalents ($MTCO_2e$)[2] in 2001 and 50,819,355 $MTCO_2e$ in 2014, and total annual land-based emissions of nitrous oxide and methane (not including livestock-related emissions) at 746,906 $MTCO_2e$ per year in 2001 and 691,339 $MTCO_2e$ per year in 2014.

Section 2: Baseline reference scenario

The baseline reference scenario is a linear extrapolation of past trends in landscape carbon stocks and land-based greenhouse gas emissions. It represents a business-as-usual scenario, in which carbon stocks and emissions continue to change at the same rate. It thus establishes a reference against which to estimate what effects efforts to alter that trajectory have on carbon stocks and emissions; those efforts include changes to land use policy and the implementation of agricultural and land management activities designed to increase landscape carbon stocks or reduce land-based greenhouse gas emissions.

In Merced County, the baseline reference scenario was based on the landscape carbon and land-based emissions estimates developed for 2001 and 2014. Extending that trend to 2030 suggests that countywide landscape carbon stocks will be 52,455,311 $MTCO_2e$ and land-based emissions will be 627,157 $MTCO_2e$. This results in a baseline net emission rate of 522,616 $MTCO_2e$ per year in 2030.

Section 3: Complementary benefits assessment

The complementary benefits assessment develops per-acre estimates of the value associated with 18 distinct benefits provided by natural and working landscapes (Table ES.1). The assessment draws on a range of data sources, detailed in the guide, to develop relationships between land cover and each of the 18 benefit types. Note that this list is not exhaustive—rather, it represents the benefit categories for which reliable data sets were available. Natural and working lands provide many more benefits than the team was able to quantify.

2 In this guide, carbon stocks and greenhouse gas emissions are expressed as metric tons of carbon dioxide equivalents, or $MTCO_2e$. Carbon dioxide equivalents provide a common denominator for tallying carbon stocks and flows and greenhouse gas emissions. See box in Section 1 of the main guide for more detail.

Table ES.1. The complementary benefit assessment includes 18 values in five categories.

Agricultural	Water	Human well-being	Biodiversity	Resilience
Agricultural land quality	Agricultural and urban water use	Flood risk reduction	Terrestrial connectivity	Flood risk attenuation
Crop value	Groundwater recharge	Air quality	Natural habitat area	Groundwater banking potential
	Water quality	Scenic value (land use changes in highly visible areas)	Conservation priority areas	Habitat stability
	Watershed integrity		Terrestrial habitat value	Climate connectivity
			Aquatic biodiversity	

Note that this list is not exhaustive—it represents the benefit categories for which reliable data sets were available. Natural and working lands provide many more benefits not listed here—such as employment—that could potentially be quantified.

Section 4: Forecasting: The TerraCount tool

TerraCount is a spatially explicit scenario analysis tool that enables users to explore the aggregate effects of various urban development patterns and the implementation of **activities**—changes in land management or agricultural practices at a landowner scale designed to reduce net greenhouse gas emissions—on landscape carbon stocks and land-based greenhouse gas emissions, as well as the complementary environmental and public benefits of natural and working lands across a jurisdiction.

The tool is configured with information generated by the processes in Sections 1, 2 and 3—landscape carbon stocks and emissions, the baseline trend in carbon stocks and emissions, baseline data and on complimentary benefits, and estimates of the per-acre impact of each activity on carbon stocks and emissions and on complimentary benefits. Users select which activities (Table ES.2) to implement and on how many acres, and also choose specific areas to conserve (no change in land cover) and to develop (conversion to urban land cover).

Table ES.2. Activity options in the TerraCount scenario analysis tool[3]

Improved nitrogen fertilizer management
Replacing synthetic nitrogen fertilizer with soil amendments
Oak woodland restoration
Cover crops
Mulching
Riparian restoration
Urban forestry
Hedgerow planting
Avoided conversion to croplands
Avoided conversion to urban
Compost application to grasslands
Native grassland restoration

3 See Appendix K for detail.

From those inputs, the tool estimates the total landscape carbon impact of the jurisdictional scenario; the landscape carbon impact of each activity included in the scenario; the impact on each complementary benefit value for the whole scenario; and the impact on each complementary benefit value from each activity included in the scenario. This section of the guide presents several example scenarios and the corresponding outputs generated by the tool. For example, for a scenario that assumes widespread planting of hedgerows (5,500 acres countywide) and cover crops (55,000 acres countywide), TerraCount estimated a cumulative increase in landscape carbon stocks of 796,771 $MTCO_2e$ over the period 2014-2030.

The version of the tool presented in the guide is configured for Merced County, but it is designed to be readily adapted to other jurisdictions. The source code is freely available.

Section 4 also discusses two issues related indirectly to alternative development scenarios and the implementation of activities. The first is the effect of development patterns on vehicle miles traveled and related GHG emissions. The second is leakage, which is a case in which an activity, or collection of activities, in one area—such as avoided conversion of grassland to urban land on a certain area of land—drives a countervailing change elsewhere, such as development in another area, thereby displacing emissions rather than yielding a net reduction.

Section 5: Implementation

A key objective of this project is to support landowners, land managers and local officials in efforts to implement activities, based on planning and accounting at a county scale. This section of the guide presents a system, called activity sheets, for standardizing the implementation and documentation of activities. It also suggests some general principles for processes to track all of the activities in a jurisdiction.

As noted above, landowners can increase landscape carbon stocks and reduce annual greenhouse gas emissions by engaging in activities, such as changes in land management and agricultural practices. Table ES.2 shows the list of 12 activities developed in this guide. Note that this list represents only a subset of the activities known to provide a climate benefit; for example, the list does not include conservation tillage and compost application to row crops.

An activity sheet is a one-page form with information that specifies, for a given activity on a particular land cover type (e.g., the planting of hedgerows on vineyard land), the following information: the monitoring and reporting guidance to be followed; the formulas to be used to generate estimates of greenhouse gas reductions; likely impacts on complementary benefit values; and any special considerations.

An activity sheet thus provides a common point of reference—both for landowners who are implementing (or considering implementing) activities and for administrators of the jurisdictional greenhouse gas inventory program, such as county staff.

Section 6: Monitoring and reporting

This section presents processes for documenting changes over time in landscape carbon stocks, land-based greenhouse gas emissions and complementary benefits values. It describes three main steps: repeating the jurisdictional inventory (Section 1); repeating the complementary benefits assessment (Section 3); and evaluating the changes in landscape carbon stocks associated with activities (Section 5).

Section 7: Recording information

The final section of the guide presents design considerations for a database that stores data generated through the processes described in Sections 1 through 6, makes that information available to collaborators and the public and facilitates analysis and reporting.

Project direction and funding

The Nature Conservancy California directed the work presented in this guide, in partnership with the California Department of Conservation, Merced County, Tukman Geospatial, the Climate Action Reserve and the Natural Resource Ecology Laboratory at Colorado State University, with input and guidance from many advisers and collaborators (see Acknowledgments section). The work was supported by a grant from the California Department of Conservation and a matching grant from The Nature Conservancy, as well as a grant from Next 10.

Introduction

David Bunn, Director, California Department of Conservation

The state of California is recognized globally as one of the most ambitious and aggressive leaders in the fight against climate change. Policies enacted in recent years to reduce petroleum combustion from transportation, increase energy efficiency and vastly increase the state's renewable energy portfolio are already having a profound impact on statewide greenhouse gas (GHG) emissions.

Stewardship of landscapes will also play a critical role in combating climate change. On this front, the state is engaged in efforts to reduce emissions and store more carbon in natural and working landscapes, with an initial minimum goal of contributing a cumulative 15 to 20 million $MTCO_2e$ to the state's 2030 emissions reduction goals.[4]

Natural and working landscapes can store carbon and reduce net GHG emissions in many ways. Restoration of riparian corridors and other ecosystems can store vast amounts of carbon in woody vegetation and soils. Land conservation can retain existing landscape carbon stocks. And the implementation of a variety of land management activities can take advantage of the capacity of these landscapes to store even more carbon.

The fate of California's natural and working landscapes is determined mainly at the local level—through, for instance, local master plans, agricultural conservation plans (including agricultural mitigation ordinances), climate action plans and decisions by private landowners.

For California to meet its ambitious GHG reduction targets, state and local governments must work together as partners with landowners and land managers. In that spirit, the state Department of Conservation has joined with The Nature Conservancy and the county of Merced to produce the GHG accounting method and scenario assessment tool presented in this guide.

The tool and methods are designed to help any local government evaluate how much carbon is stored today in the land cover and land use types in its jurisdiction, and assess how changes in land management practices and land use impact carbon stocks, GHG and the variety of other benefits provided by natural and working landscapes—flood risk reduction, groundwater recharge, agricultural productivity, habitat connectivity and more.

While this guide uses Merced County as an illustrative example, the accounting method and tool can readily be adapted for use in other counties and jurisdictions across California.

The Department of Conservation is pleased to provide these accounting methods and tool to counties, local planners and landowners throughout the state and looks forward to hearing from local partners about potential refinements. The department plans to periodically update the accounting methods, assumptions and parameters of the tool as new science and information warrants, and looks forward to working with local governments and landowners to support planning efforts and land management and conservation activities that benefit landowners and the climate.

© Erika Nortemann/The Nature Conservancy

4 California's 2017 Climate Change Scoping Plan, California Air Resources Board (2018), available at https://www.arb.ca.gov/cc/scopingplan/scopingplan.htm.

Using this guide

The tool and methods presented in this guide are designed to help local governments, landowners, planners and land managers to understand how land use, climate benefits and other environmental and public benefits are linked, and to incorporate that knowledge into decisions about land use and land management.

The guide describes a methodology for jurisdiction- and activity-level accounting and scenario analysis of three climate-relevant variables: **landscape carbon stocks**; **land-based emissions of the greenhouse gases methane and nitrous oxide**; and the **complementary environmental and public benefits of natural and working landscapes**.

- The **landscape carbon stock** is the total amount of carbon stored in soils and in woody and herbaceous vegetation. Some land management and agricultural activities can increase these stocks, drawing carbon dioxide out of the atmosphere; others, such as the development of natural lands for agriculture or urban uses, can result in a net release of carbon from soils and vegetation to the atmosphere.
- The **land-based emissions of the greenhouse gases methane and nitrous oxide** evaluated in this guide include methane emissions from wetlands and rice fields and nitrous oxide emissions from croplands and grasslands. Both methane and nitrous oxide are potent greenhouse gases, and their emission rates are influenced by land management and agricultural practices and by the type of land use. Note that the guide does not account for direct emissions from livestock or from manure management.[5]
- The **complementary environmental and public benefits** of natural and working landscapes are a collection of quantifiable values provided by the land and what it supports. This guide evaluates 18 benefits, such as pollution mitigation, wildlife habitat and groundwater recharge.

The methodology operates at two spatial scales: the *jurisdiction* level (for example, a county) and, within a jurisdiction, the *activity* level (for example, an activity designed to increase landscape carbon storage—say, planting hedgerows—implemented on a parcel). The jurisdictional and activity-level accounting systems are complementary.

The methodology supports land-based greenhouse gas reduction strategies, which are complementary to other strategies to mitigate climate change, including reducing short-lived climate pollutants, reducing vehicle miles traveled and other transportation-related emissions, reducing emissions related to energy use and so on.

In this guide, the methodology is applied to Merced County, California, but it is designed to be readily applied to other jurisdictions (for details, see "Resources and expertise needed," below, and Sections 1 through 4).

Resources and expertise needed

This guide describes in general terms—with additional detail in the appendices—the steps required to develop inventories of landscape carbon stocks, land-based greenhouse gas emissions and the complementary benefits of natural and working landscapes. The information from these inventories is then used to configure a scenario analysis tool, TerraCount.

Executing these steps requires several types of expertise. In general, the GIS and data manipulation tasks described in the guide require intermediate-level knowledge of GIS and of working with remotely sensed data sources. Some elements of the process, such as developing custom classifications to improve land cover data accuracy (see Section 1), require more advanced skills and experience.

Key GIS and data analysis skills:

- Ability to download and register web-available spatial data into a geographic information system such as ArcGIS.
- Ability to develop spatial data where needed by drawing on sources of remotely sensed data (LANDSAT, aerial photos, etc.).
- Ability to perform qualitative analysis of spatial data sources, including comparing multiple sources of data, to identify cases in which additional work to develop and refine the data is required.
- Ability to link spatial data to tabular data programs, such as Microsoft Access, and to:
  - » develop queries to summarize data
  - » link other non-spatial data to develop reports
  - » modify data in queries if needed to express growth or other changes that may be associated with certain data elements, such as forests
- Ability to synthesize and report on data findings.

5 Other efforts do attempt to quantify livestock-related greenhouse gas emissions. Appendix B of this guide includes a bibliography of dairy emissions estimation methods from the research literature. See also the California Air Resources Board Short-Lived Climate Pollutant Strategy: https://www.arb.ca.gov/cc/shortlived/shortlived.htm.

Additional skills

- Ability to identify any existing inventory data (for example, in California, a statewide inventory based on LANDFIRE had been conducted), consult with the pertinent agencies or experts, obtain the relevant data and link it with the spatial data sets.
- Ability to develop inventory estimates for land cover types for which spatial data sources such as LANDFIRE are not available. This may include literature searches for methodologies and coefficients, adaptation of related data sources, and the development of novel quantitative methodologies for estimating the inventory.

Limitations and challenges

While this guide seeks to provide guidance on how to account for land-based carbon and greenhouse gas reductions at a county scale, there are limitations and potential challenges associated with this framework for consideration.

Accounting boundaries and GHG reduction activities

This project focuses on land-based biological carbon and GHG reductions associated with different land management, restoration and conservation activities, which generally corresponds with the scope of the Natural and Working Lands Sector in California's 2017 Climate Change Scoping Plan.[6] The scope of greenhouse gases for this sector include carbon dioxide, methane and nitrous oxide.

Note that the methods presented here do not assess greenhouse gas emissions associated with livestock operations; such operations include dairies, feedlots, poultry farms and grazing livestock.

With the exception of exploring the relationship between land conservation, development and greenhouse gas emissions associated with vehicle miles traveled, the guide does not account for life cycle emissions or other indirect greenhouse gas emissions/reductions associated with land-based activities or other economic sectors, including biomass energy, landfill methane and livestock. Some resources for accounting for these activities can be found in Appendix B.

This framework and tool are designed to be modular and therefore, additional activities, sectors, and/or gases could be added to future iterations or included as part of a more comprehensive, multi-sector analysis of GHG reduction potential.

Scale of monitoring and improved accuracy achieved through jurisdictional accounting

The guidance in this guide is focused on developing a jurisdictional baseline, comprising an inventory and projection of carbon stock change and certain annual GHG emissions, and developing a monitoring approach against which specified activities aimed at reducing emissions and/or increasing carbon stocks can be measured. Where possible, the inventory and monitoring approaches are based on regional data sets (e.g., LANDFIRE) that are updated over time and provide a consistent approach to data estimation. However, many of the activities aimed at reducing emissions and/or increasing carbon stocks do not result in a changed land cover class that otherwise would affect inventory estimates. This is may be because the scale of the activity is too small to result in a land class change (e.g., hedgerow development within a land class identified as row crops) or because the emissions associated with a particular land class have been reduced as the result of specific management actions (e.g., the land class remains in row crops, but management actions reduce N_2O emissions by 40%).

The approach to monitoring requires a hybrid approach of developing general inventory estimates through remote sensing and modifying the estimates in places where activities have been applied that change the default assumptions for either carbon stocks or GHG emissions. Future jurisdictional monitoring efforts are, therefore, a sum of carbon stocks and default emissions associated with default conditions for each land cover class adjusted by summing up the changed stocks and emissions derived from the activity estimates. In any case, the precision and accuracy of estimation at the jurisdiction level are superior to those of the activity scale, as compensation for over- or underestimation is realized through the combination of multiple activities.

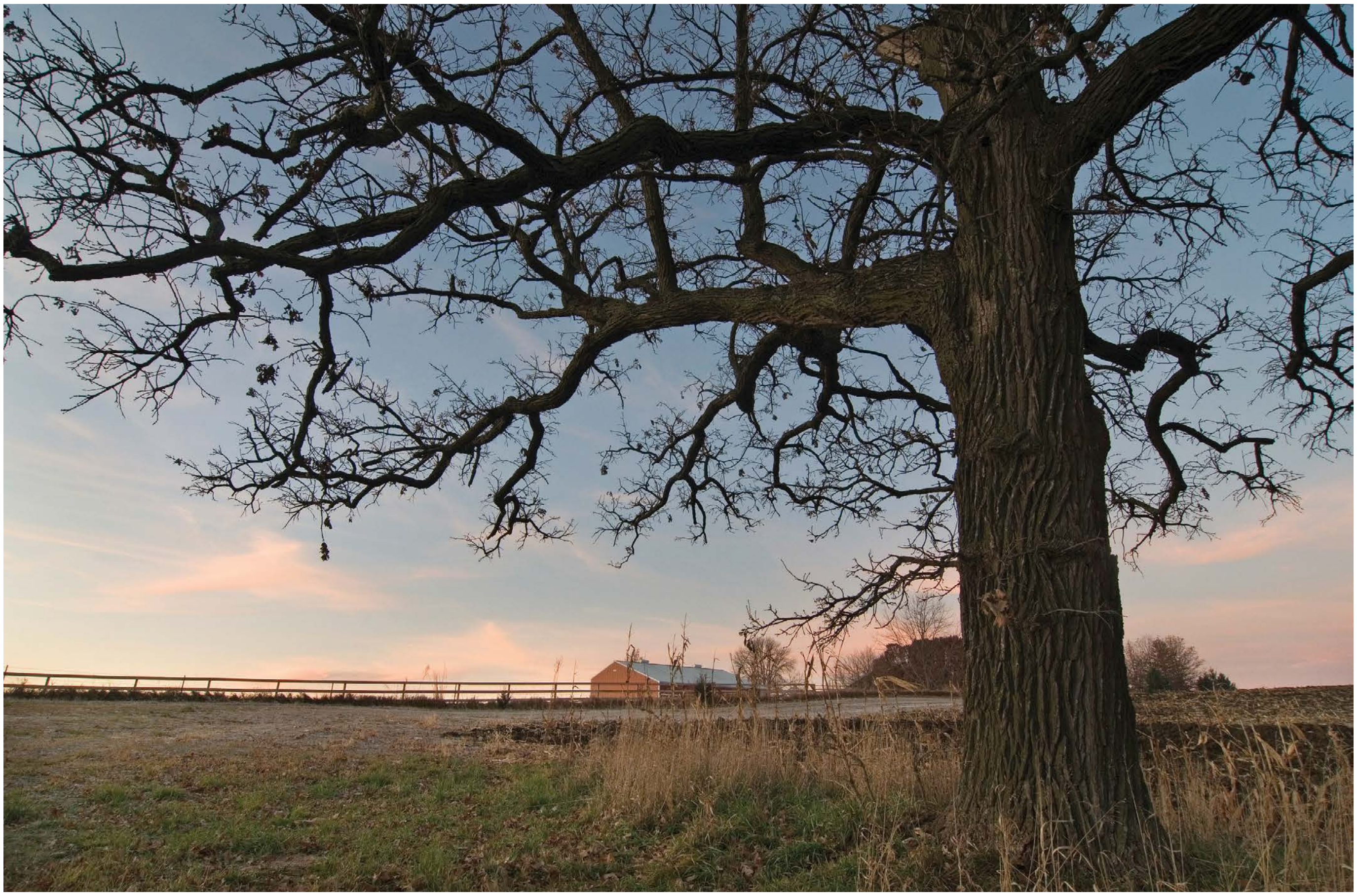
Complementary benefits assessment

The quantification of complementary benefits is limited by data availability. For many co-benefits—such as soil health—good spatial data doesn't exist.

The complementary benefit assessment is only as good as the data that supports it. The assessment uses the best available data, but data sets range in quality, completeness, resolution and precision.

The land cover data (LANDFIRE and custom classification) that underpins much of our complementary benefit assessment is regional, medium-resolution (30-meter pixel) data. This data set is intended for regional-scale analysis—not for parcel-level or landowner-level analysis and decision-making.

6 See https://www.arb.ca.gov/cc/scopingplan/scoping_plan_2017.pdf.



© Chris Helzer/The Nature Conservancy

Parts of the co-benefit analysis rely on assumptions about processes that may oversimplify natural processes.

The accounting framework and tool in this guide identify several factors, or proxies, to assess potential resilience to climate change that could be associated with the identified GHG reduction activities. These proxies include habitat stability and climate connectivity, for natural resilience, and flood risk attenuation and groundwater banking potential, for social and built resilience. These proxies are not intended to be exclusive. Additional or different proxies for resilience may be used or included in future iterations of the tool, depending on the specific goals of the users or how climate resilience may be defined.

Potential climate change impacts on forecasted GHG reductions

While historical effects of climate change are included in the baseline reference scenario, the potential effects of climate change on the GHG activities are not included. Inclusion of potential future climate impacts were beyond the scope of this project. Updates to the baseline reference and GHG reduction scenarios over regular intervals (e.g., every 10–15 years) can help address this limitation and serve as a way to integrate climate impacts over time (see Section 2).

Carbon inventory and land cover classifications

A key requirement for estimating landscape carbon stocks and emissions flows is the use of a comprehensive, regularly updated spatial data set of land use and land cover. This project relies on a time series of LANDFIRE products (Landscape Fire and Resource Management Planning Tools), which are produced by a multi-organizational program led by the U.S. Forest Service, the U.S. Department of Interior, and The Nature Conservancy. LANDFIRE products are created for the entire United States at 30-meter resolution and are updated on a two-year cycle. Due to the scale at which LANDFIRE products are produced, it is unrealistic to expect very high accuracy at every pixel or even at the landscape level. While LANDFIRE is well suited to accurately identifying certain classes of land uses, inconsistencies and inaccuracies are inevitable when working at the county scale. We provide guidance on how to determine whether such issues will lead to an unacceptable impact on the results of a project and what steps are required to correct them.

SECTION 1

Landscape carbon inventory

Jurisdictional GHG inventory

Introduction: Jurisdictional accounting

The methods presented in this guide support inventories of landscape carbon stocks and nitrous oxide and methane emissions at the county scale, an example of what is known as the "jurisdictional" approach to carbon and greenhouse gas emissions accounting.

Jurisdictional accounting operates at the level of political jurisdictions, such as a county, a collection of counties, or a state. Jurisdictional accounting is distinguished from accounting at the "activity" or "project" level primarily by scale and by the types of accounting methods used.

Jurisdictional accounting is typically applied at a fairly large scale—tens of thousands of acres or greater. Merced County, the example presented in this guide, covers 1.27 million acres. By contrast, activity-level accounting assesses the amount of carbon stored by discrete parcels of land, typically where land managers are undertaking activities designed to increase carbon sequestration or reduce nitrous oxide and methane emissions. Such parcels can be any size but are typically on the scale of dozens to thousands of acres.

Because jurisdictional accounting assesses carbon and emissions across a large area, it is usually based on large-scale spatial data sets, such as remotely sensed land cover data. The method presented here uses data from the LANDFIRE program, a long-term, satellite-based land cover mapping effort supported by the U.S. Department of the Interior and the U.S. Department of Agriculture. That information is supplemented with data from a number of other sources, detailed below.

While activity-level accounting may also be informed by satellite data, it typically involves ground-level monitoring and verification (for regulatory compliance or to meet the needs of investors in carbon storage projects, for instance).

Jurisdictional and activity-level accounting systems are complementary. In the methodology presented here, activity-level accounting is used to improve the accuracy of jurisdiction-level estimates.

Box: Units, stocks and flows

In this guide, inventories and flows of carbon dioxide and other greenhouse gases are counted using a common unit: metric tons of carbon dioxide equivalents, or $MTCO_2e$. Carbon dioxide equivalents provide a common denominator for tallying stocks and flows of carbon in solid forms such as biomass (C), as well as methane (CH_4) and nitrous oxide (N_2O). Because methane and nitrous oxide are more potent greenhouse gases than CO_2, one ton of either is equivalent to many tons of CO_2, according to the following conversions:

Table 1.1. Carbon dioxide equivalent (CO_2e) conversion factors

1 metric ton (MT) of ...	Metric tons of carbon dioxide equivalent ($MTCO_2e$)
Carbon (C)	3.67
Nitrous oxide (N_2O)[7]	298
Methane (CH_4)[8]	25
Dry biomass[9]	1.84

Important note regarding stocks and flows

Increases in landscape carbon stocks and decreases in emissions of greenhouse gases both have a positive effect on the climate, by reducing net emissions of greenhouse gases to the atmosphere. By the same token, decreases in landscape carbon stocks and increases in emissions have a negative climate effect. In this guide, increases in carbon stocks are also referred to as "CO_2 removals."

