SACRAMENTO MUNICIPAL UTILITY DISTRICT

SACRAMENTO COUNTY LANDSCAPE CARBON ASSESSMENT

INITIAL STUDY

DECEMBER 2017

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BACKGROUND

The Sacramento Municipal Utility District (SMUD) has long recognized the threats posed by climate change, and the imperative that the region, nation, and global community faces in mitigating emissions and preparing for the inevitable impact. Through strong leadership from its Board of Directors, SMUD was the first large California utility to receive more than 20% of its energy from renewable resources, and currently 50% of its power comes from carbon-free sources as part of the strategy for SMUD to reduce greenhouse gas (GHG) emissions to 10% of 1990 emissions by 2050. SMUD's Board of Directors has also established the organizational directive to "provide leadership in the reduction of the region's total emissions of greenhouse gases through proactive programs in all SMUD activities and development and support of national, State, and regional climate change policies and initiatives."[1] In support of that objective, this study seeks to improve understanding of landscape carbon sinks in Sacramento County, and opportunities to maximize landscape carbon storage in the decades to come. These findings are relevant to several audiences, including: planners seeking to understand how best to balance competing land use priorities; land owners who have the opportunity to play a vital role in contributing meaningful climate mitigation; policymakers that can help spur local actions through programs and incentives; and SMUD, which can lead through example, provide support for emission reduction activities, and has a vested interest in achieving regional climate objectives in a cost effective and equitable manner.

Conceptually, this study aligns with work being done at the state and local levels. The California Air Resources Board is working to develop statewide landscape carbon inventories as well as models such as the California Natural and Working Lands Carbon and GHG Model (CALAND)[2] to assess the impacts of land management practices on net GHG emissions. Nongovernmental organizations like The Nature Conservancy (TNC) are actively developing and testing county-level frameworks