7 The Global Warming Potential value for nitrous oxide follows the IPCC Fourth Assessment Report (available at www.ipcc.ch).
8 The Global Warming Potential value for methane follows the IPCC Fourth Assessment Report.
9 Biomass, such as the wood in trees and shrubs, is roughly 50% carbon when dried. Schlesinger WH. 1991. *Biogeochemistry: An Analysis of Global Change*. San Diego: Academic Press (fifth printing, 1995).

LANDFIRE data: Overview

The jurisdictional inventory method outlined here is designed to quantify major reservoirs and flows of landscape carbon. The landscape of Merced County is used to illustrate the inventory methodology, but the methods can be readily applied to other jurisdictions.

LANDFIRE spatial land cover data provides the foundation of the inventory method presented here. LANDFIRE data is also the foundation of the statewide inventory method for landscape carbon developed for the California Air Resources Board (CARB),[10] and the inventory presented here builds on that work. LANDFIRE data is freely available (at www.landfire.gov), well documented and widely used, and data collection is repeated at regular two-year intervals. (Current plans call for new data to be released annually beginning in 2018.)

LANDFIRE data sets are available for the entire United States at a resolution of 30 meters—meaning that each "pixel" on the land cover map generated from the LANDFIRE information is a 30-meter-by-30-meter square.

Each LANDFIRE pixel includes data on the existing vegetation type, the amount of canopy cover and the height of the vegetation. From this information, land cover categories can be developed. The Merced County project team used LANDFIRE data to distinguish six general land cover categories—forest, shrubland, grassland, urban forest, agriculture, and non-vegetated land and water—as well as dozens of subcategories, such as mixed evergreen woodland and Southern California mixed oak woodland and savanna. Subcategories can then be further characterized by the density and size of the woody vegetation—trees or shrubs—detected by the imagery used in the project.

Carbon is sequestered in multiple places, or carbon pools, in landscapes—in the trunks, branches and roots of living trees, in dead wood and litter (e.g., dead leaves) on the ground, in the soil, in shrubby vegetation and so on. For each carbon pool, methods specified below are used to translate the LANDFIRE land cover information for each pixel into a figure for the mass of carbon in that pixel. The mass of carbon in all the carbon pools in each pixel in the county can then be added together to generate a figure for the total mass of carbon sequestered in the county's landscapes.

Building on the LANDFIRE data foundation: Custom classifications

The LANDFIRE land cover classifications are not 100% accurate. They may be sufficiently accurate across an entire jurisdiction to use without modification (with "sufficiently accurate" determined by the needs and capacities of the jurisdiction and the entity doing the inventory work). But it might make sense to improve the accuracy of the inventory by correcting or replacing the LANDFIRE data through "custom classifications."[11]

The first step in determining whether such modifications are warranted is an initial assessment of the magnitude of the potential improvement in accuracy that such modification would yield.

Two types of potential modifications should be considered: first, correcting errors in LANDFIRE land cover classifications, and, second, the need for a more precise characterization of land cover and associated carbon stocks—for instance, to account for changes in landscape carbon over time that LANDFIRE data cannot detect or to capture in the data a particular land cover type of local importance.

Other important initial considerations include the availability of resources (funding and expertise) to do the custom classification work and the importance of producing a highly accurate inventory for the jurisdiction as a whole and for each land cover type (that is, how much accuracy matters in the local context).

Errors in land cover classification result from the LANDFIRE data being wrong—for instance, showing as grassland an area that is actually shrubland. These errors can be identified in many ways. Some approaches include:

1. Compare the LANDFIRE data to independent spatial data sources such as county field-level pesticide use permits[12] or other local government-produced maps/data.
2. Consult local experts (in, for instance, agriculture, forestry or ecology) for review of the land cover classifications based on their knowledge of the county's land use.
3. Visually compare LANDFIRE classifications to satellite imagery.

---

10 The CARB inventory method is described in: Battles JJ, Gonzalez P, Collins BM et al. 2013. California Forest and Rangeland Greenhouse Gas Inventory Development. California Air Resources Board, Sacramento (Final Report, Agreement 10-778). Available at https://www.arb.ca.gov/cc/inventory/pubs/battles%20final%20report%2030jan14.pdf. The inventory methods were expanded in: Saah D, Battles J, Gunn J et al. Technical improvements to the greenhouse gas (GHG) inventory for California forests and other lands. Submitted to: California Air Resources Board, Agreement #14-757, 2015. 55 pages. Available at https://www.arb.ca.gov/cc/inventory/pubs/arb_pc173_v004.pdf.

11 See Appendices C and D for more information on custom classifications.

12 See, for instance, http://www.co.merced.ca.us/2132/Pesticide-Use-Reporting.

© Sherry Smith/istock

In general, error detection efforts should seek to identify large groups of misclassified pixels that will have a significant impact on the jurisdiction-wide carbon inventory. Low-density "speckling" of incorrect pixels is inevitable in this type of satellite-based land cover classification and in most cases will not have a major impact on the jurisdiction-wide inventory.

Three examples of error correction from Merced County:

- LANDFIRE data incorrectly classified more than 130,000 acres of grassland in the eastern portion of the county as shrubland. Since shrubland has a higher carbon density than grassland, and 130,000 acres is a significant portion of the county land area, it was necessary to correct this error with a custom classification.
- Water: Most water area in the county is in the form of reservoirs. The surface area of these reservoirs fluctuates during the year as well as from year to year. Because of this complexity, custom classification was used to define representative polygons for the water surface area in 2001 and 2014.
- Urban forest: LANDFIRE data in urban areas included a number of errors—for instance, classifying parks, school fields and cemeteries as grassland or forest. Custom processing (e.g., comparison with satellite photo imagery) and data on urban areas from the U.S. Census Bureau were used to define a GIS polygon for each contiguous urban area in the county.

The other general type of custom classification involves developing a more precise characterization of the land cover type and its carbon stocks.

This type of custom classification is useful for representing cropland landscape carbon storage more accurately—for instance, by improving the precision of boundary definition for land cover types.

In the Merced County example, the data sources and methods used to generate spatial data on sub-types of agricultural land were as follows:

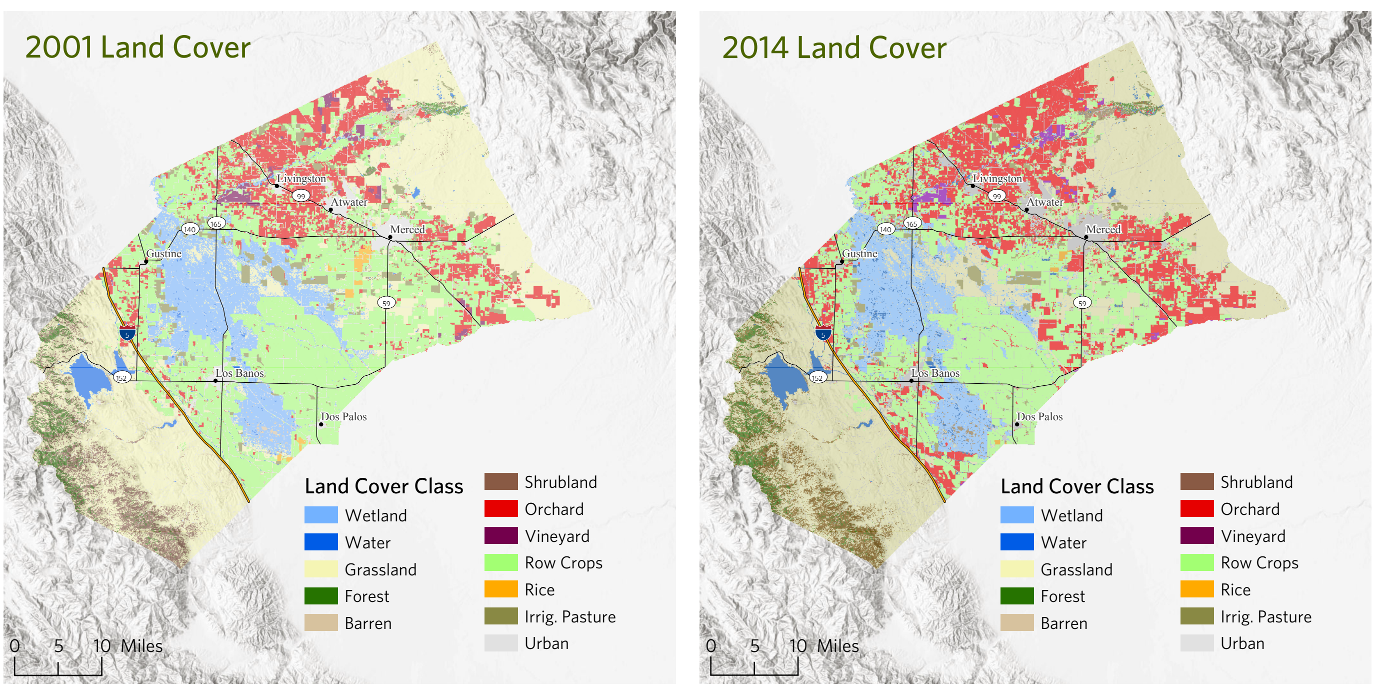
- GIS data on all field boundaries and orchard crop types was collected from the state Pesticide Use Reporting program.[13] The program mapped most cropland in Merced County.
- Data on annual crop types was extracted from the USDA Cropland Data Layer.[14]
- The result was spatial data on five general crop categories (see map below): orchards, vineyards, annual row crops, rice and irrigated pasture.[15]

For the Merced County inventory, three categories of LANDFIRE land cover classifications were suitable as is: barren land, forestland and shrubland. Together, these land cover types account for about 9% of the land in the county. Nine custom classifications were performed for the remaining land cover types: wetland, grassland, irrigated pasture, orchard land, rice land, row crop land, urban land, vineyard land and open water (Table 1.2, Figure 1.1).

13 See https://www.cdpr.ca.gov/docs/pur/purmain.htm.
14 USDA-NASS. 2009–2014. Cropland Data Layer. Published crop-specific data layer [Online]. Available at https://nassgeodata.gmu.edu/CropScape (accessed May 2016). USDA, National Agricultural Statistics Service, Washington, DC.
15 Management practices and nitrogen application rates vary somewhat within each of these categories; this study did not attempt to capture those variations.

Table 1.2. General land cover classes by data source in Merced County inventory

General Land Cover Class	Data Source	2001 acres	2014 acres	Change	% Change
Barren	LANDFIRE	47,211	47,930	719	1.5%
Forest	LANDFIRE	19,121	19,012	-109	-0.6%
Shrubland	LANDFIRE	46,240	45,219	-1,021	-2.2%
Wetland	Custom classification	127,558	116,629	-10,929	-8.6%
Grassland	Custom classification	401,476	420,087	18,612	4.6%
Irrigated pasture	Custom classification	39,600	25,039	-14,562	-36.8%
Orchard	Custom classification	135,633	200,593	64,960	47.9%
Rice	Custom classification	4,754	1,211	-3,543	-74.5%
Row crops	Custom classification	370,517	303,379	-67,137	-18.1%
Vineyard	Custom classification	45,587	51,207	5,619	12.3%
Urban	Custom classification	11,001	9,849	-1,151	-10.5%
Water	Custom classification	16,561	25,147	8,587	51.9%
	Total:	**1,265,258**	**1,265,303**	**45**	



▲ **Figure 1.1.** Land cover types for the 2001 and 2014 inventories for Merced County. Land cover types shown here reflect the results of the custom classification process.

The maps on the preceding page show the land cover types for the 2001 and 2014 inventories, after custom classifications have been applied.

Note that some observed changes appear to be transient. For instance, wetland area in 2014 was 9% lower than in 2001. This appears to be due to differences in precipitation (2014 was drier than 2001), which led to some areas of wetland being classified as grassland.

Converting LANDFIRE data and custom classifications to landscape carbon stock and emissions estimates

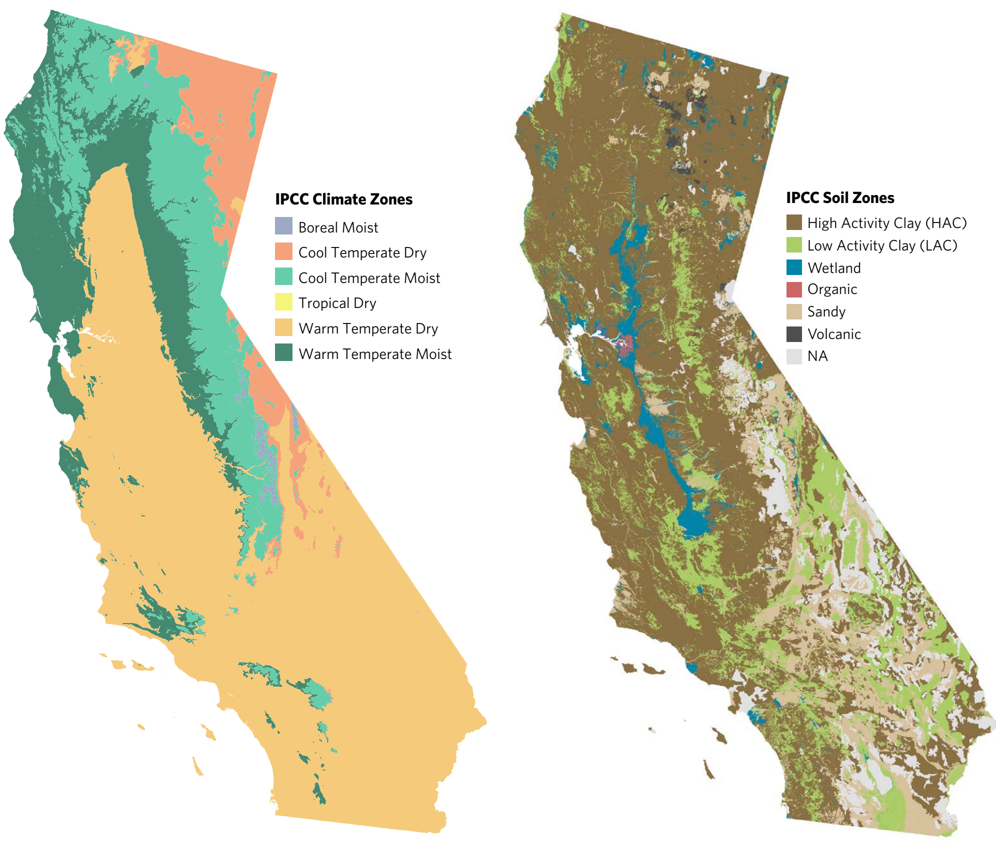
A range of methods are available for translating land cover data to estimates of landscape carbon stocks and emissions. The Merced County example illustrates several data sources and analytic approaches, supported by references in scientific literature, that can be employed.

These approaches fall into three main categories: soil carbon stocks, non-soil carbon stocks (mainly plant biomass) and greenhouse gas emissions.

Soil carbon

For all land cover classes, soil carbon is estimated using reference values that may then be adjusted to account for management or conservation activities designed to increase carbon storage.

The reference soil carbon values are based on spatial data on soil type and climate, combined with land cover data and, where applicable, cropping information. (Land cover and cropping data are developed as described above.) Soil data from the national Soil Survey Geographic Database[16] and long-term weather data[17] were used to generate spatial data sets of IPCC soil zones and IPCC climate zones[18] (Figure 1.2).



▲ **Figure 1.2.** IPCC climate zones and soil zones for California.

16 Natural Resources Conservation Service. 2015. Web Soil Survey. United States Department of Agriculture, Available at https://websoilsurvey.nrcs.usda.gov.

17 Three weather data sources were used: (1) Hijmans RJ, Cameron SE, Parra JL et al. 2005. Very high resolution interpolated climate surfaces for global land areas. *International Journal of Climatology* 25: 1965–78. 2005. Available at https://doi.org/10.1002/joc.1276. (2) Zomer RJ, Trabucco A, Bossio DA et al. 2008. Climate Change Mitigation: A Spatial Analysis of Global Land Suitability for Clean Development Mechanism Afforestation and Reforestation. *Agric. Ecosystems and Envir.* 126: 67–80. Available at https://doi.org/10.1016/j.agee.2008.01.014. (3) Zomer RJ, Bossio DA, Trabucco A et al. 2007. Trees and Water: Smallholder Agroforestry on Irrigated Lands in Northern India. Colombo, Sri Lanka: International Water Management Institute. 45 pages. (IWMI Research Report 122). Available at http://www.iwmi.cgiar.org/publications/iwmi-research-reports/iwmi-research-report-122.

18 IPCC. 2006. 2006 IPCC Guidelines for National Greenhouse Gas Inventories, Vol 4. Agriculture, Forestry and Other Land Use. H.S. Eggleston, L. Buendia, K. Miwa, T. Ngara, and K. Tanabe (eds.). Japan: IGES, Prepared by the National Greenhouse Gas Inventories Programme. Available at https://www.ipcc-nggip.iges.or.jp/public/2006gl/vol4.html.

These data sets were then combined with land use data (from the sources described above) to generate reference soil carbon values for the top 20 centimeters[19] of soil, for each combination of IPCC soil zone, IPCC climate zone and land cover type in the county.[20]

For croplands and grasslands, the analysis incorporated additional steps to enable more accurate assessments of carbon stocks associated with cropping practices, and to account for changes in soil carbon stocks due to agricultural and land management activities.

For all croplands, reference soil carbon stocks incorporated cropping data from the USDA Cropland Data Layer,[21] with typical rates of nitrogen (N) fertilizer[22] and typical cultural practices for California.[23]

For grasslands and irrigated pasture, reference soil carbon conditions assumed extensive grazing and no application of fertilizer or compost.

With these parameters defined, carbon in the top 20 centimeters of soil in each pixel was modeled using COMET-Planner,[24] via an interface for spatial data.

For instance, high-activity clay soil (common in Merced County) in the "warm temperate dry" climate zone with a land use classification of annual row crops was assigned a reference soil carbon stock of 25 $MTCO_2e$ per acre. Soil type has a large influence on capacity for carbon storage. The full list of the reference carbon stock values is provided in Appendix C.

A variety of agricultural practices (referred to in this guide as "activities") have been demonstrated to increase soil carbon stocks when implemented over extended periods. These activities include the application of organic amendments such as compost or manure; the planting of seasonal cover crops; and a variety of other practices.

The effects of implementing these and other activities are presented in the "activity sheets" section (see Section 5) and can be modeled in the TerraCount tool, described in Section 4.

In addition, the effects of two agricultural practices—reduced tillage and manure application—known to have been widely implemented in Merced County were incorporated into the 2001 and 2014 inventories.

Based on information from a survey of Merced County farmers conducted by the Conservation Tillage Information Center,[25] reduced tillage was estimated to be practiced on 26% of the annual cropland in the county. It was assumed that reduced tillage had been practiced on these lands for an average of 10 years,[26] yielding an average increase over the reference value of 0.73 $MTCO_2e$ of soil carbon per acre, based on figures from COMET-Planner.

The extent of manure application in the county was estimated at 46%, based on data from a survey of Merced County farmers conducted for this study (see Appendix E) as well as statistics on average manure production in the county.[27] It was assumed that manure had been applied for an average of 10 years on these lands, yielding an average increase over the reference value of 2.04 $MTCO_2e$, based on figures from COMET-Planner.

For the 2001 and 2014 Merced County inventories, sufficiently precise quantitative information was not available on the use of conservation practices on land cover types other than annual row crops. So, for all other land cover types, the reference carbon stock figures were used without modification.

Other carbon pools

Carbon in forest, shrubland and barren land cover vegetation

For forest, shrubland and barren land cover types, LANDFIRE data on vegetation type, size and density was converted to CO_2e values using the methods developed by Saah et al. for CARB.[28] These methods yield estimates of carbon stocks in the following pools:

- Above- and belowground live and dead trees and woody debris
- Litter and duff
- Woody shrubs

19 Following the Comet-Farm standard (see below).
20 See www.comet-planner.com and: Swan A, Easter M, Chambers A et al. 2017. COMET-Planner: Carbon and Greenhouse Gas Evaluation for NRCS Conservation Practice Planning. Available online at http://comet-planner.nrel.colostate.edu/COMET-Planner_Report_Final.pdf. For information on the IPCC soil and climate classifications, see https://www.ipcc-nggip.iges.or.jp/public/2006gl/pdf/4_Volume4/V4_03_Ch3_Representation.pdf#page=37&zoom=100,-10,793.
21 USDA-NASS. 2009–2014. Cropland Data Layer. Published crop-specific data layer. Available at https://nassgeodata.gmu.edu/CropScape (accessed May 2016). USDA, National Agricultural Statistics Service, Washington, DC.
22 USDA-ERS. 2014. Agricultural Resource Management Survey (ARMS). U.S. Department of Agriculture, Economic Research Service, Washington DC. Available at https://www.nass.usda.gov/Surveys/Guide_to_NASS_Surveys/Ag_Resource_Management.
23 USDA-NASS. 2010. Field Crops: Usual Planting and Harvesting Dates, October 2010. U.S. Dept. of Agriculture, National Agricultural Statistics Service, Washington, DC. Available online at http://usda.mannlib.cornell.edu/usda/current/planting/planting-10-29-2010.pdf.
24 COMET-Farm and COMET-Planner are widely used, publicly available agricultural carbon inventory and accounting tools developed by USDA and Colorado State University. http://cometfarm.nrel.colostate.edu and www.comet-planner.com.
25 CTIC. 2004. National Crop Residue Management Survey Summary. Conservation Tillage Information Center, West Lafayette, IN. See http://www.ctic.purdue.edu/CRM.
26 COMET-Planner estimates are 10-year predictions. Additionally, the most recent available tillage data is from 2004; it was assumed that rates did not change in the 2004-2014 period.
27 National Ag Statistics Service (NASS). 2018. Quick Stats Database. https://quickstats.nass.usda.gov (accessed January 28, 2018).
28 Saah D, Battles J, Gunn J et al. 2015. Technical improvements to the greenhouse gas (GHG) inventory for California forests and other lands. Submitted to California Air Resources Board, Agreement #14-757. 55 pages. Available at https://www.arb.ca.gov/cc/inventory/pubs/arb_pc173_v004.pdf.

The Saah et al. methodology covers other LANDFIRE land cover types, including urban vegetation, shrubs and grasslands. In the Merced County example, the custom methods described below were used for these land cover types. But in other counties, it may be appropriate to use the Saah et al. methods more broadly. (See above for a discussion of when custom classification methods may be appropriate.)

Orchard and vineyard woody biomass

The mass of carbon stored in each acre of orchard and vineyard land—the carbon in trees and vines, and their roots—was estimated from values published in the research literature for the predominant orchard crops in Merced County (Table 1.3).

Table 1.3. Per-acre woody biomass $MTCO_2e$ values used in the analysis for orchard and vineyard land cover types.

Crop	$MTCO_2e$/acre
Almonds	24.1[29]
Walnuts	34.9[30]
Pistachios	34.9[31]
Peaches	29.1[32]
Grapes	4.3[33]

Herbaceous carbon in grasslands, wetlands, rice, annual row crops and irrigated pasture

The above- and belowground biomass in grasslands, wetlands, rice, annual row crops and irrigated pasture is transient. That is, the presence of biomass varies widely throughout the year, with increased biomass during certain periods of the year, depending on factors that include precipitation, temperature and day length. This biomass largely decomposes at other parts of the year, or it is harvested or consumed by grazing animals. The decision to include this herbaceous carbon is optional, because the carbon quantities involved are small compared with soil carbon and woody biomass.

References to support estimates for the various types of herbaceous biomass were scarce. The team used grasslands as a base (a number of references are available for herbaceous biomass in grasslands) and made assumptions to develop estimates for the other land cover types. In grasslands, non-soil biomass content was estimated at 3 $MTCO_2e$ per acre.[34] The same value was used for annual croplands. Wetlands and irrigated pasture were assumed to store 4.5 $MTCO_2e$ per acre. Rice was assumed to have 1.5 $MTCO_2e$ per acre.

Urban forest woody biomass

The carbon in urban forest woody biomass was estimated through the following two steps:

- Estimate tree canopy cover in the urban area: The i-Tree Canopy tool,[35] developed by the U.S. Forest Service, was used to estimate the fraction of the urban area covered by tree canopy as 10% (in both 2001 and 2014).
- Convert canopy cover to a carbon stock figure: The tree canopy areas in 2001 and 2014 were multiplied by a conversion factor of 133 $MTCO_2e$ per acre for urban tree cover (for 100% canopy cover)[36] to yield the final estimate of 13.3 $MTCO_2e$ per acre.

Note that for urban areas, woody biomass in trees is the only pool of aboveground biomass estimated. Urban areas are defined according to U.S. Census Bureau boundaries.

Methane and nitrous oxide emissions

Emissions from three general sources were estimated. Emissions from sources not listed here were not assessed.

N_2O emissions from croplands and grasslands

Annual croplands, orchards/vineyards and managed pasture typically receive nitrogen additions in the form of synthetic nitrogen fertilizer and/or organic nitrogen amendments, such as manure or compost. All sources of nitrogen in soils, including fertilizers, manures, plant residues, and biologically fixed N, contribute to soil N_2O emissions via denitrification and nitrification processes. Agricultural lands receiving high nitrogen additions produce larger N_2O emissions than lands where the main source of nitrogen is biological fixation, such as extensive rangelands (grasslands). A variety of factors influence the quantity of nitrogen that is converted to N_2O,

29 Marvinney E, Kendall A, Brodt S. 2015. Life Cycle–based Assessment of Energy Use and Greenhouse Gas Emissions in Almond Production, Part II. *Journal of Industrial Ecology* 19(6): 1019–29. https://doi.org/10.1111/jiec.12333.
30 E Marvinney, personal communication, 2016.
31 Estimated as being similar to walnuts.
32 Montanaro G, Tuzio AC, Xylogiannis E et al. 2016. Carbon budget in a Mediterranean peach orchard under different management practices. *Agric. Ecosyst. Environ.* 238: 104–13. https://doi.org/10.1016/j.agee.2016.05.031.
33 Kroodsma D, Field C. 2006. Carbon Sequestration in California Agriculture, 1980–2000. *Ecological Applications* 16(5): 1975–85. https://doi.org/10.1890/1051-0761(2006)016[1975:CSICA]2.0.CO;2.
34 Ryals R and Silver WL. 2013. Effects of organic matter amendments on net primary productivity and greenhouse gas emissions in annual grasslands. Ecological Applications 23(1):46–59. https://doi.org/10.1890/12-0620.1.
35 http://www.itreetools.org.
36 Bjorkman J, Thorne JH, Hollander A et al. 2015. Biomass, carbon sequestration and avoided emission: assessing the role of urban trees in California. Information Center for the Environment, University of California, Davis. Available at https://escholarship.org/uc/item/8r83z5wb.

including soil moisture, soil oxygen content, temperature, crop type, the type of fertilizer and various properties of the soil itself.[37]

The Merced County inventory followed the general IPCC approach for estimating N_2O emissions, which assumes that 1% of nitrogen additions (fertilizer, organic amendments and plant residues) are lost as N_2O. Assumptions about average annual nitrogen additions were based on data from a number of sources; nitrogen addition figures and references are provided in Appendix C, Table C.8.

Methane emissions from rice land

Methane is generated by the decomposition of organic matter in the anaerobic environment created when rice fields are flooded. Methane from flooded rice cultivation in Merced County was estimated using the approach described in the USDA entity-scale inventory guidance.[38] Rice cultivation in Merced County was assumed to be typical of California flooded rice cultivation, with a growing season of 120 days, straw incorporated less than 30 days before planting, preseason flooding of greater than 30 days, no use of compost/manure or cover crops, and crop residues tilled into the soil more than 30 days prior to planting.

Note that Merced County is not a major rice-growing region. The method used for this example could be applied in California counties where rice is grown more extensively (primarily the Sacramento Valley).

Wetland methane emissions

Wetlands emit methane from the decomposition of organic matter. Wetlands that are continuously inundated—wet year-round—have estimated methane emissions of 5.8 $MTCO_2e$/acre, while intermittently inundated wetlands have estimated methane emissions of 1.3 $MTCO_2e$/acre.[39] Continuously inundated wetlands in Merced County were estimated to be 5% continuously inundated and 95% intermittent.[40] Based on these proportions, a prorated level of methane emissions was calculated at 1.5 $MTCO_2e$ per acre of wetland in the county.

Results from the Merced County inventory

In Merced County, the above methods were used to generate estimates of carbon stocks and emissions in 2001 and 2014. The results of this inventory are presented below in Tables 1.4, 1.5 and 1.6. From 2001 to 2014, landscape carbon stocks increased by an estimated 1.25 million $MTCO_2e$, an increase of 2.5%. The main driver of this increase was a shift from row crops to orchard crops, which are associated with higher per-acre carbon stocks.

37 Nitrogen amendment practices change over time due to economic, regulatory and other factors. Those changes were not evaluated in this study.
38 Eve M, Pape D, Flugge M et al. (eds). 2014. Quantifying Greenhouse Gas Fluxes in Agriculture and Forestry: Methods for Entity-Scale Inventory. Technical Bulletin Number 1939. Office of the Chief Economist, U.S. Department of Agriculture, Washington, DC. https://www.usda.gov/oce/climate_change/Quantifying_GHG/USDATB1939_07072014.pdf.
39 2013 supplement to the 2006 IPCC Guidelines for National Greenhouse Gas Inventories: Wetlands.
40 Personal communication with Ric Ortega, general manager and director of policy and government affairs, Grassland Water and Resource Conservation Districts, Merced County.

Table 1.4. Carbon stocks by land cover class, from the 2001 and 2014 Merced County inventories, with carbon stock changes (all figures are $MTCO_2e$)[41]

	2001			2014		
	Non-soil Carbon Stocks*	Soil Carbon Stocks	Total Carbon Stocks	Non-soil Carbon Stocks*	Soil Carbon Stocks	Total Carbon Stocks
Land cover class	$MTCO_2e$					
Barren (mostly roads)	36,091	-	36,091	32,481	-	32,481
Forest	3,146,408	576,333	3,722,741	3,253,471	568,312	3,821,782
Shrubland	4,209,025	1,400,088	5,609,113	4,096,609	1,362,438	5,459,047
Wetland	568,357	4,826,826	5,395,184	519,661	4,484,219	5,003,880
Grassland	1,192,565	12,533,972	13,726,538	1,247,852	13,150,913	14,398,765
Irrigated Pasture	176,443	882,558	1,059,001	111,343	558,083	669,426
Orchard	3,440,720	2,987,828	6,428,548	5,088,587	4,641,236	9,729,823
Rice	7,062	136,700	143,762	1,797	34,870	36,666
Row Crops	1,100,605	10,148,190	11,248,795	901,199	8,363,528	9,264,727
Urban	541,671	1,354,965	1,896,636	608,418	1,524,688	2,133,105
Vineyard	47,382	253,604	300,986	42,422	227,202	269,624
Water	-	-	-	-	-	-
Total	**14,466,331**	**35,101,065**	**49,567,396**	**15,903,839**	**34,915,489**	**50,819,328**

	2030			Summary 2001-2014	
	Non-soil Carbon Stocks*	Soil Carbon Stocks	Total Carbon Stocks	2001-2014 Carbon Stock Changes	2001-2014 Annualized Carbon Stock Changes
Land cover class	$MTCO_2e$			$MTCO_2e/yr$	
Barren (mostly roads)	28,039	-	28,039	(3,610)	(278)
Forest	3,385,240	558,439	3,943,679	99,041	7,619
Shrubland	3,958,249	1,316,101	5,274,350	(150,066)	(11,544)
Wetland	459,726	4,062,549	4,522,275	(391,304)	(30,100)
Grassland	1,315,896	13,910,225	15,226,121	672,227	51,710
Irrigated Pasture	31,221	158,728	189,949	(389,575)	(29,967)
Orchard	7,116,730	6,676,200	13,792,931	3,301,275	253,944
Rice	-	-	-	(107,096)	(8,238)
Row Crops	655,776	6,167,021	6,822,797	(1,984,068)	(152,621)
Urban	690,568	1,733,577	2,424,145	236,469	18,190
Vineyard	36,318	194,707	231,025	(31,362)	(2,412)
Water	-	-	-	-	-
Total	**17,677,764**	**34,777,546**	**52,455,311**	**1,251,931**	**96,302**

**Non-soil carbon stocks includes above-ground and below-ground live and dead biomass.*

41 See Appendix C for detail on the land cover classifications.

Table 1.5. Nitrous oxide and methane emissions by land cover class, from the 2001 and 2014 Merced County Inventories (all figures are $MTCO_2e$)

	2001			2014		
Non-adjusted	**Soil nitrous oxide**	**Methane**	**Total emissions**	**Soil nitrous oxide**	**Methane**	**Total emissions**
Land cover class	**$MTCO_2e$/yr**					
Barren (mostly roads)	-	-	-	-	-	-
Forest	-	-	-	-	-	-
Shrubland	-	-	-	-	-	-
Wetland	-	191,388	191,388	-	174,990	174,990
Grassland	9,748	-	9,748	10,200	-	10,200
Irrigated pasture	39,263	-	39,263	24,777	-	24,777
Orchard	108,134	-	108,134	159,922	-	159,922
Rice	550	8,409	8,959	304	4,640	2,279
Row crops	385,362	-	385,362	315,542	-	315,542
Urban			-	-	-	-
Vineyard	4,051	-	4,051	3,627	-	3,627
Water	-	-	-	-	-	-
			746,906			691,339

**Methane and nitrous oxide emissions do not include enteric methane or manure management emissions.*

Table 1.6. Average annual carbon stock changes, emissions and carbon stock change net of emissions, based on 2001 and 2014 inventory data

Baseline adjusted	Annualized CO_2 removals from carbon stock change*	Average annual non-CO_2 emissions	Average annual net emissions (carbon stock change + emissions)
Land cover class	**MT CO_2e/yr**		
Barren (mostly roads)	278	-	278
Forest	(7,619)	-	(7,619)
Shrubland	11,544	-	11,544
Wetland	30,100	173,098	203,198
Grassland	(51,710)	10,253	(41,457)
Irrigated pasture	29,967	23,105	53,073
Orchard	(253,944)	165,898	(88,046)
Rice	8,238	4,480	12,718
Row crops	152,621	307,486	460,107
Urban	(18,190)	-	(18,190)
Vineyard	2,412	3,578	5,991
Water	(0)	-	(0)
Total	**(96,302)**	**687,898**	**591,592**

**CO_2 removals (increases in landscape carbon stocks) are shown as negative in this table so that the removals can be summed with the emissions to arrive at a net emissions value.*

The baseline reference scenario

The baseline reference scenario is a jurisdictional projection of "business as usual" landscape carbon stocks and emissions. It serves as a reference against which the effects of activities and other land management or policy changes intended to increase carbon stocks or reduce emissions can be measured.

The baseline reference scenario is a simple linear extrapolation of historic carbon and GHG inventory data. As such, it does not attempt to account for future changes in conditions—such as climate change and state water policy—that may affect land use and land cover. However, the linear extrapolation method has the advantage of being objective, simple and transparent. For these reasons, similar methods have been used internationally for jurisdictional approaches to reduce emissions from forest degradation and forest loss.[42] There is general agreement that a baseline reference scenario should be based on at least two historical inventory estimates separated by at least 5 years. More inventory estimates should yield a more accurate baseline reference scenario. See below for a discussion of potential cases in which the baseline scenario should be revised.

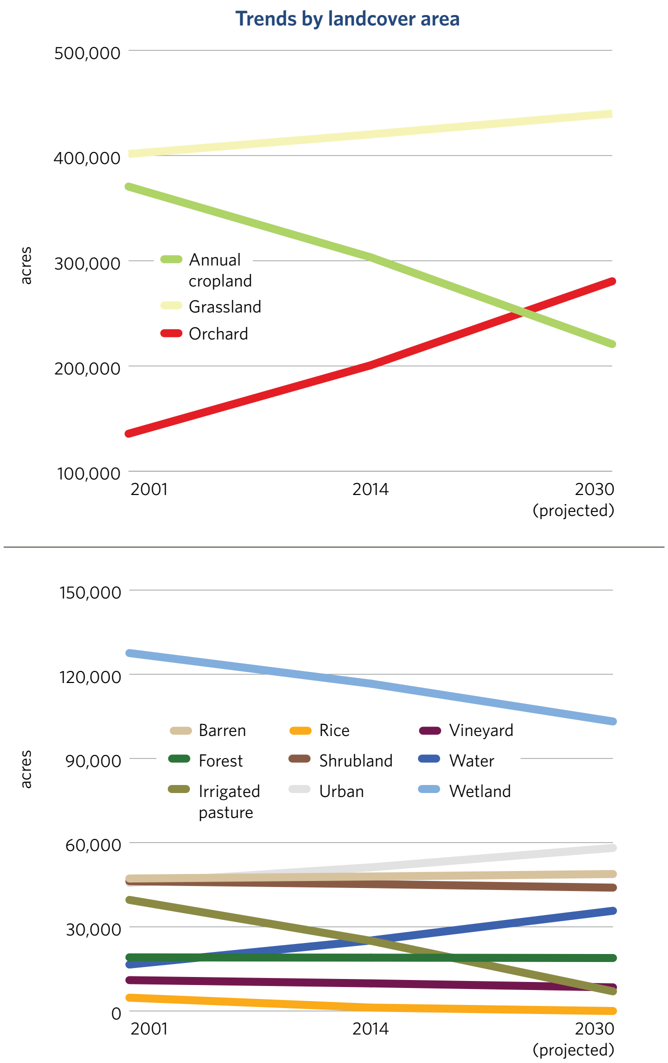
Merced County baseline reference scenario

To generate the baseline reference scenario, the trend established by the 2001 and 2014 inventory data for each land cover class was extended to 2030 (Figure 2.1). The year 2030 was chosen to align with the multiple state programs that use 2030 as a target date for the achievement of greenhouse gas reductions.

If, for an individual land cover class, the landscape carbon stock reached zero during the 2014–2030 extrapolation period, the acreage value for that land cover class was set at zero for all future years (that is, negative acreage values were not allowed).

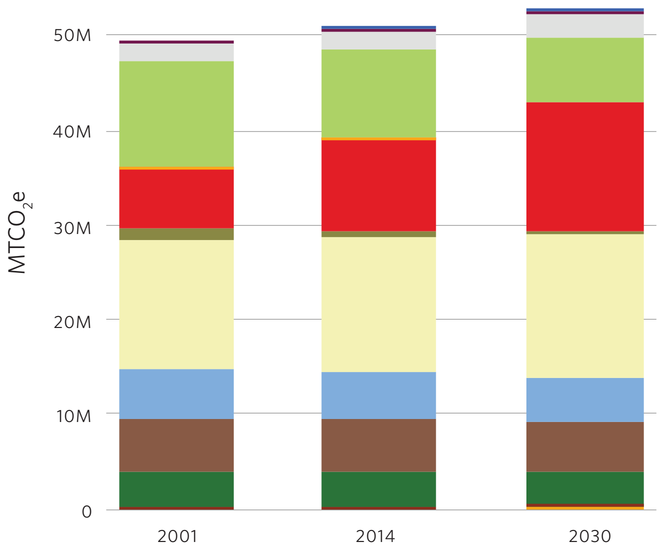
In Merced County, this occurred for rice land. Rice acreage totaled 4,755 acres in 2001 and 1,210 acres in 2014, an average rate of decline of roughly 273 acres per year. Extrapolating that average rate of decline, the projected acreage reaches zero in the fifth year after 2014 (and then becomes less than zero, a nonsensical result).

To compensate for setting rice land to zero in 2019 and subsequent years, an equal acreage of grassland (just under 3,000 acres by 2030) was added to keep total countywide land area constant. Grassland was chosen because it covers a large area; the adjustment increased the total grassland area by less than 1%.



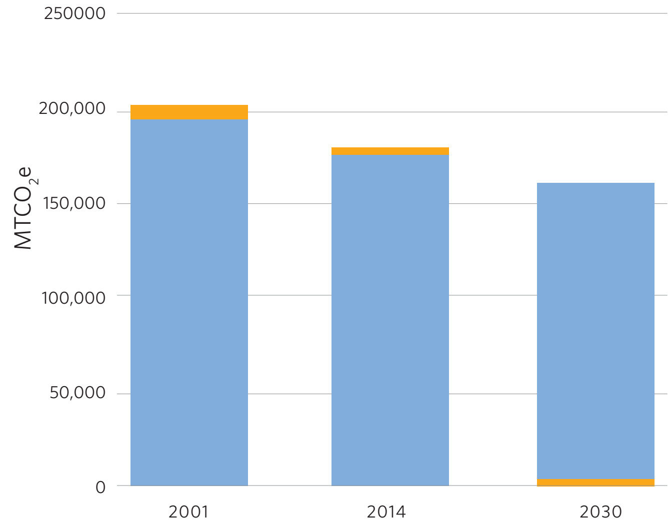
▲ **Figure 2.1.** Land cover acreage trends for the baseline reference scenario in Merced County, 2001–2030. Chart is split to make trends in smaller-acreage land cover types visible.

42 See Forest Carbon Partnership Facility, Carbon Fund Methodological Framework, at https://www.forestcarbonpartnership.org/sites/fcp/files/2016/July/FCPF%20Carbon%20Fund%20Methodological%20Framework%20revised%202016.pdf.



Non-soil carbon stocks includes above-ground and below-ground live and dead biomass.

▲ **Figure 2.2.** Landscape carbon stocks by land cover type for Merced County: 2001, 2014 and projected baseline reference scenario values for 2030.

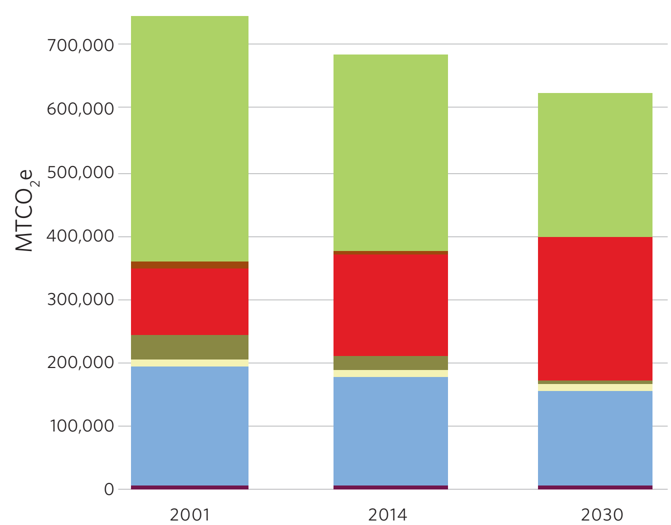


Methane and Nitrous Oxide emissions do not include enteric methane or manure management emissions.

▲ **Figure 2.3.** Annual methane emissions in Merced County from wetland and rice land sources: 2001, 2014 and projected baseline reference scenario values for 2030.

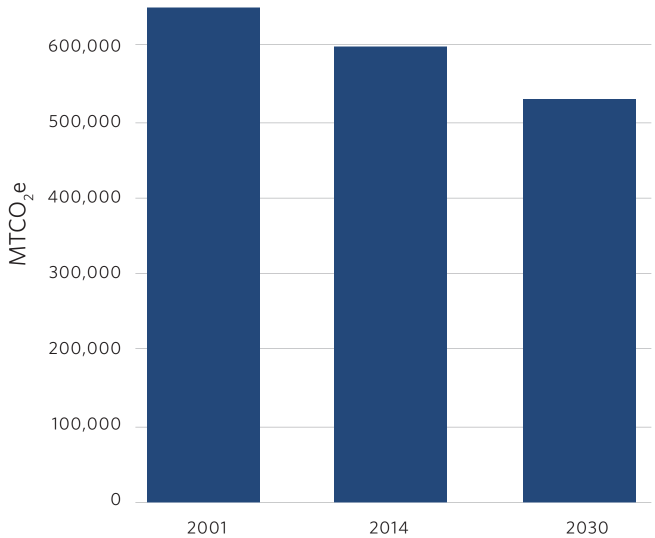
Methane and Nitrous Oxide emissions do not include enteric methane or manure management emissions.

▲ **Figure 2.4.** Annual nitrous oxide emissions in Merced County: 2001, 2014 and projected baseline reference scenario values for 2030.



Methane and Nitrous Oxide emissions do not include enteric methane or manure management emissions.

▲ **Figure 2.5.** Annual methane and nitrous oxide emissions in Merced County: 2001, 2014 and projected baseline reference scenario values for 2030.



Modeled trace gas emissions do not include enteric methane or manure management emissions. Emissions predictions for 2030 assume land use and management trends from 2001 to 2014 remain constant.

▲ **Figure 2.6.** Combined net annual emissions (annual methane and nitrous oxide emissions less the annual rate of increase in landscape carbon stocks) in Merced County: 2001, 2014 and projected baseline reference scenario values for 2030.

Summing across all land cover classes yields a trend for countywide landscape carbon stocks (Figure 2.2). The trends in carbon stocks in Merced are driven largely by the shift from row crops to orchards observed between 2001 and 2014, with orchards consisting of substantially higher carbon stocks per acre compared with row crops.[43]

The carbon stock trend accounts for a portion of the jurisdictional baseline. Methane and nitrous oxide emissions are included in the final determination of the reference level. The majority of land-based methane emissions in Merced County are from wetlands. These emissions are seen as declining, since the land cover inventory indicates that there is a trend of less area in wetlands out to 2030 (Figure 2.3). Methane emissions from rice production are trending toward zero as rice cultivation is anticipated to halt in Merced County.

43 Interviews with agricultural experts in the county (Appendix E) indicated that this particular trend may not continue at the same rate from 2014 to 2030. This information was not incorporated into the baseline projection, which, as described earlier in this section, is a simple extrapolation that has been widely used in other greenhouse gas accounting frameworks.

© U.S. Department of Agriculture

Nitrous oxide emissions are also an important component of the jurisdiction's baseline. Nitrous oxide originates from the use of nitrogen fertilizers in agriculture use. Overall nitrous oxide emissions in Merced County are declining due to reduced area in row crops (Figure 2.4). Most of the row crops are being converted to orchards, which are also fertilized with nitrogen. But, according to the inventory methods described in Section 1, per-acre nitrous oxide emissions associated with orchards are less than those associated with row crops. Note that this comparison reflects average emissions across many row crop and orchard types, with varying rates of nitrogen fertilization. Depending on which specific orchard crop replaces which specific row crop, emissions could be similar or greater in the orchard system.

The overall combined emissions trend of nitrous oxide and methane in Merced County is shown in Figure 2.5.

The final baseline reference for Merced County is established by summing the nitrous oxide and methane emissions and subtracting the carbon stock flux for each of the reference period years and extending the trajectory to 2030, as shown in Figure 2.6.

© Erika Nortemann/The Nature Conservancy

Revisions to the baseline reference scenario

The value of maintaining a baseline for a pre-established period of time is that it provides a stable, consistent reference against which changes in landscape carbon stocks and emissions can be measured.

The baseline reference scenario developed for Merced County is considered to be valid until 2030, at which time it will be reassessed based on updated inventory information. The year 2030 was chosen to coincide with the target date for California's 2030 greenhouse gas reduction programs. A baseline projection lifetime of up to 20 years may be reasonable.

Baseline reference scenarios may also be adjusted due to catastrophic events that result in substantial losses of carbon or emissions that deviate from historic trends that informed the baseline. Major changes in land cover, such as a large wildfire, may provide a reason to evaluate impacts through a a jurisdictional inventory and consider an adjustment to the baseline reference scenario.

To the extent possible, such a revision should use the same methods that were applied in the landscape carbon inventories used to develop the original baseline, only recognizing that the stochastic perturbation results in a changed trend from that which was assumed.

For example, a wildfire that consumes 80% of the shrublands within a jurisdiction creates a short-term landscape carbon loss trend that is not likely to continue, and that in fact is likely to be reversed as shrubland vegetation regrows. In such a case, the recovery of the shrublands should be considered in the revision to the baseline. Consultation with foresters, ecologists or other resource professionals may be helpful in establishing a realistic landscape carbon trajectory for the county's shrublands, which in turn will influence the new baseline reference scenario.

It is recommended that a threshold of 10% be considered as a sufficient deviation from the projected baseline to warrant a revision of the baseline. Planners will have to use an educated judgment that a change of this magnitude has occurred, as a full revised inventory would be necessary to determine with confidence.

SECTION 3

Complementary benefits assessment

Storing carbon is just one of the many benefits provided by natural and working landscapes. Other values include agricultural productivity, groundwater recharge, improved water quality, flood risk reduction, wildlife habitat and many more.

Efforts to increase carbon storage must consider the potential impacts—positive and negative—on these complementary benefits. A spatial inventory of complementary benefits provides information on the values associated with each piece of land in the county (each 30-meter-by-30-meter pixel, following the same grid approach used for the landscape carbon inventory above).

Such an inventory provides the basis for the development of strategies under which efforts to sequester carbon are aligned with other public and environmental benefits. Documentation of complementary benefits can also help to engage other sectors, such as agriculture, and to leverage funding. Spatial data on these complementary benefits is built into the TerraCount scenario analysis tool described below, allowing for analysis and comparison of such strategies and for quantification and visualization of impacts.

A jurisdictional assessment of complementary benefits draws on a range of data sources. For the Merced County project, 18 distinct benefits were identified. These complementary benefits are documented through the collection of data sources presented in Table 3.1 (with more detail in Appendix F-2). The maps on the following pages show several examples of these spatial data sets overlaid on the map of Merced County.

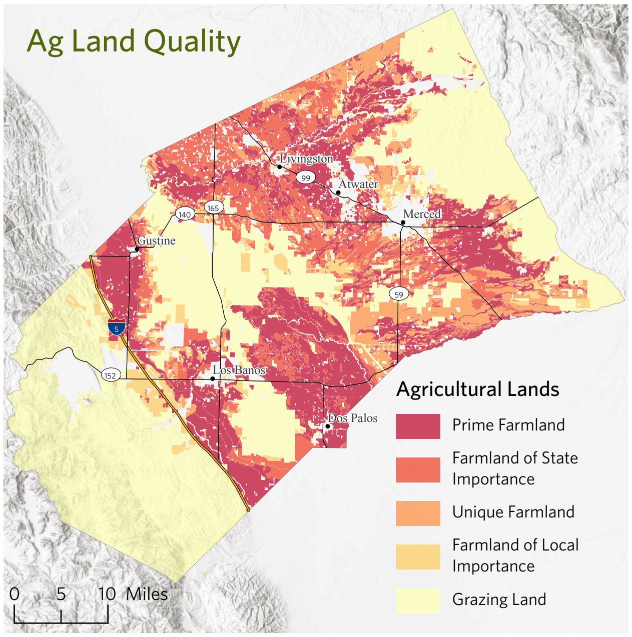
Table 3.1. Complementary benefits and their data sources (see Appendix F-2 for more detail)

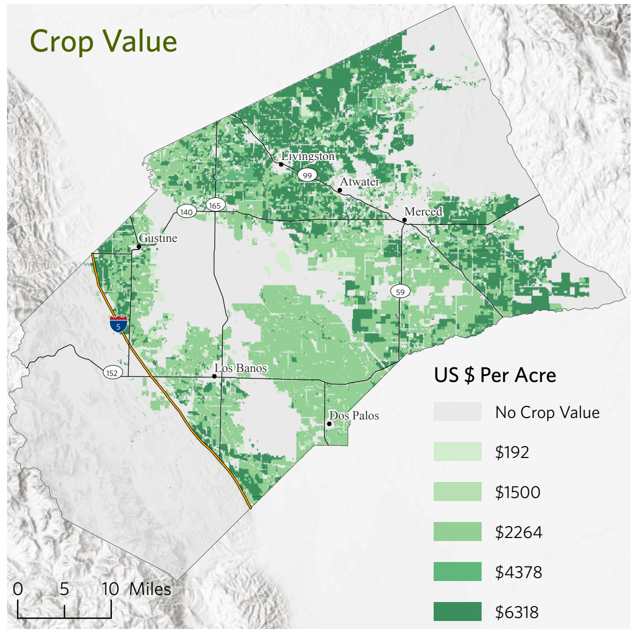
	Complementary benefit	Data sources	Reporting metrics
Agriculture	**Agricultural land quality**	State of California Farmland Mapping and Monitoring Program (FMMP)	Net change in area of each FMMP class (prime farmland, unique farmland, farmland of statewide importance, and farmland of local importance) converted from agriculture to urban use
	Crop value	Spatial Data—LANDFIRE and TNC custom classification Value Info—Merced County Crop Reports	Net change in crop value (total $)
Water quality	**Agricultural/ urban water conservation**	Spatial Data—LANDFIRE and TNC custom classification Value Info California Department of Water Resources (CDWR)	Net change in water demand for agricultural and urban use (acre-feet/year)
	Groundwater recharge	CA Basin Characterization Model (Flint & Flint)	Net change in potential groundwater recharge (acre-feet/year)
	Water quality	UC Davis Nitrate Study (http://groundwaternitrate.ucdavis.edu) Spatial Data—LANDFIRE and TNC custom classification.	Net change in nitrate leaching to groundwater (tons/year) and nitrate runoff in surface water (tons/year)
	Watershed integrity	**Catchments**—NHD Plus Version 2 **Naturalness**—Custom Classification **Thalwegs**—NHD Plus, Merced County	Net change in acreage of watersheds based on the % naturalness of subwatersheds and % naturalness in a 150-meter buffer of thalwegs
Human well-being	**Flood risk reduction**	FEMA Floodplains	Net change in land use within the 100-year floodplain (natural, agricultural, and urban)
	Air quality	Calif. Air Resources Board (CARB), Dr. Varsha Gopalakrishnan, Ohio State University	Net change in mass of air pollutants sequestered by natural land cover classes (metric tons of NO_2, SO_2, PM_{10}, $PM_{2.5}$, CO and O_3)
	Scenic value	Viewshed Analysis on USGS Digital Elevation Model	Net change in land use in areas sorted by visibility from public areas, parks, and roadways.

	Complementary benefit	Data sources	Reporting metrics
Biodiversity	**Terrestrial connectivity**	CDFW Essential Habitat Connectivity Project—Combined Resistance Raster and Essential Connectivity Areas (ECAs)	Net change in area of land classes that either facilitate or limit terrestrial species movement; reporting also includes the area of such lands that fall within Essential Connectivity Areas
	Natural habitat area (acres)	LANDFIRE and TNC custom classification	Area of natural land cover
	Priority conservation areas (acres)	Audubon Important Bird Areas C - CDFW Essential Connectivity Areas 150m Buffer of Streams and Rivers TNC ecoregional priority conservation areas	Net change in land cover (natural, agricultural or urban) within priority conservation areas
	Terrestrial habitat value	CWHR, FRAP, others	Area of habitat degraded or improved for: 1) amphibians 2) mammals 3) birds 4) reptiles 5) threatened and endangered species
	Aquatic biodiversity value/richness	TNC Freshwater Blueprint (2018)	Net change in land cover (natural, agricultural or urban) in watersheds with the highest aquatic biodiversity
Resilience	**Flood risk attenuation**	Federal Emergency Management Agency (FEMA)	Net change in land cover (natural, agricultural or urban) in the 500-year floodplain (urban, natural and farmland acres)
	Groundwater banking potential	Soil Agricultural Groundwater Banking Index (SAGBI)	Net change in land cover (natural, agricultural or urban) in undeveloped land suitable for groundwater banking (SAGBI rating of good or excellent)
	Habitat stability	Thorne et al. climate change exposure by macrogroup	Net change in land cover (natural, agricultural or urban) in climate change refugia areas where habitat is more likely to be stable (score of 0 to 80 for climate exposure in Thorne et al.[44])
	Climate connectivity	TNC Omnidirectional Circuit Scape Model for Climate Change Connectivity	Net change in land cover (natural, agricultural or urban) in linkages important for climate-driven species movement (a combination of current remaining linkages and connectivity to future climates)

44 Thorne JH, Choe H, Boynton RM, Bjorkman J, Albright W, Nydick K, Flint AL, Flint LE, and Schwartz MW. 2017. The impact of climate change uncertainty on California's vegetation and adaptation management. *Ecosphere* 8(12). https://doi.org/10.1002/ecs2.2021.

Figure 3.1. Example spatial benefit data for current (generally 2014) conditions in Merced County





Agricultural Land Quality

The California Farmland Mapping and Monitoring Program (FMMP)[45] provides spatial data on the quality of agricultural land. The program uses five classifications for farmland and grazing land—listed below, with the acres of each reported in Merced County

- Prime farmland: 269,243 acres
- Farmland of statewide importance: 154,209 acres
- Unique farmland: 115,234 acres
- Farmland of local importance: 61,670 acres

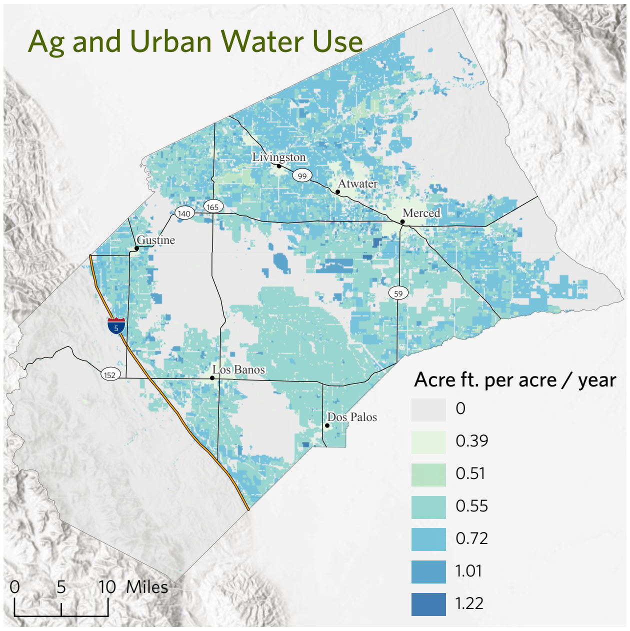
(See the FMMP site for details on the classification methodology: http://www.conservation.ca.gov/dlrp/fmmp)

Crop Value

Per-acre annual farmland crop value across the county is estimated using the custom classifications developed for this project (see inventory section), supplemented with county crop data. There are five specific agriculture classes in the LANDFIRE data set, and a per-acre crop value was calculated for each ag type.

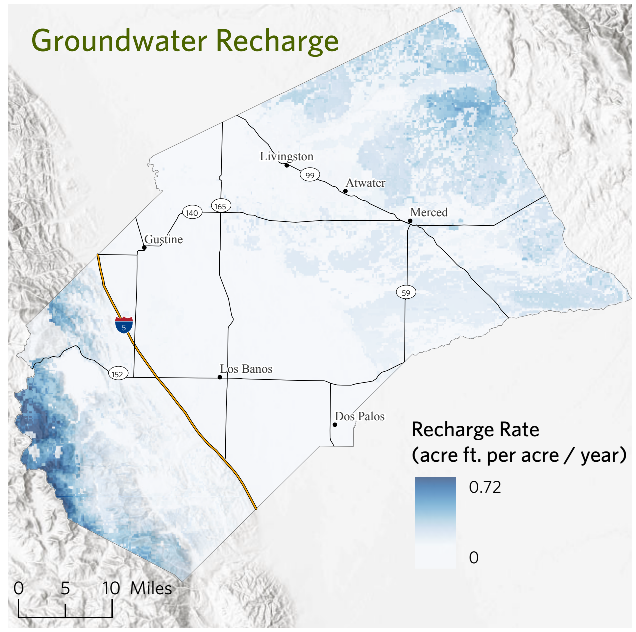
45 www.conservation.ca.gov/dlrp/fmmp.

▼ **Figure 3.1.** Continued



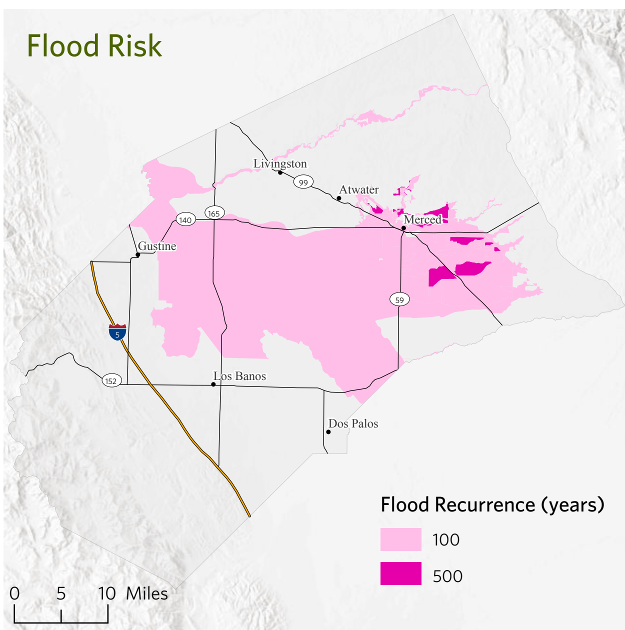
Water use

Water demand per acre is mapped for the county's urban and agricultural areas, based on per-acre crop water use data and average urban water use data.



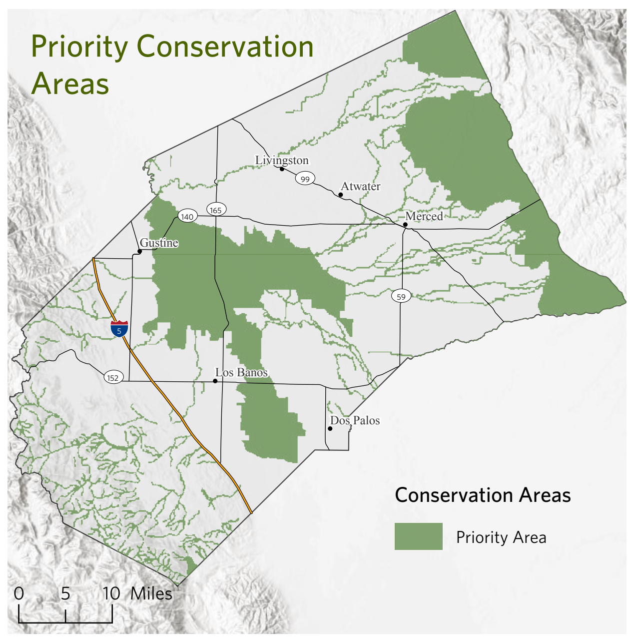
Groundwater recharge

Average annual groundwater recharge is mapped at 270-meter resolution for the county, based on USGS data (see http://climate.calcommons.org/bcm).



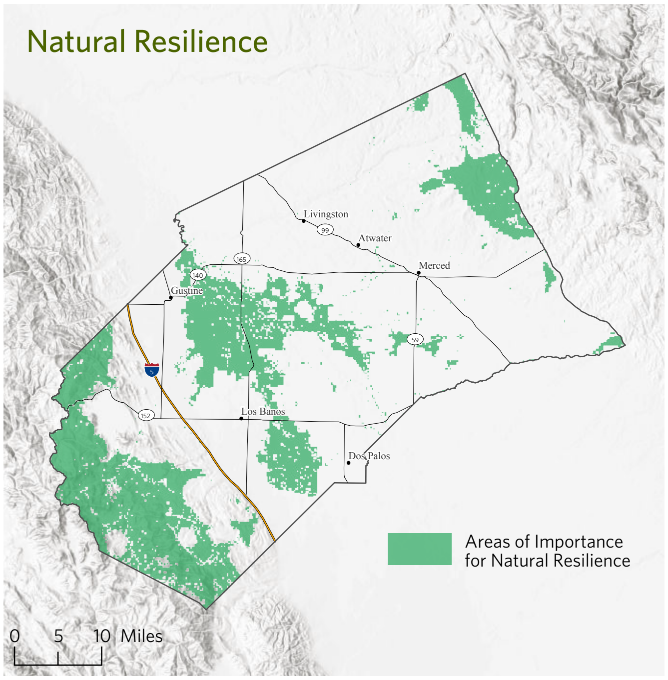
Flood Risk

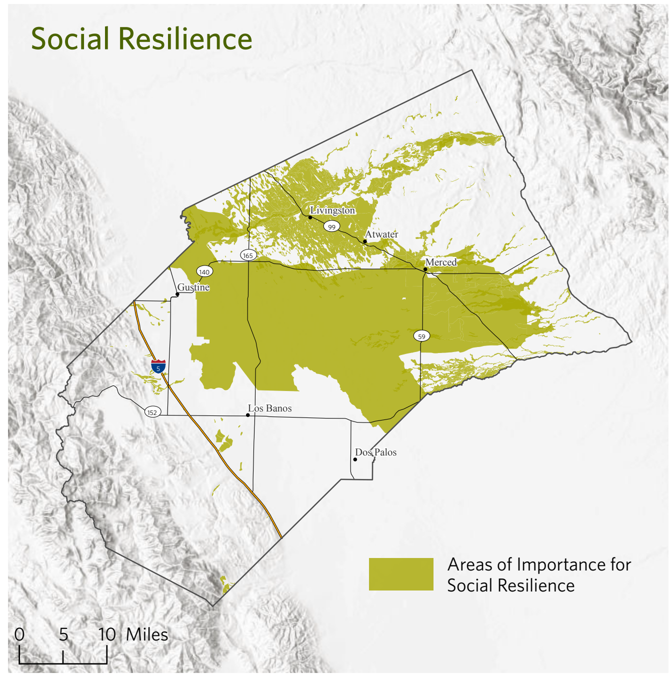
Maps of the 100-year and 500-year floodplains from the Federal Emergency Management Agency (FEMA) are used to represent the flood risk to developed areas.



Priority conservation areas include the following designated areas: TNC Ecoregional Priority Conservation Areas, Audubon Important Bird Areas and California Department of Fish and Wildlife Essential Connectivity Areas

▼ **Figure 3.1.** Continued





Natural resilience

For our work, natural resilience is the sum of two components: habitat stability and climate connectivity. The tool reports out on changes in land cover for areas that either are mapped as climate refugia by Thorne et. al. or are mapped as climate linkages. Climate refugia are areas where current vegetation is predicted to be relatively stable and less vulnerable to climate change; climate linkages are areas that connect current to future climate zones.

Social and built resilience

For this project, we selected various data sets to use as "proxies" for resilience, which isn't easily represented spatially. For our work, social and built resilience is the sum of two components: flood risk attenuation and groundwater banking potential. The tool reports out on the changes in land cover for areas that are either in the 500-year floodplain (FEMA) or in areas of the highest groundwater banking potential (SAGBI).

SECTION 4

Forecasting—scenario analysis of GHG reductions and complementary benefits

The landscape carbon inventory and complementary benefits assessment together provide information on current conditions, while the baseline reference scenario charts a business-as-usual future.

That information also provides the starting point for the development and evaluation of jurisdiction-wide plans to increase landscape carbon stocks and reduce greenhouse gas emissions. We can begin to look at how what we do from this point forward—changes in land use and the implementation of activities intended to deliver a climate benefit—influences landscape carbon stocks, greenhouse gas emissions and the complementary benefits provided by landscapes.

A key part of such planning is the creation and analysis of spatially explicit scenarios of future land use changes and activities.

This section presents a tool, TerraCount, for developing and analyzing such scenarios. As presented here, it is tailored to Merced County, but it can be adapted to other geographies.

This section provides an overview of how TerraCount works, as well as an in-depth treatment of its application to three specific scenarios—countywide riparian restoration, countywide cover cropping and hedgerow planting and countywide conservation (avoided conversion of land cover types). Each scenario analysis also includes a documented cost-benefit analysis.

This section also covers the analysis of indirect effects of land-based activities intended to deliver a net reduction in greenhouse gas emissions. These indirect effects can include what's known as leakage; changes in the total number of vehicle miles traveled (which alters vehicle-related emissions); and changes in landscape carbon stocks that can result from shifts in urban development and land conservation patterns.

Scenario analysis tool: TerraCount overview

TerraCount is a GIS model that that estimates how changes in land use, land management and land cover affect landscape carbon storage and influence a variety of other potential benefits—including agricultural land values, water resources, biodiversity and human well-being. TerraCount is designed to help identify areas where conservation goals are aligned with opportunities to reduce net greenhouse gas emissions.

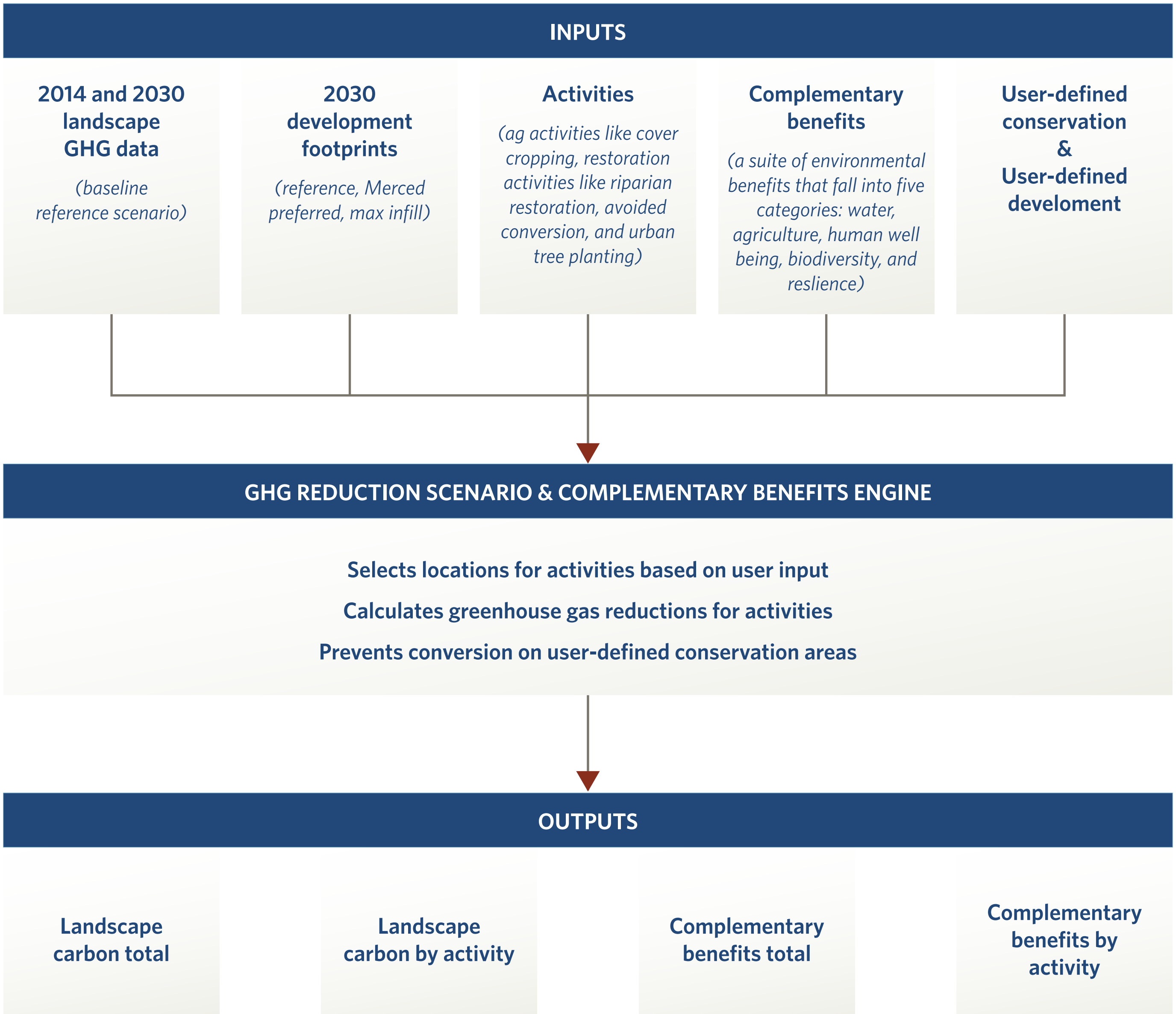
Planners can use the tool to run scenarios for an entire county or for any defined sub-area within the county. Because TerraCount is highly configurable, it can be used to model the effects of a wide range of land use policies, conservation and land management strategies, and restoration programs.

This section describes how TerraCount works, with reference to examples from Merced County. Appendices F and G provide detailed technical documentation, as well as information about download and installation as well as configuration for use in other areas.

© Gary N. Crabb

Framework

Figure 4.1 provides a schematic of the tool's framework, illustrating the inputs, outputs and analysis workflow.



▲ **Figure 4.1.** Schematic of the TerraCount tool: Inputs, analysis, outputs

TerraCount runs as a Python toolbox in ESRI's ArcGIS Desktop software. It can be downloaded and run on any computer with ArcGIS Desktop (ArcGIS Pro or ArcMap). The link to download the tool and full operating instructions are provided in Appendix F. The code for the tool is publicly available for download and use as a GitHub repository (https://github.com/mtukman/mercedtool), and users are welcome to fork the repository, suggest or contribute changes/fixes or add modules.

Installing and running the tool requires familiarity with ArcGIS Desktop. Installation involves downloading and adding the ESRI Python toolbox to ArcGIS Desktop and downloading the supporting Merced data sets to a PC with at least 16GB of RAM and 10GB of free disk space for the data. Installation takes a few minutes and is documented in the GitHub readme. The tool will run on any level of ArcGIS for Desktop (basic, standard or advanced) and doesn't require any ESRI extensions.

Inputs

Each TerraCount analysis is based on five categories of inputs, described below.

1. Landscape carbon inventory data

The tool uses the land cover data developed for the 2014 jurisdictional inventory described above (LANDFIRE data supplemented with custom classifications). The tool also requires a 2030 estimate of land cover. For this project, that estimate was based on outputs of the models ST-SIM (for natural landscapes)[46] and Envision Tomorrow[47] (for urban landscapes).

2. Predefined development footprints

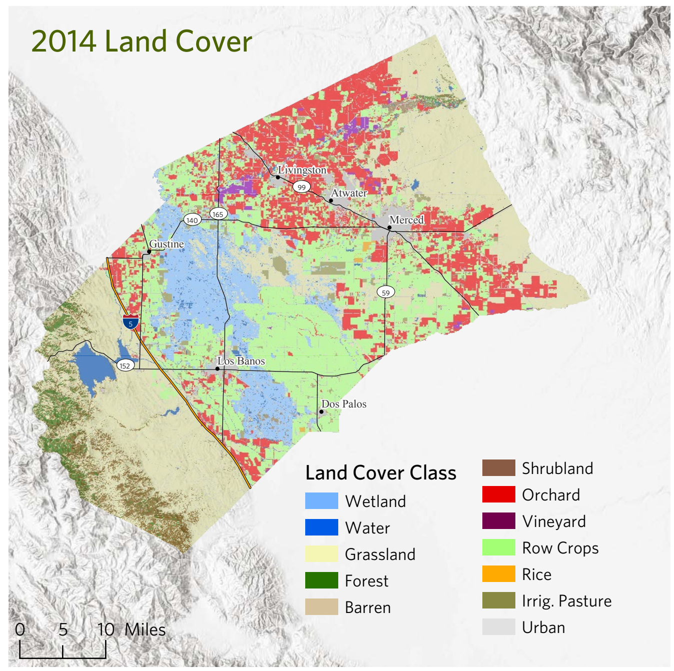
The tool includes three predefined sets of assumptions regarding patterns of development through 2030. Each of these "footprints" represents a different pattern of urban and suburban development, a major driver of the conversion of natural and working landscapes to residential, business and industrial uses. The incorporation of these footprints into TerraCount allows the user to see the effect of different development patterns on landscape carbon storage and complementary benefits over time.

The three footprints are:

1. A *reference* footprint, which continues the development and land conversion patterns observed in the 2001–2014 baseline period.
2. The *Merced County preferred* footprint, created by the Merced County Association of Governments, which represents the county's official preferred vision for land development through 2030.
3. A *maximum infill* footprint, which focuses on developing land within the county's core urban areas.

The three footprints were "painted" using Envision Tomorrow. All three footprints assume the same rate of growth for jobs and the residential population. TerraCount provides full reporting for all three footprints each time the tool is run.

© Ian Shive



▲ **Figure 4.2.** 2014 actual Merced County land cover used to model the 2030 land cover corresponding to the 2030 jurisdictional carbon baseline reference scenario.

46 See Appendix G for detail.
47 See envisiontomorrow.org.

3. Activities

The user can model the effects of implementing any number of activities. Twelve activities are available (Table 4.1). To calculate the greenhouse gas reductions associated with implementing an activity, TerraCount uses the methods documented in the activity sheets (see Section 5, below).

All activities specified by the user in the tool are considered to be new activities—a change from the baseline trend established by the 2001 and 2014 inventories.

Table 4.1. List of land management and agricultural activities designed to increase landscape carbon stocks or reduce emissions of methane or nitrous oxide. See Section 5 and Appendix K for full documentation.

Activity	Description
Improved nitrogen fertilizer management	Managing the amount (rate), source, placement (method of application) and timing of plant nutrients and soil amendments
Replacing synthetic nitrogen fertilizer with soil amendments	Full or partial replacement of synthetic nitrogen fertilizer with soil organic matter amendments, such as manure or other organic by-products
Oak woodland restoration	Restoration of oak woodlands (across the ranges of blue oak and valley oak) in areas where present-day land cover is grassland or other candidate land cover classes
Cover crops	Grasses and forbs (non-leguminous) planted for seasonal vegetative cover
Mulching	Addition of crop or straw residues
Riparian restoration	Restoration of woody riparian vegetation in areas near streams and rivers
Urban forestry	Planting of trees in urban areas, resulting in increased urban tree canopy cover
Hedgerow planting	Planting of hedgerows in orchards and vineyards
Avoided conversion to croplands	A reduction in conversion to cropland as compared with the baseline
Avoided conversion to urban	A reduction in conversion to urban as compared with the baseline
Compost application to grasslands	Application of a half-inch-thick layer of compost on grassland and rangeland
Native grassland restoration	Restoration of native grasses

For each activity, the user specifies the following:

- the year the activity is begun (any year from 2014 through 2029)
- the number of years to full adoption (the tool assumes a linear adoption rate, so if the activity is implemented on 2,000 acres over 5 years, it will assume that 400 acres of the activity will be added each year)
- the target number of acres over which it is implemented

Using random selections of blocks of pixels, TerraCount applies each activity to land suitable for the activity. For instance, oak woodland restoration can be conducted only on grassland or shrubland; mulching can be conducted only on annual croplands and rice; and riparian restoration can be implemented only within 100 feet of a stream centerline or 1,000 feet of a river centerline.

Each activity has an adoption cap that represents that activity's maximum *countywide* acreage. The adoption caps were calculated by evaluating existing adoption and estimating a realistic upper limit for additional adoption based on interviews with in-county experts (Appendix E) and biophysical limitations. The tool implements an activity on suitable areas up to the countywide adoption cap. Table 4.2 shows the adoption caps for for each activity.

Table 4.2. Adoption caps in TerraCount for each activity*

Activity	Adoption cap (acres)
Riparian restoration	25,000
Oak woodland restoration	52,000
Cover crops	55,000
Mulching	40,000
Improved nitrogen fertilizer management	80,000
Hedgerow planting	5,500
Native grassland restoration	17,000
Replacing synthetic nitrogen fertilizer with soil amendments	20,000
Compost application to non-irrigated grasslands	15,000

**Adoption caps were not set for two activities: avoided conversion to croplands; and avoided conversion to urban.*

4. Complementary benefit data sets

Storing carbon is just one of the many benefits provided by natural and working landscapes. Efforts to increase carbon storage must consider the potential impacts—positive and negative—on these other benefits. This type of analysis can help to identify strategies where efforts to sequester carbon are aligned with other public and environmental benefits. It can also help to engage other sectors, such as agriculture, and to leverage funding.

TerraCount accounts for five categories of benefits—agriculture, water, human well-being, terrestrial biodiversity and resilience—provided by natural and working lands, a total of 18 types of benefits (Table 3.1). The categories and the 18 individual benefits are the same as those described above in the complementary benefits assessment section.

TerraCount includes spatial data on each of these benefits for Merced County. When the tool runs, it generates a table for each benefit that reports the increase or decrease in that benefit as a result of the implementation of activities and changes in land cover.

For the case of an activity, consider a scenario that restores woody riparian vegetation. If some of the land that was restored to woody riparian vegetation by 2030 in the scenario was agriculture in 2014, crop value (one of the complementary benefits) will be reduced. At the same time, water conservation will increase as water use decreases when agricultural lands are converted to woody riparian vegetation. Another complementary benefit that would be affected is terrestrial connectivity: when agricultural land is restored to woody riparian vegetation, terrestrial connectivity potential increases.

For changes in land cover, TerraCount relies on 2014 land cover data, which is derived from LANDFIRE and our custom classification, and a 2030 land cover reference scenario generated using the ST-SIM simulation model and Envision Tomorrow (as described in the first part of this section, "Landscape carbon inventory data"). When TerraCount runs, it calculates the net change in each benefit arising from changes in land cover or land management that deviate from the reference scenario.

5. User-defined development footprint and land conservation

Users have the option of uploading their own development footprint, which is then evaluated as a fourth development footprint in addition to the three pre-created footprints.

The user also has the option of selecting areas for "conservation," which prevents changes in land cover type. The user defines polygons for conservation; when TerraCount runs, those areas become masks to any land cover changes. The avoided conversions include:

TerraCount can evaluate the effects of avoiding conversion from these land cover types ...		... to these land cover types
Wetland	➡	Annual cropland
Grassland	➡	Annual cropland, urban or orchard
Annual cropland	➡	Urban, orchard or irrigated pasture
Irrigated pasture	➡	Annual cropland, urban or orchard
Orchard	➡	Annual cropland, urban or irrigated pasture
Vineyard	➡	Orchard

Running TerraCount

To run TerraCount, the user first specifies the collection of information that defines a scenario—the intensity of land conversion, which lands will be excluded from development, which activities will be performed and on how many acres and so on.

Once these constraints and instructions have been entered, the tool is ready to run.

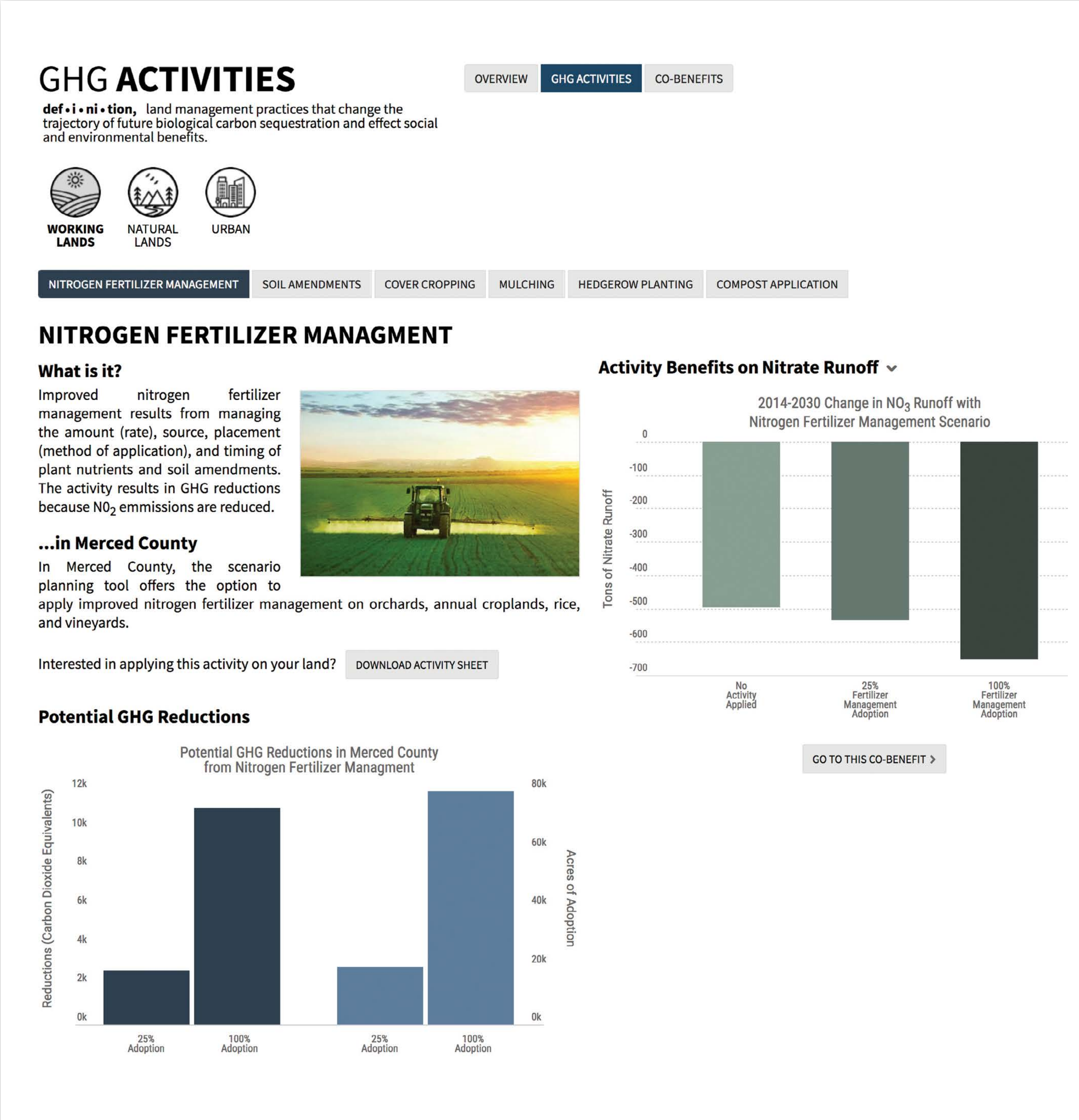
TerraCount calculates the landscape carbon impacts associated with each activity by: 1) identifying the land covers suitable for the activity, 2) identifying the geographies suitable for the activity, 3) randomly selecting—from among the areas defined in steps 1 and 2—a subset of suitable areas based on user-defined timing of implementation and 4) applying the activity reductions to the areas selected in step 3.

The tool provides four outputs:

1. total landscape carbon impact of the scenario
2. landscape carbon impact of each activity included in the scenario
3. the impact on each complementary benefit value for the whole scenario
4. the impact on each complementary benefit value from each activity included in the scenario

Web app for visualizing TerraCount results

A web application displays the results of scenarios produced in TerraCount. The application allows the user to compare results from various scenarios and analyze the effects of a number of activities applied in a variety of ways. The web application, hosted by the California Department of Conservation, is available online at https://maps.conservation.ca.gov/TerraCount/tool. Note: The web application does not allow the user to create and run scenarios in TerraCount; rather, it allows viewing and comparison of the inputs and results of a collection of predefined scenarios.



▲ **Figure 4.3.** Screenshot of the interface of the TerraCount web application.

Example: Countywide implementation of activities

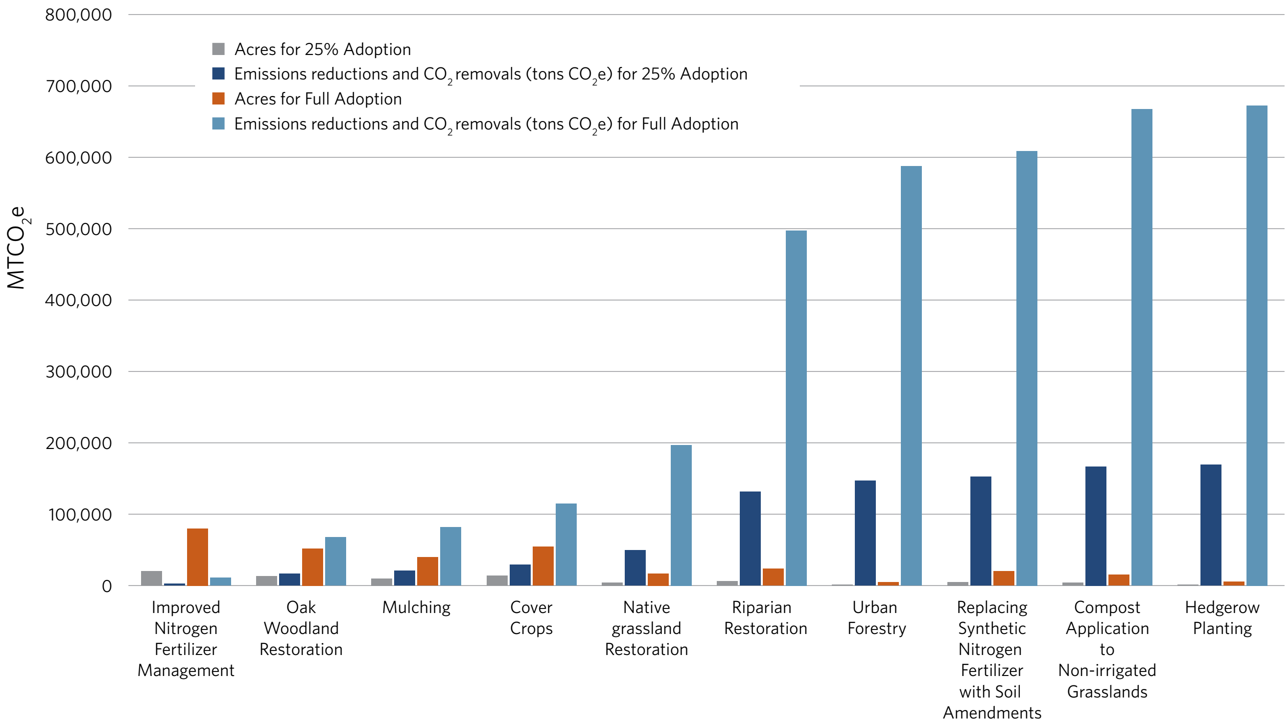
To illustrate how the tool can be used to assess the potential benefits of activities, we conducted a series of runs in which each activity was applied first to 25% of eligible areas in Merced County and then to 100% of eligible areas. Each activity was initiated in 2014 and ramped up to full implementation over 6 years. After the sixth year, the activity continues for its defined duration—10 years for most agricultural activities, longer for activities that sequester woody vegetation, such as urban tree planting.

Table 4.3 and and Figures 4.4 and 4.5 show the results. The activities that result in the growth of woody vegetation—urban tree planting, oak woodland restoration, riparian restoration and hedgerow planting—had the highest potential GHG benefits.

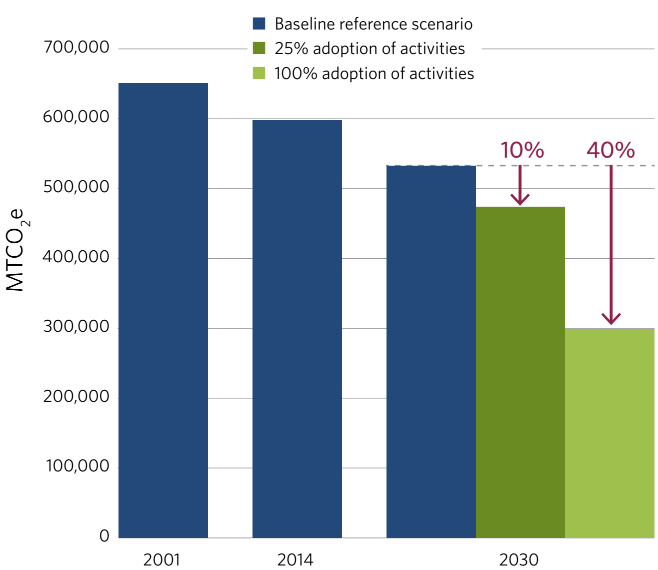
Table 4.3. Net greenhouse gas reductions from implementation of specific activities on 25% and 100% of all suitable acreage in Merced County based on runs of TerraCount. All $MTCO_2e$ figures represent the cumulative benefit from 2014 through 2030.*

Activity	Acres for 25% adoption	Emissions reductions and CO_2 removals (tons CO_2e) for 25% adoption	Acres for full adoption	Emissions reductions and CO_2 removals (tons CO_2e) for full adoption
Improved nitrogen fertilizer management	19,997	2,780	79,983	11,118
Oak woodland restoration	13,010	16,792	52,006	67,665
Mulching	10,007	20,614	39,671	81,722
Cover crops	13,750	29,137	54,193	114,833
Native grassland restoration	4,253	49,260	17,006	196,982
Riparian restoration	6,253	131,519	23,714	497,459
Urban forestry	1,104	146,946	4,414	587,604
Replacing synthetic nitrogen fertilizer with soil amendments	5,003	152,232	19,407	608,811
Compost application to non-irrigated grasslands	3,750	166,853	15,000	667,443
Hedgerow planting	1,383	169,140	5,500	672,672

**The "avoided conversion to croplands" and "avoided conversion to urban" activities were not included in this analysis, as it was challenging to determine reasonable thresholds for 25% and 100% avoided conversion.*



▲ **Figure 4.4.** Cumulative combined emissions reductions and CO_2 removals, 2014–2030, for each of 10 activities based on 25% adoption or full adoption countywide.



▲ **Figure 4.5.** Combined net annual emissions reduction potential (emissions reductions plus CO_2 removals) in 2030 for 10 specified activities, assuming countywide rates of adoption of 25% and 100%.

Three Merced County examples

This section uses examples from Merced County to illustrate how TerraCount can be used to forecast changes in landscape carbon stocks, greenhouse gas emissions and the complementary benefits provided by natural and working landscapes.

Three scenarios are presented, each based on the widespread implementation of one or two activities:

- Countywide riparian restoration
- Countywide cover cropping and hedgerow planting
- Countywide avoided conversion

The presentation of each scenario includes a detailed discussion of the inputs to TerraCount as well as the outputs. Three case studies are included as well, each illustrating the application of the activity or activities from the three scenarios in specific locations in Merced County.

In addition, each scenario analysis includes the results of a cost-benefit analysis, following methods presented in Appendix H. Costs include direct costs, such as the cost of labor, equipment and materials, as well as opportunity costs, like forgone agricultural revenue, where applicable. Benefits include, where appropriate and quantifiable, financial estimates of carbon benefits, water savings and reduced flood loss as well as the value of the complementary benefits provided by natural and working landscapes.

Scenario 1: Countywide riparian restoration

California's riparian forests cover less land today than in pre-settlement times, creating the potential for restoration in some areas. Though riparian areas in Merced County represent a small fraction of the landscape, they provide important services, including flood attenuation, protection of water supply and habitat for fish and wildlife. They are also an important conduit for movement of terrestrial and aquatic species.

Riparian restoration, as applied by the tool, converts nonforested areas adjacent to streams and rivers into areas of woody riparian vegetation, simulating the planting of trees in these areas. As the TerraCount results below show, riparian restoration delivers net reductions in greenhouse gas emissions as well as increases for many categories of complementary benefits, including water quality, watershed integrity, flood risk reduction, agricultural and urban water conservation, air quality, scenic value and biodiversity.

Riparian restoration applied countywide

For this run of the tool, the riparian restoration activity was first applied in 2014, with a 6-year ramp-up for all suitable acres to adopt the activity. It was applied on all suitable acres across the county (no adoption cap was applied).

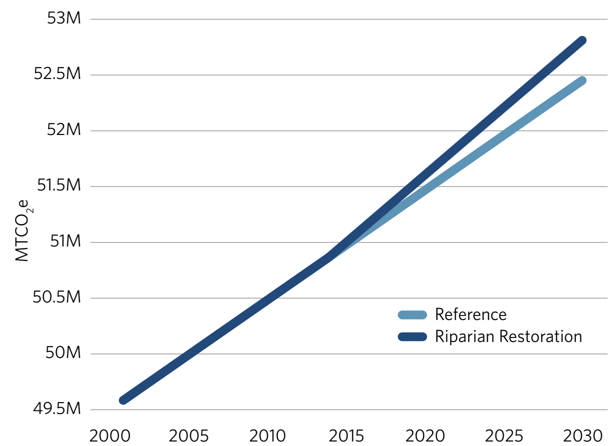
The tool defines suitable land for riparian restoration as non-water areas of certain land cover types in the functional riparian zone that don't have existing woody vegetation, subject to the following:

- Suitable land cover types (classified by LANDFIRE or custom classification) are: grassland, irrigated pasture, annual cropland, vineyard, rice, orchard, wetland (the land cover type "wetland" is herbaceous wetlands, rather than woody wetlands) or barren.
- The functional riparian zone is defined as being within 1,000 feet of a river centerline or 100 feet of a stream centerline that is classified as supporting woody riparian vegetation (see Appendices F and G for more details).

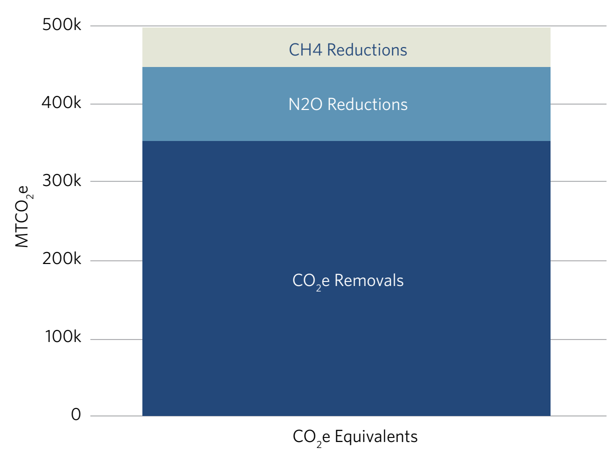
Using these specifications (which are built into the tool), the total area for full adoption of riparian restoration countywide is 23,714 acres.

The tool applies reduction rates for riparian restoration annually for each year that the activity is applied, from 2014 through 2030. TerraCount uses an annual net greenhouse gas reduction rate for riparian restoration of 1.0 $MTCO_2e$ per acre per year, based on the rate used in COMET-Planner (discussed in the "Landscape carbon inventory" section).[48]

Figures 4.6a and 4.6b show the increase in landscape carbon stocks (equivalent to net greenhouse gas reductions) from the application of riparian restoration countywide for all suitable areas. The estimated net increase in carbon stocks from 2014 to 2030, compared with the reference scenario, is 497,459 $MTCO_2e$.



▲ **Figure 4.6a.** 2001–2030 countywide landscape carbon stocks for the baseline reference scenario and a scenario that assumes maximum adoption of riparian restoration starting in 2014.



▲ **Figure 4.6b.** Cumulative 2014–2030 countywide CO_2 removals and emission reductions for adoption of maximum riparian restoration.

48 Note: For agricultural activities, COMET-Planner net greenhouse gas reduction rates are based on the annual average for a 10-year project lifespan. For riparian restoration in TerraCount, by contrast, the COMET-Planner 10-year rate continues to be applied even after the 10th year of the activity, to account for the continued growth of the restored riparian trees and shrubs.

© Mary Ann Griggs/The Nature Conservancy

Costs and benefits of riparian restoration

Following methods presented in Appendix H, costs for the countywide restoration scenario are an estimated $643,918,750, including direct as well as opportunity costs. Direct costs include those associated with removal of introduced species, planting and establishment of native vegetation and ongoing management. Opportunity costs include forgone agricultural returns, which, in this scenario, are dominated by forgone returns of orchard production.

The methods presented in Appendix H also yielded valuations for three benefits associated with the riparian restoration scenario (compared with the reference): reductions in net greenhouse gas emissions, water use and flood risk. The greenhouse gas benefits, when using the social cost of carbon,[49] are valued at $7,910,000. The value of anticipated water savings and reduction in flood loss are $106,000,000 and $60,000, respectively.

There are a number of other benefits associated with riparian restoration that can't be easily assigned a dollar value (and that are not included in the valuation above). These complementary benefits include interception and absorption of air pollutants by vegetation, increased habitat quality and terrestrial connectivity, water conservation and flood attenuation.

© Erika Nortemann/The Nature Conservancy

49 The social cost of carbon estimates the long-term economic costs attributable to greenhouse gas emissions. The value used in this analysis is $15.90 per $MTCO_2e$ in 2017 dollars.

Riparian restoration of the San Joaquin River

The "re-wetting," or riparian restoration, of the San Joaquin River through Merced County provides a case study for using TerraCount to approximate the net greenhouse gas emission reductions and associated complementary benefits of applying riparian restoration in a specific geography in Merced County.

Friant Dam, completed in 1942, impounds San Joaquin River water as it flows out of the Sierra Nevada. Water diverted from the dam into the Friant-Kern and Madera canals irrigates the extensive farmlands of the Southern San Joaquin Valley, and for decades the diversions essentially dried up the San Joaquin River during the dry season. A 2008 ruling, however, obliged the U.S. Bureau of Reclamation, the operator of the dam, to maintain "restoration flows" in the river of at least 200 cubic feet per second (cfs) during the dry season, starting in 2014, for the purpose of maintaining habitat.

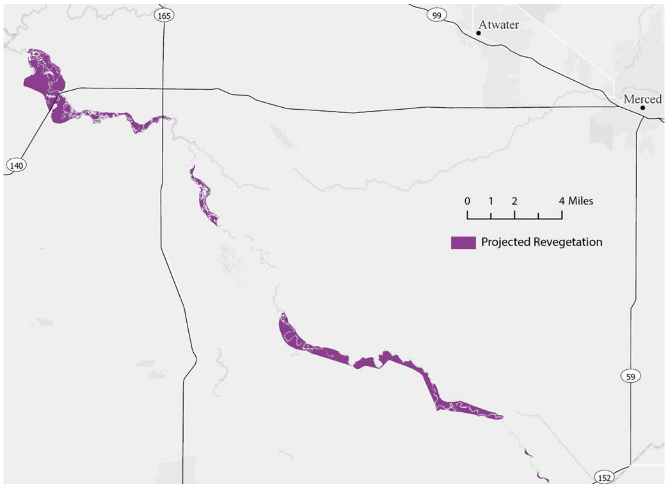
A 2014 Bureau of Reclamation study[50] found that approximately 2,230 acres of natural riparian vegetation recruitment would occur in Merced County as a result of the restoration flows.

Based on this estimate, for our case study, the riparian restoration activity was applied on 2,230 acres, selected by TerraCount based on riparian restoration eligibility rules from the larger area of suitability (4,900 acres total) shown in Figure 4.7.

The charts in Figure 4.7 show the outputs from the TerraCount run, including estimates of changes by 2030, compared with the reference scenario. The area of analysis is the 4,900-acre "area of suitability" for restoration. In the reference scenario, no restoration is applied. In the restoration scenario, riparian restoration is applied to 2,300 of the 4,900 acres.

CO_2 removals: Natural recruitment of woody riparian vegetation along re-wetted stretches of the river in Merced County is expected to result in total emissions reduction and carbon stock increases of 77,932 $MTCO_2e$.

Crop value: Agricultural land is suitable for riparian restoration if it is in or near a riparian area. There are significant areas of agricultural land along the San Joaquin River in the restoration area identified by the Bureau of Reclamation. Some of these areas were restored to woody riparian vegetation by the tool during the 2014–2030 period. As a result, total crop value decreased in the areas where the activity was applied.



▲ **Figure 4.7.** Areas suitable for riparian restoration from San Joaquin River "re-wetting." Shaded areas represent potential revegetation sites: areas affected by restoration flows and not already occupied by woody riparian vegetation. Source: Stillwater Sciences, 2003. "Restoration objectives for the San Joaquin River." Prepared for Natural Resources Defense Council and Friant Water Users Authority. http://www.stillwatersci.com/resources/2003stillwater_sjr_restobjs_report.pdf.

Water use: The TerraCount results indicate that agricultural and urban water use is reduced from riparian restoration along the San Joaquin River. This is because agricultural land, which required irrigation, was converted in the scenario to riparian vegetation, which is not irrigated.

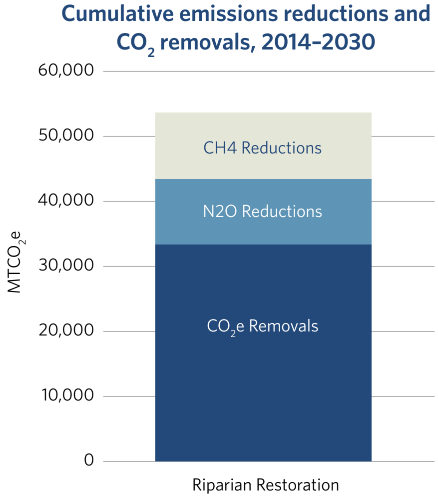
Terrestrial connectivity: Improvement in connectivity is one result of the restoration of agricultural land to natural land, which presents fewer barriers to species movement. The tool run reports an increase in areas of high movement potential by 2030 for terrestrial organisms, resulting in a significant overall improvement in terrestrial connectivity.

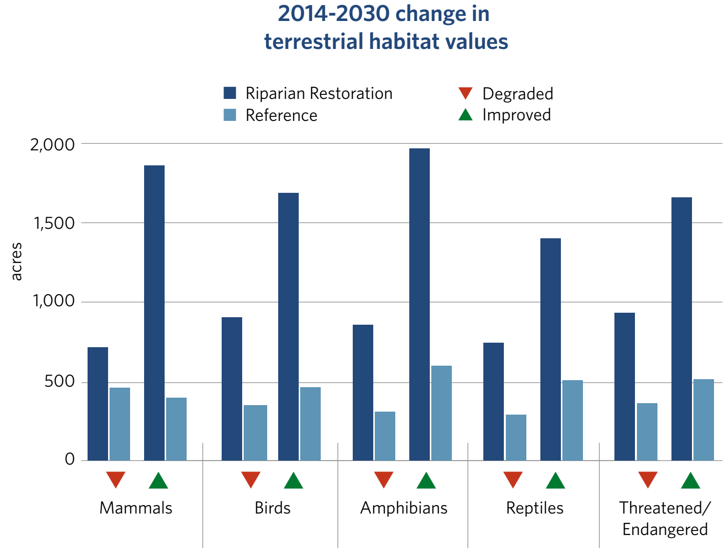
Terrestrial habitat quality: Habitat suitability improves across the board for all species guilds (mammals, birds, amphibians and reptiles) and for threatened and endangered species. Riparian restoration restores woody habitat (forest and woodlands) in non-woody near-stream areas.

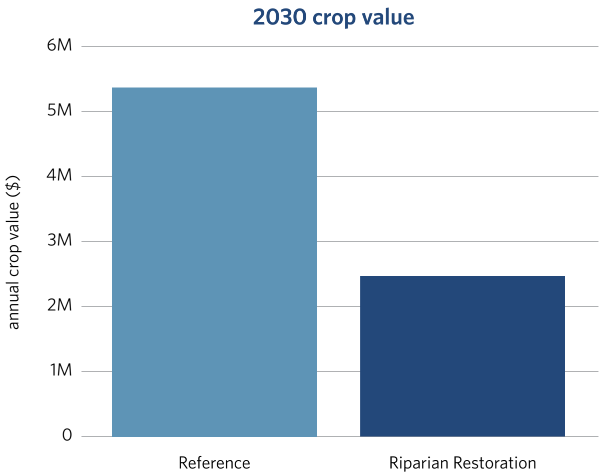
Air pollutant sequestration: The TerraCount run suggests that air pollutant sequestration will increase for all major pollutants except carbon monoxide. Riparian restoration increases canopy cover and leaf area, which results in an increase in dry deposition for most of the major pollutants.

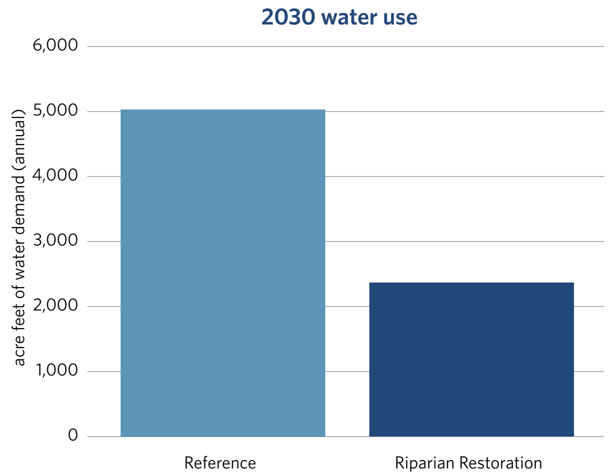
50 United States Bureau of Reclamation. 2014. San Joaquin River Restoration Program. Riparian Habitat Mitigation and Monitoring Plan.

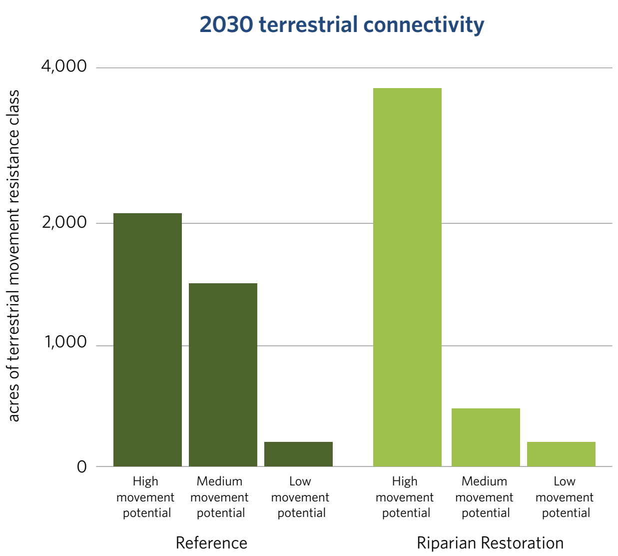
▶ **Figure 4.8.** Results from the TerraCount evaluation of the San Joaquin River re-wetting restoration scenario: cumulative net emissions reductions, 2014–2030; changes in terrestrial habitat quality, 2014–2030; and 2030 differences between the restoration and reference scenarios for crop value, water use, terrestrial connectivity and air pollutant sequestration.

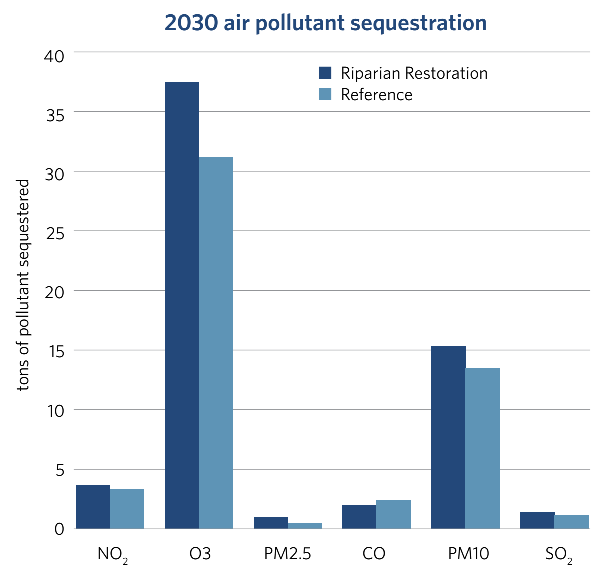












Scenario 2: Countywide cover cropping and hedgerow planting

The second scenario implemented cover cropping and hedgerow planting countywide.

In cover cropping, grasses and forbs are planted for seasonal vegetative cover. The practice promotes soil health as the cover crops' root system stabilizes soil, increases soil porosity and encourages beneficial soil organisms. Since cover crops contribute to soil carbon sequestration, they help to reduce net greenhouse gas emissions.

Hedgerow planting, as it is applied in Merced County, involves planting rows of woody vegetation (shrubs and small trees) along field borders and in gaps between blocks of vineyards and orchards. Hedgerow plants provide habitat for pollinators and wildlife and sequester carbon in their roots, branches and stems.

TerraCount inputs

Cover cropping and hedgerow planting were initiated in 2014, with a steady 6-year phase-in period for all suitable acres. TerraCount includes an adoption cap for implementation of agricultural activities. The adoption cap is intended to set a realistic limit on acreage of implementation—20% of all suitable acres for cover cropping and 30% for hedgerow planting. With these caps, cover cropping is implemented on just over 54,000 acres, and hedgerow planting on 5,500 acres (in the assumptions built into the tool, 10% of area within any vineyard or orchard is available for hedgerow canopy).

The annual net greenhouse gas emissions reduction rate for hedgerow planting is based on the 10-year rate used in COMET-Planner. For cover cropping, TerraCount uses an average of COMET-Planner reduction rates for several different kinds of cover cropping.

Table 4.4: TerraCount inputs for the cover cropping and hedgerow planting scenario.

Activity	Suitable geography/land cover	Adoption cap	Acres of full adoption
Cover cropping	Orchards and some annual croplands (vineyards and some annual croplands already have high adoption in Merced)	20% of suitable acres	55,000
Hedgerow planting	Orchards and vineyards	30% of suitable acres, but only 10% of that area actually with hedgerow cover after implementation	5,500

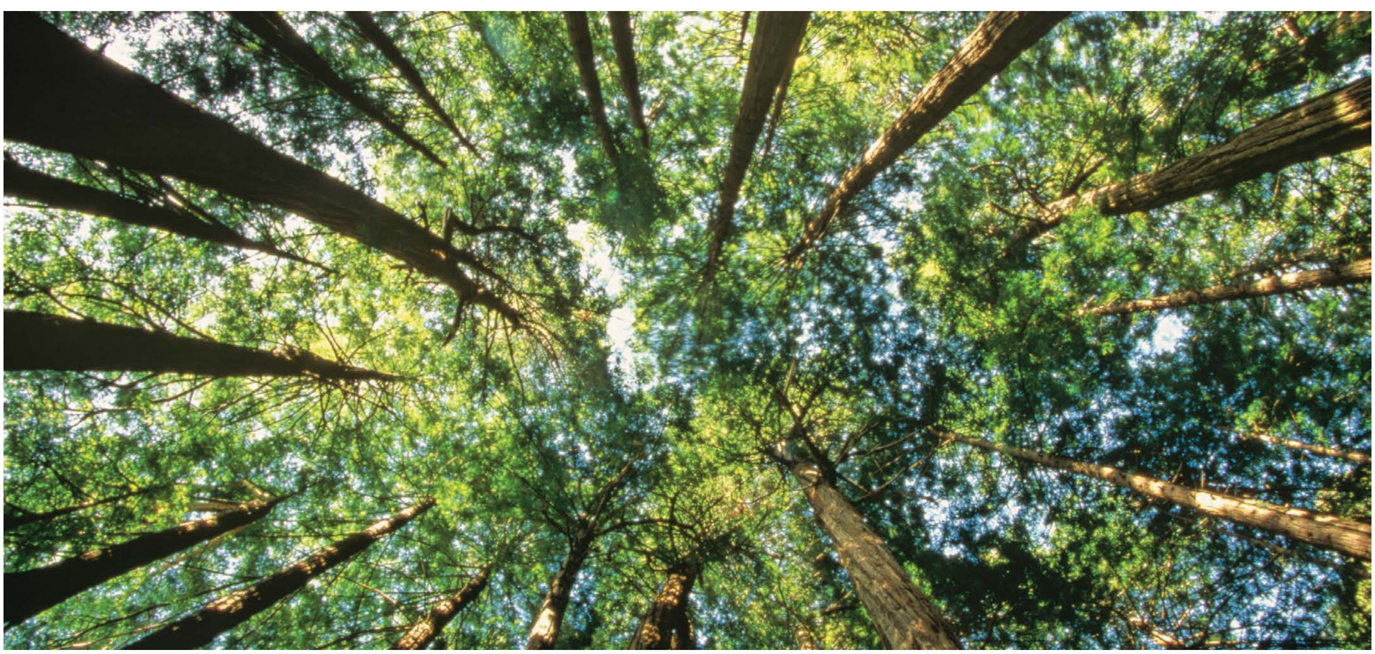
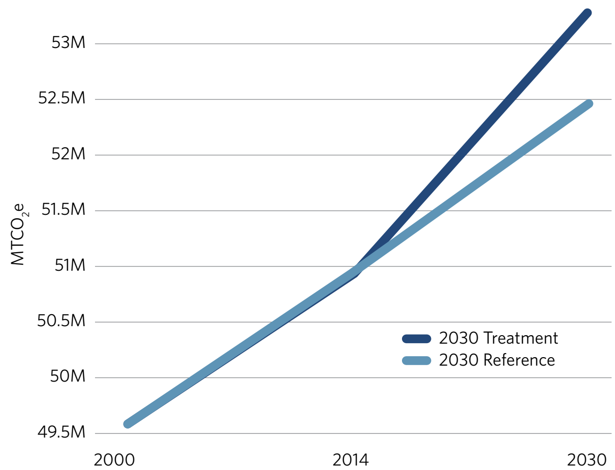
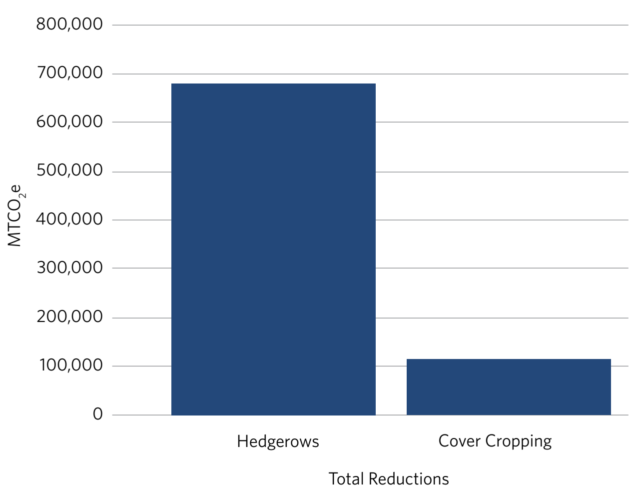


Figure 4.9, below, shows the net increase in landscape carbon stocks (CO_2 removals) calculated by TerraCount for this scenario. The cumulative benefit is 796,771 $MTCO_2e$ when compared with the reference scenario.



▲ **Figure 4.9.** 2001-2030 countywide landscape carbon stocks for the baseline reference scenario and a scenario that assumes maximum adoption of cover cropping and hedgerow planting activities starting in 2014.



▲ **Figure 4.10.** Cumulative combined emission reductions and CO_2 removals, 2014–2030, for maximum adoption countywide of hedgerow planting and cover cropping.

Cover cropping and hedgerow planting: Estimated costs and benefits

The estimated cost associated with the countywide cover cropping and hedgerow planting scenario is $96,750,000 ($5,230,000 for cover cropping and $91,520,000 for planting hedgerows). The estimate reflects the estimated direct costs of labor, equipment and materials to 1) establish permanent vegetation such as grass and legumes in the alleyways and between tree and vine rows in the case of cover crops, and 2) establish a single row of woody vegetation. No opportunity costs are foreseen, and there is no land use change in this scenario.

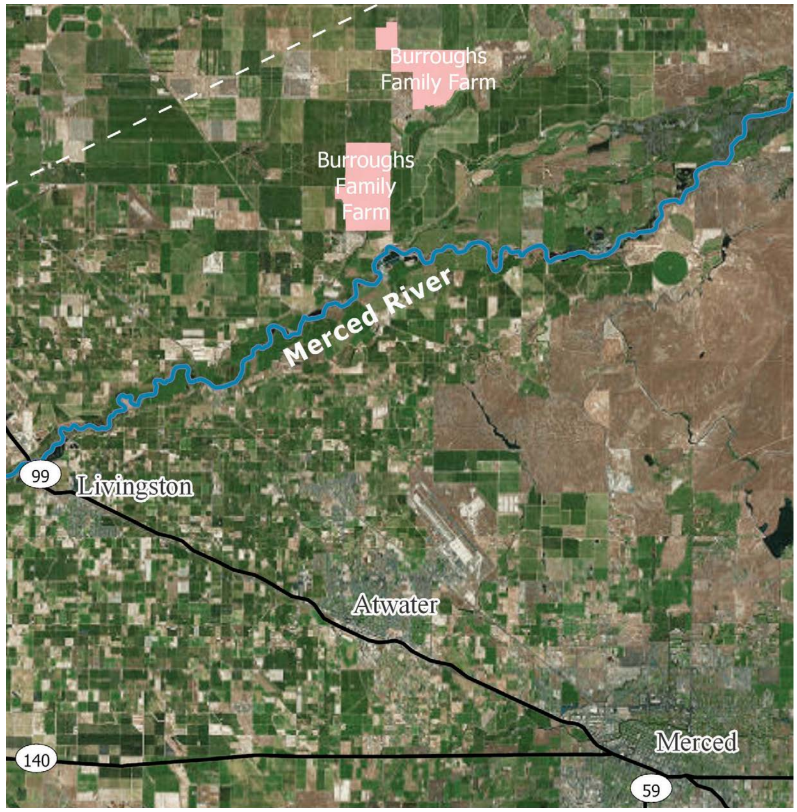
The carbon benefits of this scenario, compared with the reference case, are estimated to be $13,100,000. A number of other benefits associated with cover cropping and hedgerow planting can't easily be assigned a dollar value and are not included in the valuation above. These complementary benefits include, but are not limited to, enhanced soil quality and stabilization, habitat for wildlife species such as birds, and an increase in pollinators. For more detail on the methods used to develop these estimates of costs and benefits, please see Appendix H.

Cover cropping and hedgerows at Burroughs Family Farm

Ward and Rose Burroughs and their children farm 2,600 acres of land in northeastern Merced County, producing milk, almonds, olive oil and eggs. The farm was founded more than 100 years ago.

In the past 15 years, the Burroughs have transitioned to organic production methods and have begun a number of regenerative agricultural practices, including hedgerow planting, cover cropping, replacing synthetic nitrogen fertilizer with compost amendments, and mulching with almond hulls and shells from a local processor.

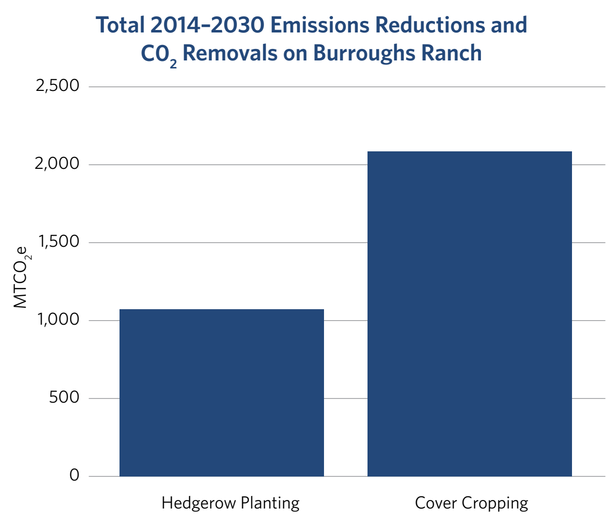
In addition to the agricultural practices that are the focus of the Merced Project (the benefits of which are quantified below), the Burroughs Family has implemented a number of other practices, including improved tillage and managed intensive grazing. Managed intensive grazing involves intensive grazing on small areas of pasture for short periods of time in order to increase the benefits of grazing for grassland ecosystems while reducing the negative impacts. The Burroughs family has also worked to restore the health of the riparian portions of their property and to encourage establishment of wetland plants and woody vegetation in low-lying areas of their farm (Figure 4.11). The Burroughs farm is contributing to research on agricultural practices being conducted by the California State University, Chico, Regenerative Agriculture Program. One aim of this research is to better quantify the benefits to soil health of cover cropping.



▲ **Figure 4.11.** Burroughs Family Farm location.

The Burroughs Family Farm provides an example of a medium-scale operation in the Central Valley where implementation of cover cropping and hedgerow planting has been successful. The Burroughs family reports that their soil quality has improved and that the number and diversity of birds and pollinators has increased since they went organic and implemented hedgerows and cover crops.

Using information on the extent of cover cropping (896 acres in almond and olive orchards) and hedgerow planting (7.5 acres of hedgerow canopy at the edge of orchard blocks) on the Burroughs farm, TerraCount estimated a total net greenhouse gas reduction benefit of 3,154 $MTCO_2e$ by 2030. This number is likely a conservative estimate of the overall benefits of the farm's practices, since it counts just two of the many carbon-sequestering activities that have been implemented.



▲ **Figure 4.13.** Estimated cumulative combined emissions reductions and carbon stock increases at Burroughs Family Farm, 2014–2030, due to cover cropping and hedgerow planting practices.

Heifers grazing in an almond orchard with cover crops. © Burroughs Family Farm

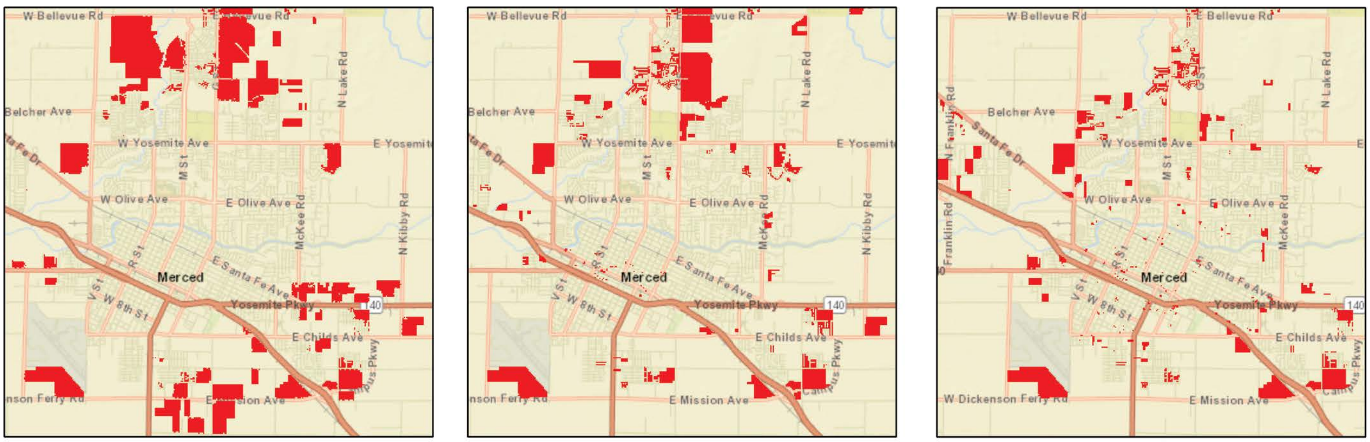
▲ **Figure 4.12.** Establishment of vegetation in swale on Burroughs Farm.

Scenario 3: Countywide avoided conversion of natural and working lands

Avoided conversion—countywide

This section summarizes the result of using TerraCount to evaluate the effects of applying the avoided conversion activity in Merced County. For these runs of the tool, we chose to begin applying the activity in 2014 and allowed 6 years for adoption across all suitable acres. The analysis assesses the difference in landscape carbon stocks and annual methane and nitrous oxide emissions rates between the original land cover type and the converted (that is, urban) land cover type. Indirect emissions, such as changes in vehicle miles traveled, are not considered. Emissions related to residential or business activities on urban lands (from household electricity and natural gas use, for instance) are also not considered.

The tool comes with a range of pre-created 2030 development scenarios. These scenarios include a "sprawl" reference scenario that reflects the baseline reference (2001–2014) development patterns ; Merced County's "preferred scenario," which was developed by the Merced County Association of Governments and represents Merced County's vision of developed land use in 2030; and a "max infill" scenario, which focuses on urban infill development (Figure 4.14).[51] Each scenario assumes the same increase in population and jobs between 2014 and 2030.



Reference scenario | Merced preferred scenario | Max infill scenario

▲ **Figure 4.14.** New development (red) in the area surrounding the city of Merced for the Merced County reference, preferred, and maximum infill development scenarios, 2030.

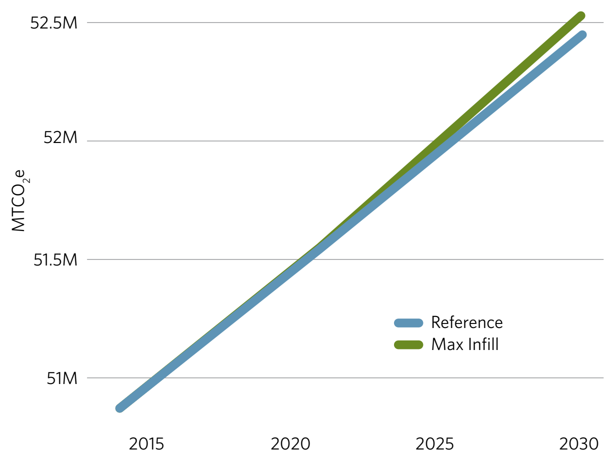
Table 4.5. Merced County development scenarios

2030 Development scenario	Acres of simulated land conversion to developed land use (2014–2030)	Description
Reference	8,285	Simulates a continuation of the type of development that occurred in Merced County between 2001 and 2014
Max infill	3,293	Simulates maximum infill-type redevelopment of the urban core
Merced County preferred scenario	4,535	Merced County's preferred scenario for 2030, developed by Merced County Association of Governments

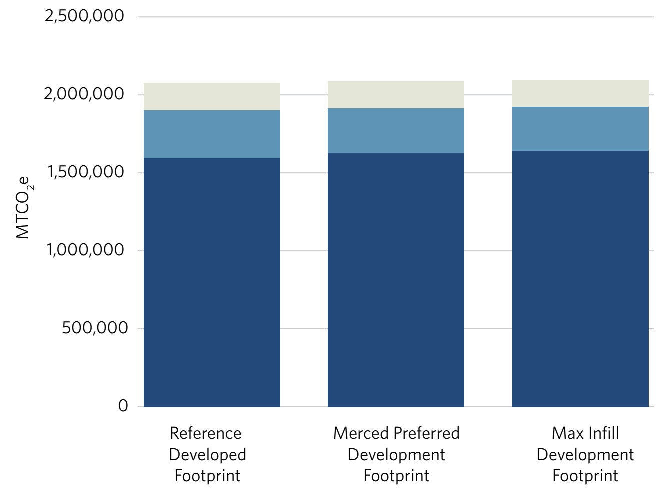
51 The Merced County preferred scenario was modified slightly to account for the county's planning window having a later end date than our project's forecasting window (2035 versus 2030).

Figure 4.15, below, shows the TerraCount results for the carbon stock changes and emissions reductions associated with a countywide max infill 2014–2030 development pattern versus the baseline reference scenario. The max infill scenario results in an increase in landscape carbon stocks (that is, CO_2 removals) of 47,658 $MTCO_2e$ by 2030 and a reduction in developed area of 4,990 acres compared with the reference development scenario. For the Merced preferred scenario, the corresponding figures are carbon removals of 34,783 $MTCO_2e$ compared with the reference scenario and a reduction of developed area of 3,750 acres. These figures represent only changes in landscape carbon stocks, not changes in land-based greenhouse gas emissions.

Average per-acre reductions are about 9 $MTCO_2e$ per acre—consistent with avoided conversion of land that is mainly annual cropland and grassland, which have relatively low carbon densities.



▲ **Figure 4.15.** Landscape carbon stocks, 2014–2030, for the max infill and reference development scenarios. In the Merced preferred scenario (not shown in chart), landscape carbon stocks in 2030 were estimated to be 12,875 MTCO2e lower than in the max infill scenario.



▲ **Figure 4.16.** Combined cumulative carbon removals and nitrous oxide and methane emission reductions, 2014–2030, for the reference development, Merced preferred, and max-infill scenarios.

Costs and benefits of avoided conversion (max-infill vs. reference)

Following methods presented in Appendix H, the cost associated with the avoided conversion applied in the max-infill scenario is $14,673,977. This figure reflects the estimated opportunity costs associated with forgone agricultural returns. The baseline reference scenario has an estimated opportunity cost of $38,103,282. The difference between the two scenarios suggests that avoiding or minimizing conversion could result in an estimated savings of $23,429,305 in agricultural returns.

The value of the net greenhouse gas reductions (20,562 $MTCO_2e$) calculated in the max-infill scenario, compared with the reference case, is estimated at $720,000, based on the social cost of carbon.[52] The value of the avoided loss of the flood risk reduction benefit provided by natural and working lands is estimated to be $1,200,000. Water demand increases slightly compared with the reference scenario.

Many other benefits are associated with avoiding or reducing the conversion of agricultural land and natural lands to urban development. These benefits are not quantified here; they include, but are not limited to, the maintenance of food production, resource-dependent jobs and habitat for fish and wildlife species, ongoing protection of air and water quality benefits, and flood protection.

52 This estimate considers only the landscape-related net greenhouse gas emissions reductions, assuming a social cost of carbon of $15.90 per $MTCO_2e$ in 2017 dollars. It does not estimate the net greenhouse gas emissions reductions in other sectors, such as transportation and energy, that may result from avoided conversion.

Avoided conversion at Flying M Ranch

▲ **Figure 4.17.** The Flying M Ranch.

In the 1980s, Jon Myers, an aviation pioneer, environmentalist and philanthropist, donated three conservation easements on his Merced County ranch, totaling 4,800 acres, to The Nature Conservancy, with the requirement that the land never be developed or converted to cropland. The value of the easements at the time of transfer was about $1.9 million for the 4,800 acres.

The Nature Conservancy permits limited grazing on the land, which is habitat for endangered species including the tri-colored blackbird, several species of freshwater shrimp, and a number of rare plants. The Flying M Ranch hosts a significant acreage of vernal pools and is part of the Merced Grasslands, one of California's largest vernal pool complexes. Figure 4.17 shows the location of the ranch and the extensive complexes of vernal pools in the area.

For our avoided conversion case study at the Flying M Ranch, we evaluated two alternative scenarios: full (100%) development of the ranch and partial (50%) development of the ranch. The tool was used to calculate the benefits of avoiding the land conversion associated with these development scenarios.

Compared with full development, conservation results in avoiding the conversion of 4,800 acres of natural land to developed land—thus avoiding a reduction in landscape carbon stocks of 44,116 $MTCO_2e$.[53]

In addition to the GHG benefits of avoided conversion at the Flying M Ranch, the tool reports on an array of associated environmental benefits from partial and full avoided conversion of the Flying M Ranch to development:

Water use: From avoiding conversion at the Flying M, the tool shows an annual conservation of almost 9,000 acre-feet per year compared with a scenario where the ranch was fully converted to developed land uses. With the land under conservation easement and managed for rangeland and habitat uses, water demand is (and will continue to be) very low.

Groundwater recharge: Groundwater recharge is reduced by about 2 acre-feet per year in the full-development scenario and by a very small amount in the partial-development scenario. The difference arises from the application of partial development to the southern half of the ranch, where groundwater potential (from the California Basin Characterization Model) is significantly lower than in the northern half of the Ranch.

Terrestrial connectivity: Avoiding conversion at Flying M Ranch results in the retention of high-species-movement-potential habitat on the ranch's lands. In the full-development scenario, the entire ranch is converted from natural land cover (high movement potential) to developed land cover (low movement potential). By conserving the ranch, this high-movement-potential habitat will not be lost.

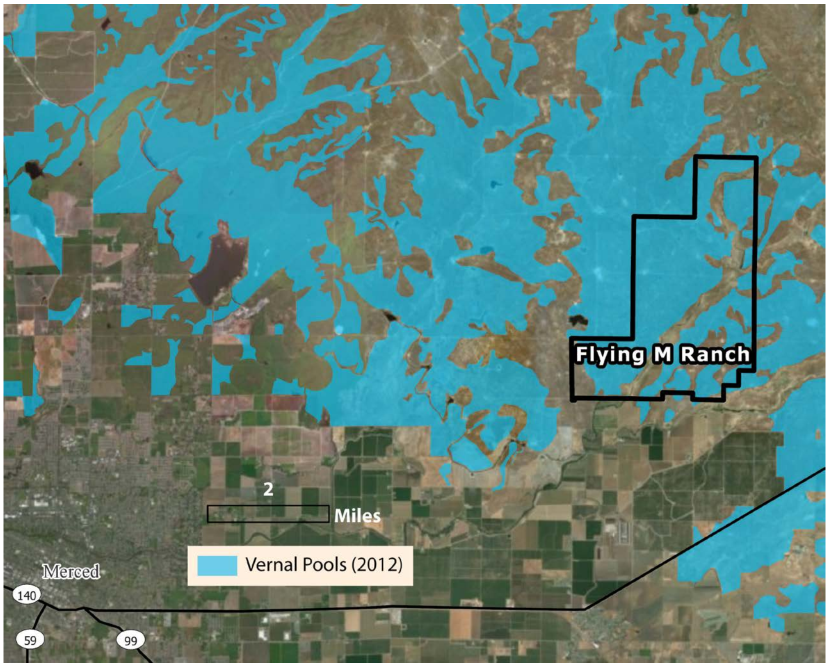
Habitat quality: The tool projects significant degradation to habitat quality by 2030 for amphibians, mammals, birds, reptiles and threatened and endangered species for both full-development and partial-development scenarios. Conserving the ranch avoids this degradation.

Air pollutant sequestration: The tool shows that avoiding conversion of the Flying M Ranch increases sequestration of all the major pollutants. Converting natural lands to development removes a large percentage of the vegetation that helps to sequester pollutants through dry deposition.

Highly visible land: Fully developing the Flying M Ranch would result in the conversion of about 40 acres of highly visible land (areas that can be seen from a large part of the county) to a developed land cover.

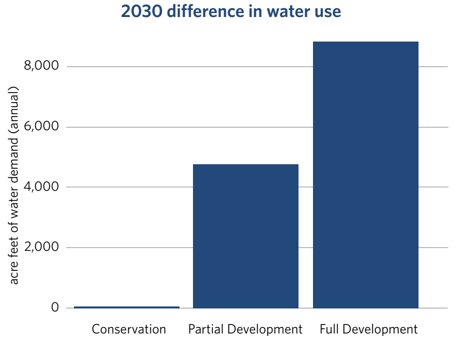
Resilience: The TerraCount results show that full development results in the conversion of more than 1,000 acres of natural land to developed land in areas defined as contributing to natural resilience. In the tool, natural resilience is the sum of two components: habitat stability and climate connectivity. The tool reports changes in land cover for areas that are either mapped as climate refugia (stable habitat)[54] or as climate linkages. Climate refugia are areas where current vegetation is predicted to be relatively stable and less vulnerable to climate change; climate linkages are areas that connect current to future climate zones.

53 The analysis does not consider emissions from residential and business activities on developed land, such as emissions associated with electricity and natural gas use.
54 Thorne JH, Choe H, Boynton RM et al. 2017. The impact of climate change uncertainty on California's vegetation and adaptation management. *Ecosphere* 8(12). https://doi.org/10.1002/ecs2.2021.



◀ **Figure 4.18.** The Flying M Ranch is located in a large complex of vernal pools on the eastern edge of the Great Valley.

▼ **Figure 4.19.** Impacts on complementary benefits in 2030 from the TerraCount evaluation of the Flying M Ranch partial development and full development scenarios compared with the conservation scenario: water use, groundwater recharge potential, terrestrial connectivity, terrestrial habitat value, air pollutant sequestration, scenic value and climate connectivity.



Development scenarios and transportation emissions estimates

Counties or other jurisdictions seeking to reduce GHG emissions jurisdiction-wide may wish to explore and understand potential synergies and benefits that could occur across economic sectors. For example, synergies to reduce GHG emissions could occur between land management and biomass energy production, where harvested materials from land may be used to produce biomass energy to displace fossil fuel combustion. Efforts to conserve or maintain natural and working lands to sequester carbon can also complement efforts to promote more compact development and reduce emissions from transportation (e.g., vehicle miles traveled, or VMT). With Merced County as an example, this guide provides some guidance on how a jurisdiction could explore this latter opportunity.

Use of travel models to estimate VMT

Use of a travel model or scenario planning tool is an effective way to estimate vehicle miles traveled (VMT) and corresponding GHG emissions. A reduction in VMTs may be used as a proxy for reducing emissions from transportation. Scenario planning tools like Envision Tomorrow can estimate VMTs based on different patterns of development across a jurisdiction or region. Other scenario tools that enable transportation analysis, like UrbanFootprint,[55] may also be used. In the case of Merced County, Envision Tomorrow's Household Travel App was used to estimate VMTs associated with different scenarios.

To explore the potential synergies between the conservation of Merced County's natural and working lands and VMT emissions, the development scenarios used in TerraCount (see Section 4) were applied within Envision Tomorrow to estimate VMTs. If a jurisdiction is interested in exploring the relationship between different land conservation scenarios, urban development and VMTs, it is important to use the same scenarios for TerraCount and the selected travel model.

Scenario Development

For the Merced County illustrations, several spatially explicit projections of 2030 urban land use that represent a range of development patterns were developed. As mentioned earlier (page 50), three scenarios were "painted," the reference scenario that simulates the development patterns of the project's baseline period (2001 to 2014), a max-infill scenario that focuses on developing the urban core, and Merced's County's preferred scenario, which was developed by the Merced County Association of Governments and represents Merced County's vision of developed land use in 2030 (Table 4.5). Each of the three painted scenarios assumed the same population growth and the same number of new jobs between 2014 and 2030.

55 See https://urbanfootprint.com.

As referenced previously, the three development scenarios were used in TerraCount to understand their implications on carbon and a suite of complimentary benefits.

Vehicle miles traveled (VMT) estimates from development scenarios

The Envision Tomorrow Household Travel App was used to estimate VMTs for each of the 2030 development scenarios. The results from the Household Travel App are shown in Table 4.6.[56]

Table 4.6. Vehicle miles traveled associated with different land conservation and urban development scenarios

2030 Development Scenario	VMT per Capita
Reference	13.7
Merced County preferred scenario	12.4
Max infill	12.7

Based on the results of the modeling, the baseline reference scenario would result in higher VMT than Merced County's preferred scenario and the max-infill scenario. The results highlight some synergies between efforts to reduce VMT and related greenhouse gas emissions and efforts to conserve land and avoid land carbon emissions. Note that the max-infill scenario has slightly higher VMT than the preferred scenario. This difference results from the max-infill scenario maximizing housing densities on vacant land, which means that much of the new housing and job creation would likely be located in areas outside of existing town centers where pedestrian connectivity and a mix of uses already exist.

The benefit of Merced County, or other jurisdictions, generating these VMT scenarios concurrent with land conservation scenarios (via TerraCount) is the ability to understand more fully the GHG implications of different land conservation and development scenarios and identify opportunities where climate and other benefits can be optimized.

For more detailed information regarding the VMT estimates and methods associated with these scenarios, please see Appendix I.

Accounting for leakage

In the context of accounting for the benefits of activities intended to increase landscape carbon stocks or reduce greenhouse gas emissions, "leakage" refers to the displacement of greenhouse gas emissions from one place to another due to such activities (see Appendix J). For instance, a restriction in one place on the development of natural land for housing (which would result in a loss of plant biomass and soil carbon, resulting in a net emission of CO_2e) may not result in a net avoidance of emissions, because land may be developed elsewhere.

There are two broad types of leakage. "Internal leakage" occurs within a jurisdiction, for instance from one parcel to another within the jurisdiction boundaries. "External leakage" represents leakage outside the jurisdiction.

The purpose of accounting for leakage is to avoid overestimates of the carbon benefit that results from an activity intended to reduce net greenhouse gas emissions. Greenhouse gases have the same impact on climate change regardless of where they are emitted, so local emissions reductions should be discounted by any emissions increases that happen elsewhere as a result of the activity.

A benefit of the jurisdictional monitoring approach presented in this guide is that, by estimating total landscape carbon stocks across the entire jurisdiction, it accounts for cases of internal leakage.

Identifying and addressing external leakage involves two main steps: determining whether leakage is likely, and then developing an appropriate remedy. Figure 4.20 presents a standard approach to this type of analysis.

Certain activities targeting landscape carbon storage are known to have low leakage risk, while others are known to have a high leakage risk. Activities with a low leakage risk include urban forestry and voluntary farming practices, such as mulching, reduced fertilizer use and the replacement of synthetic fertilizer with soil amendments such as compost. The restriction of urban development on natural or working lands is an activity with a notably high risk of leakage. Other high-risk activities include eliminating timber harvest on forestlands traditionally included for wood production and prohibiting the conversion of natural landscapes to agriculture production.

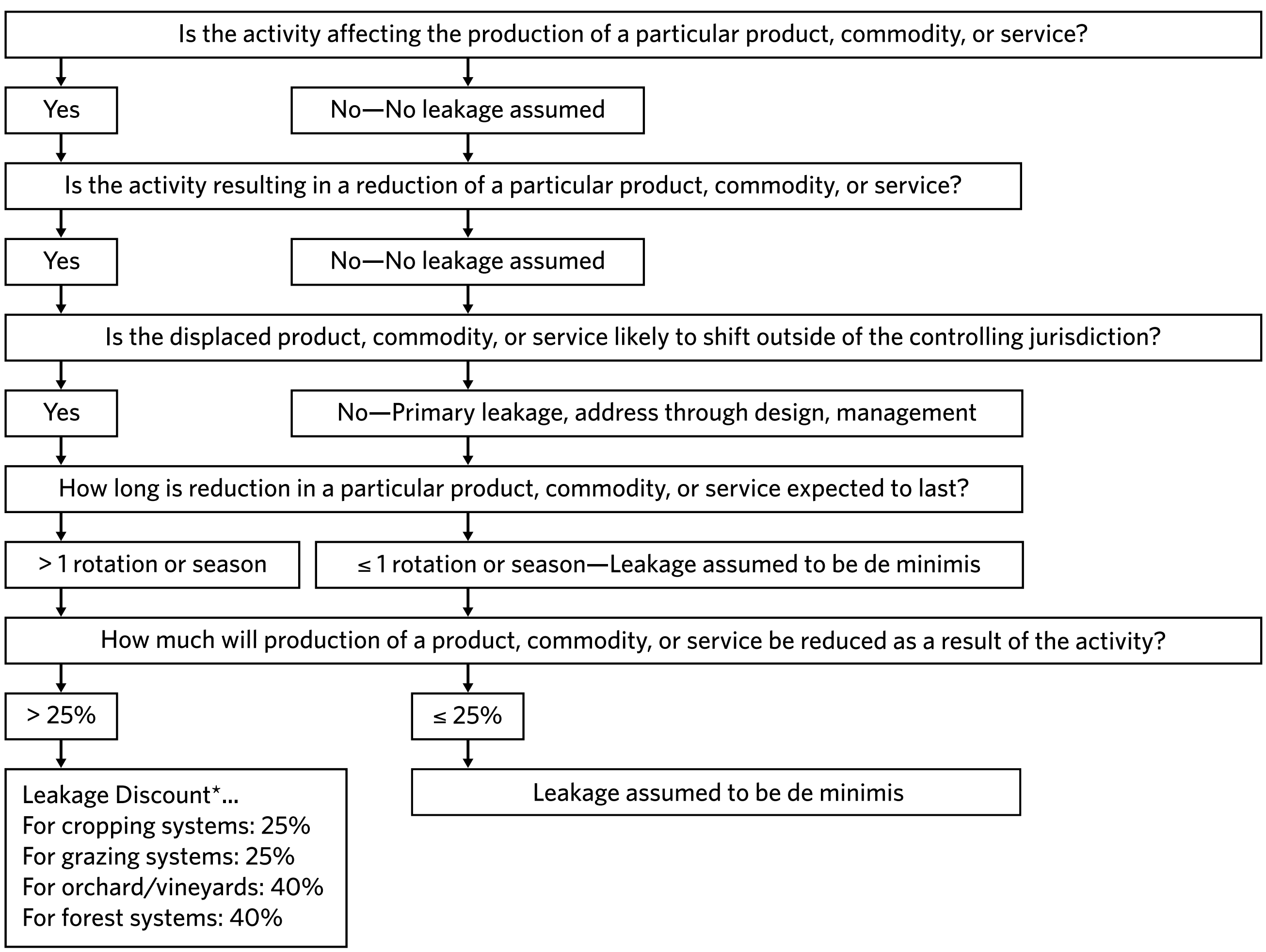
56 It should be noted that these VMT numbers are modeled estimates for household-based VMT (per capita). As such, they represent miles driven and trips originating from or ending at a place of residence. These metrics do not capture trips from outside Merced County ending in Merced County. In addition, they are a product of a single model and haven't been calibrated against local data or against a travel demand model.

Figure 4.20 presents a series of questions that help assess whether an activity's leakage risk can be captured and managed within the jurisdiction. Where that is not possible, it recommends standard discounts to emissions reduction estimates.

A general approach to avoiding leakage is to take steps to reduce the incentives to shift emissions-generating activities to new locations. Three examples of this approach follow:

- Afforestation on agricultural lands could be accompanied by efforts to increase the productivity of remaining agricultural lands, reducing the pressure to cultivate new lands.
- An industrial forest that is managed to hold more carbon over time could also continue some harvesting of forest products, or understocked areas could be restored and harvested to help minimize pressure to increase forest harvest elsewhere.
- Plans to increase the conservation of agricultural lands or open space could be balanced by increasing infill development in existing urban areas to absorb any decrease in housing development that was planned previously for the open space and agricultural areas that were conserved.

External Leakage Discount Assessment



*Discount applied to total estimated GHG reductions if one of these baseline conditions exists and is not ameliorated

▲ **Figure 4.20.** Evaluating and addressing leakage.

SECTION 5

Implementation: Tracking activities

© Devan King/The Nature Conservancy

As noted earlier, landowners can increase landscape carbon stocks and reduce annual greenhouse gas emissions by engaging in activities such as changes in land management and agricultural practices (see Table 4.1 for the list of activities developed in this guide).

This section describes a system, called activity sheets, for standardizing the implementation of activities and estimating the associated greenhouse gas benefits. It also suggests some general principles for processes to track the activities in a jurisdiction.

An activity sheet is a one-page form with information that specifies four types of information for a given greenhouse gas reduction activity on a particular land cover type—say, the planting of hedgerows (an activity) in vineyards (a land cover type). The four types of information are:

- the monitoring and reporting protocols to be followed
- the formulas to be used to generate estimates of greenhouse gas reductions
- likely impacts on other land-based values (referred to elsewhere in this guide as "complementary benefits")
- other considerations

An activity sheet establishes a standard for the implementation of a specific greenhouse gas reduction activity on a specific land cover type. It is a common point of reference for users, including landowners who are implementing or considering implementing activities and administrators of the jurisdictional greenhouse gas inventory program, such as county staff.

An example activity sheet is shown in Figure 5.1. Appendix K provides context and explanation for each element in the sheet.

Activity Sheet

Basic Activity Information and Requirements

Activity Identifiers	Activity Unique ID	Land Cover Type	Activity Name
	ORC-HPL	Orchard	Hedgerow planting

Definition of Activity	The activity case is the establishment of dense vegetation in a linear design to achieve a natural resource conservation purpose on areas managed as orchards. Implementation of the activity shall be based on NRCS Conservation Practice Standard 422.
Definition of Baseline	The baseline case is the continued management of orchards in areas where hedgerows are to be installed.

Criteria for Applicability of Activity	Land Cover Sub-Types	Land Cover Conditions	Other
	All orchard subtypes	Any orchard condition for which hedgerows would achieve one of the purposes stated under NRCS Conservation Practice Standard 422	Activity requires commitment to growing and maintaining hedgerow over reduction activity period

Activity Reporting

Landowner must report the following to [activity record keeping entity, e.g., registry]:

1. Assessors Parcel Numbers of parcels where activity is being implemented
2. Map of activity area, including total acreage upon which activity is being implemented
3. Date of activity initiation
4. Anticipated duration of activity (max. based on duration of analysis above)
5. Ongoing reporting throughout activity implementation (e.g., annual reports), as required and reviewed by [the jurisdiction]

Compliance Monitoring

Activity locations are subject to random selection for monitoring by [county officials] to ensure activity is being implemented and maintained for the entire activity duration period. Monitoring will be based on any one or a combination of the following: on-site visual inspection, receipts or other evidence of implementation, interviews with regulatory agency personnel with oversight over activity site, or requested submission of geotagged photographs. Additional monitoring may be conducted as determined by [the jurisdiction]. In the event of non-performance, [the jurisdiction] will determine the appropriate remedial actions.

GHG Assessment

GHG Pools		1 Standing Live and Dead Trees	2 Shrubs	3 Lying Dead Wood	4 Litter and Duff	5 Herbaceous	6 Soils	7 Harvested Wood Products
GHGs Addressed	CO_2	X	X	-	-	-	X	-
	CH_4	-	-	-	-	-	-	-
	N_2O	-	-	-	-	-	X	-

Leakage Estimate	Default Leakage Discount	Mitigating Condition That Lowers Probability of Leakage to 0%
	40%	If <25% of total production area associated with activity site is affected

Estimation of GHG Reductions

Total estimated reductions = $R \times I \times D \times (100\% - L)$

Where:

R = Per acre annual reduction rate	8.233	t CO_2e/acre/yr
I = Total acreage upon which activity is to be implemented	[*TBD*]	acres
D = Duration of activity, as committed to by landowner*	[*TBD*]	years
L = Leakage discount (default rate, unless mitigating condition present)	40%	

*Reduction rate is applicable for up to 10 years, which is the maximum duration of the activity.

Co-Benefits Associated with Activity

(-) = Decrease; (+) = Increase; (+/-) = Increase or decrease, depending on site conditions; [*blank*] = No change

Agricultural Quality

	Ag land quality
	Crop value

Climate Resilience

	Habitat stability
	Climate connectivity
	Flood risk attenuation
	Groundwater banking potential

Human Well-Being

+	Air quality
+	Scenic value
	Flood risk reduction

Water Quality

	Ag/urban water conservation
+	Water quality
	Groundwater recharge potential
+	Watershed integrity

Biodiversity

+	Terrestrial connectivity
+	Natural habitat area
+	Priority conservation areas
+	Terrestrial habitat value
+	Aquatic biodiversity value/richness

▲ **Figure 5.1.** An example of an activity sheet—in this case for hedgerow planting (an activity) on orchard land (a land cover type). See Appendices K and L for documentation and all of the activity sheets developed for Merced County.

For Merced County, 93 activity sheets were developed (Appendix L). They represent a subset of all possible combinations of an activity and a land cover type. Activity sheets were developed for the combinations judged to be most likely to be implemented by landowners, based on guidance from local experts in Merced County (Appendix E). Links to all 93 activity sheets are provided in Table 5.1:

Table 5.1. Links to activity sheets

Activity	Link to activity sheets for all combinations of land cover and activity evaluated
Improved nitrogen fertilizer management	https://carb.press/fertmngmt
Replacing synthetic nitrogen fertilizer with soil amendments	https://carb.press/compost
Oak woodland restoration	https://carb.press/oak-restoration
Cover crops	https://carb.press/covercrops
Mulching	https://carb.press/mulching
Riparian restoration	https://carb.press/riparian-restoration
Urban forestry	https://carb.press/urban-tree-planting
Hedgerow planting	https://carb.press/hedgerow
Avoided conversion to croplands	https://carb.press/ac-cropland
Avoided conversion to urban	https://carb.press/ac-urban
Compost application to non-irrigated grasslands	https://carb.press/cag
Native grassland restoration	https://carb.press/grass-restoration
Silvopasture establishment[57]	http://carb.press/silvo

57 Note: Silvopasture establishment is not included as an option in TerraCount, but activity sheets have been developed for it.

Monitoring progress over time

Changes in carbon stocks and complementary benefits values over time are assessed through **monitoring**, which consists of three main elements:

1. repeating the **jurisdictional inventory**
2. evaluating the changes in landscape carbon stocks associated with specific land management or agricultural **activities**
3. repeating the **complementary benefits assessment**

Repeating the jurisdictional inventory: Timing

The jurisdictional inventory should be repeated every 5 to 10 years.

A key reason not to repeat the inventory more frequently is that some of the data sets on which the process relies are updated only once every few years; data sets must be updated in order for the inventory process to detect changes. In addition, the inventory process is costly and time-consuming and requires technical resources.

The main reason to avoid allowing too much time to pass before repeating the inventory is the likelihood that the baseline reference scenario will become significantly inaccurate. For this reason, repeating the inventory before 10 years pass is recommended.

Monitoring implementation of activities

As explained above, the jurisdictional inventory provides a countywide estimate of landscape carbon stocks net of emissions. Repeating the inventory provides estimates of large-scale changes in land cover and the associated changes in landscape carbon stocks net of emissions. However, as is also explained above, the jurisdictional inventory methods will not detect changes in landscape carbon stocks arising from activities. To assess the cumulative effect of activities, they must be monitored separately.

The activity sheets (Section 5) lay out the approach to monitoring each type of activity. There are two general types of monitoring for activities: performance monitoring and compliance monitoring.

Performance monitoring seeks to estimate the net greenhouse gas reductions associated with the implementation of the activity. Following the template provided in the activity sheets, performance monitoring gathers data on the duration and extent of the activity as well as measures of its results—the degree to which the intended increase in woody vegetation, for instance, was successful (in the case of an implementation of riparian restoration, hedgerow planting or oak woodland restoration).

Compliance monitoring and reporting is designed to provide assurance that activities are being implemented in accordance with initial plans and documentation. Compliance monitoring focuses on ensuring that the landowner or implementing agency is following through.

Repeating the complementary benefits assessment

As with the jurisdictional inventory, the complementary benefits assessment can be repeated to incorporate updated sources of data. However, some data sources for these benefits change little over time, or are structured so that comparisons over time are not likely to be instructive.

For the Merced County example, 13 of the 18 can be usefully updated over time. These are:

- Agricultural land quality
- Crop production value
- Water quality (because it relies on broad land covers, e.g., riparian restoration)
- Watershed integrity
- Flood risk reduction
- Terrestrial connectivity
- Natural habitat area
- Priority conservation areas
- Terrestrial habitat value
- Aquatic biodiversity
- Flood risk attenuation
- Groundwater banking potential
- Habitat stability
- Climate connectivity

For detail on the data sources, see Appendix F-2.

SECTION 7

Recording information

© Bridget Besaw

To accurately tally the increases in landscape carbon stocks and reductions in greenhouse gas emissions that may result from the implementation of many activities across a jurisdiction, a system is needed to record information about the activities.

To facilitate analysis and reporting, a database system should be established to record information about activities undertaken in the jurisdiction. Such a system is typically called a registry.

As with any data repository, investment in careful design as well as resources for ongoing maintenance are critical to a well-functioning and useful system. Concerns about landowner privacy and data security must also be addressed.

More considerations for registry design are included in Appendix M.

Complementary uses

While the GHG accounting method and tool presented in this guide focus on land-based opportunities for climate mitigation, they can also support or be integrated with other policy or management objectives, given their complementary benefit nature. Below are descriptions of just a few state and local examples.

California state policies

The Sustainable Groundwater Management Act (SGMA)

SGMA requires governments and water agencies of high and medium priority basins to halt overdraft and bring groundwater basins into balanced levels of pumping and recharge. Under SGMA, these basins should reach sustainability within 20 years of implementing their sustainability plans.[58]

TerraCount may be used to identify opportunities to achieve both GHG reductions and groundwater recharge and places where GHG reduction activities on fallow lands may be eligible for state funding.

California Environmental Quality Act (CEQA) mitigation

Under CEQA, lead agencies must analyze the greenhouse gas emissions of proposed projects and must reach a conclusion regarding the significance of those emissions (see CEQA Guidelines § 15064.4). When a project's greenhouse gas emissions may be significant, lead agencies must consider a range of potential mitigation measures to reduce those emissions (see CEQA Guidelines § 15126.4(c)). Lead agencies must analyze potentially significant impacts associated with placing projects in hazardous locations, including locations potentially affected by climate change (see CEQA Guidelines § 15126.2(a)). Lead agencies may significantly streamline the analysis of greenhouse gases on a project level by using a programmatic greenhouse gas emissions reduction plan meeting certain criteria (see CEQA Guidelines § 15183.5(b)).[59]

TerraCount can show how and where activities can reduce GHG emissions and potential for habitat mitigation.

The Sustainable Communities and Climate Protection Act of 2008 (SB 375)

SB 375 supports the state's climate action goals to reduce greenhouse gas (GHG) emissions through coordinated transportation and land use planning, with the goal of more sustainable communities.[60]

Under SB 375, CARB sets regional targets for GHG emissions reductions from passenger vehicle use. In 2010, CARB established these targets for 2020 and 2035 for each region covered by one of the state's metropolitan planning organizations (MPO). ARB will periodically review and update the targets as needed.

Each Sustainable Community Strategy (SCS) is required to consider "the best practically available scientific information regarding resource areas and farmland in the region." (Cal. Gov. Code § 65080(b)(2)(B).) Farmland is defined as agricultural land that is 1) outside urban spheres of influence (SOIs) as they existed on January 1, 2008, and 2) classified by the state or a local agency as prime, of statewide importance or unique (collectively, "important farmland") (Cal. Gov. Code § 65080.01(b)). To the extent that these areas are treated as constraints to development in MPOs' land use scenarios—or actively conserved as part of a regional mitigation program—SCSs can help direct growth away from habitat, farmland and open space.

SB 375 calls upon MPOs or county transportation agencies to "consider financial incentives for cities and counties that have resource areas or farmland," such as transportation investments related to agriculture and "financial assistance for counties . . . that contribute towards the [GHG] reduction targets by implementing policies for growth to occur within their cities" (Cal. Gov. Code § 65080(b)(4)(C)).

TerraCount and the landscape carbon and land-based emissions inventory methods presented in this guide complement strategies in SB 375 by providing a landscape-level assessment of those resources that can support SCSs and potentially identifying complementary reductions that can be achieved through the land sector, in combination with efforts to reduce vehicle miles traveled.

58 See https://www.water.ca.gov/Programs/Groundwater-Management/SGMA-Groundwater-Management.
59 See http://opr.ca.gov/ceqa/climate-change.html.
60 See https://www.arb.ca.gov/cc/sb375/sb375.htm.

The 2018 Safeguarding California Plan

This plan is the state's road map for everything state agencies are doing and will do to protect communities, infrastructure, services and the natural environment from climate change impacts. The plan is intended to serve as a guide for State government that both makes its efforts transparent to the public and holds agencies accountable for real progress. It lays out the next steps to achieve the State's climate resilience goals and how those objectives will be achieved. The plan first describes overarching strategies recommended by the California Natural Resources Agency, the State's lead agency on climate change adaptation, and then outlines ongoing actions and next steps to make California more resilient to climate change.

TerraCount provides a resilience index, which identifies activities to enhance climate resilience: http://resources.ca.gov/climate/safeguarding.

The California Water Action Plan

This plan is a road map for the first 5 years of the state's journey toward sustainable water management. It provided the foundation for Proposition 1, the 2014 water bond, and the administration's legislative agenda. The California Water Action Plan was developed to meet three broad objectives: more reliable water supplies, the restoration of important species and habitat, and a more resilient, sustainably managed water resources system (water supply, water quality, flood protection and environment) that can better withstand inevitable and unforeseen pressures in the coming decades.

This project will help identify groundwater recharge opportunities as well as optimize GHG reduction activities and water quality, such as improved forest management and riparian restoration: http://resources.ca.gov/california_water_action_plan.

California Air Resources Board Scoping Plan target for natural and working lands

In the 2017 update to the Air Resource Board Scoping Plan, a greenhouse gas reduction target was set for the natural and working lands sector. The plan states, "We should aim to manage our natural and working lands in California to reduce GHG emissions from business-as-usual by at least 15-20 million metric tons in 2030" (ES13). This tool can inform land conservation and management actions to achieve reductions and provide technical infrastructure for GHG accounting: https://www.arb.ca.gov/cc/scopingplan/scoping_plan_2017.pdf.

California Climate Investments

California Climate Investments (CCI) is a statewide initiative that puts billions of cap-and-trade dollars to work reducing greenhouse gas emissions. The expenditure of these funds is determined every year in the budget process and to date has allocated hundreds of millions of dollars for natural and working lands projects. This tool can help counties tap into this funding source: https://ww2.arb.ca.gov/our-work/programs/california-climate-investments.

County/local policies

Agricultural mitigation programs

The 2030 Merced County General Plan recognizes the need for protection of the county's agricultural resources. Specifically, the Agricultural Land Mitigation policy calls for "establishing and implementing an agricultural mitigation program that matches acres converted with farmland acres of similar quality to those converted preserved at a 1:1 ratio." In Merced, the Board of Supervisors has determined that, in some circumstances, it is in the best interest of the people of Merced County to allow conversion of agricultural land to proceed, but to also require that such conversion be accompanied by mitigation that provides increased protection for other, comparable agricultural land. This tool can be used to identify candidate areas for protection.

Climate action plans

TerraCount can help inform local climate action plans as counties determine the best suite of actions to take to reduce their greenhouse gas emissions. By informing the inventory and reduction potential of different actions, counties can better incorporate natural and working lands into their local climate action planning.

Community plans

TerraCount can serve as a decision support tool, helping counties look at constraining urban growth and at how to conserve fringe areas of the county's urban areas.

Conclusions

Counties and local governments are among the key entities that are impacted by climate change. Many are searching for the best ways to address it at a local level.

As this guide shows, conservation, restoration and changes in land management and agricultural practices offer significant opportunities for counties and landowners to address climate change and reduce GHG emissions while achieving important complementary benefits such as protection of air and water quality, preservation of biodiversity, and conservation of prime agricultural land and habitat for fish and wildlife species.

Merced County, the case study in this guide, illustrates several of these opportunities.

Other counties may also be interested in including land use and land management as part of their long-term climate plans and strategies. This guide, including its GHG accounting framework and tool, are designed to support counties and landowners in doing so.

It is a tool kit to help counties understand the climate value of their lands and how to integrate this value most effectively into long-term plans to optimize benefits for the climate and their communities.

The guide provides a tool and a standard accounting method for counties to estimate the GHG reduction potential of different land use and land management scenarios throughout their jurisdictions. It also provides a method and guidance for incorporating other complementary public benefits that may be achieved through different land-based activities. Guidance is also provided for implementing the activities and monitoring and reporting progress over time.

Counties and other jurisdictions may now, like Merced County, use this overall framework to support their climate plans, their land management and conservation goals, and other desired public benefits. The state may also use this framework to align state climate policy incentives with local planning and implementation.

© David Sanger

© slobo/istock

Appendix A: Glossary of terms and acronyms

Baseline reference scenario: a counterfactual scenario against which changes in CO_2 removals and greenhouse gas emissions are measured over time

Biological emissions: greenhouse gas emissions that are released directly from biomass, both alive and dead, including soils

Carbon dioxide removal: the calculated total amount of carbon dioxide removed from the atmosphere for a period of time

Carbon pools: a greenhouse gas reservoir where carbon is stored in biomass, such as roots, leaves, soil, branches, trunks and wood products

Carbon sequestration: the process by which carbon dioxide is removed from the atmosphere and stored over time in carbon reservoirs, or "sinks," such as forests, soils and oceans

Carbon stocks: the quantity of carbon contained in living and dead biomass, including leaves, branches, trees, roots, soil and harvested wood

Complementary benefits: ancillary public and environmental benefits that result from the implementation of activities to reduce or remove GHG emissions

External leakage: leakage (see "leakage" definition below) that occurs outside of the jurisdiction

Global warming potential: the relative warming of a greenhouse gas over a specified period of time, as compared with carbon dioxide (GWP of 1). GWP allows for the conversion of different greenhouse gas emissions into the same emissions unit, carbon dioxide equivalents (CO_2e).[61]

Greenhouse gas: those gaseous constituents of the atmosphere, both natural and anthropogenic, that absorb and emit radiation at specific wavelengths within the spectrum of thermal infrared radiation emitted by the earth's surface, by the atmosphere itself and by clouds. This property causes the greenhouse effect.[62]

Greenhouse gas reduction: a calculated decrease in GHG emissions relative to a project baseline over a specified period of time[63]

Greenhouse gas removal: the calculated total mass of a GHG removed from the atmosphere over a specified period of time[64]

Indirect effects: unintended greenhouse gas emissions, reduction or removals that are indirectly facilitated, in part or in whole, by actions to reduce emissions elsewhere or in another economic sector

Internal leakage: leakage (see below) that occurs within the jurisdiction as a result of an activity

Land-based greenhouse gas emissions: greenhouse gas emissions associated with the management and disturbance of land

Leakage: the displacement of greenhouse gas emissions from one place to another due to emission-reduction activities. It is caused by a direct or indirect shift of activities that create those emissions from within an emissions accounting system to outside of that system.[65]

Activity (or nested activity): land management, restoration or conservation activity within a jurisdiction (e.g., landowner scale) that reduces or removes greenhouse gas emissions

Acronyms

C: carbon

CH_4: methane

CO_2e: carbon dioxide equivalent

MTCO_2e: metric ton of carbon dioxide equivalent

N_2O: nitrous oxide

GHG: greenhouse gas

GWP: global warming potential

VMT: vehicle miles traveled

61 https://ww2.arb.ca.gov/about/glossary.
62 https://ww2.arb.ca.gov/about/glossary.
63 https://www.arb.ca.gov/cc/capandtrade/ctlinkqc.pdf.
64 https://www.arb.ca.gov/cc/capandtrade/ctlinkqc.pdf.
65 Henders S and Ostwald M. 2012. Forest carbon Leakage Quantification Methods and Their Suitability for Assessing Leakage in REDD. Forests 3: 33–58. https://doi.org/10.3390/f3010033.

Appendices

Appendices B through M are online at:
https://maps.conservation.ca.gov/TerraCount/Documents/

Appendix B: Resources for counties, landowners and other users

Appendix C: Inventory methods and detailed results

Appendix D: Custom classification methods detail

Appendix E: Merced County agricultural expert survey

Appendix F: TerraCount tool manual

Appendix F-2: Detail tables for complementary benefits and activities

Appendix G: TerraCount tool data-processing overview

Appendix H: Cost-benefit analysis methods

Appendix I: Vehicle miles traveled methods

Appendix J: Leakage discussion and references

Appendix K: Activity sheets documentation

Appendix L: Merced County activity sheets—all

Appendix M: Considerations for systems to record information

"Prior to this project, the county did not have the means to quantify the greenhouse gas implications of community land use decisions as related to the management and conservation of working lands. This tool will enable county staff to do just that, which supports the community's decision making process as policy and planning work continues. In addition, the tool provides the ability to identify other benefits associated with conservation and improved land management. We look forward to using this tool to support and work with local landowners who want to manage their land in a more sustainable manner."

—STEVE MAXEY, MERCED COUNTY

"Over the past few years I have seen more heat and drought conditions in Merced County. As a farmer my goal is to produce more crop which means I need to be sure we have the healthy soils and healthy water. I can help do this with putting in cover crops and hedgerows to build up the soil with carbon which will allow more water penetration to store that most valuable resource we need, water."

—JEAN OKUYE, MERCED FARMER

"As climate change exacerbates water scarcity and threatens wetland habitat in the Grassland Ecological Area of Merced county, Resilient:Merced can help inform our management decisions to maximize carbon sequestration and refuge water-related co-benefits. This county guide and the TerraCount tool will be great resources for us, helping to characterize land use changes and prioritize wildlife conservation and working lands easements as well as steer habitat restoration in and around our last remaining Central Valley Wetlands."

—RIC ORTEGA, GRASSLAND WATER & RESOURCE CONSERVATION DISTRICTS

CALIFORNIA CONSERVATION

The Nature Conservancy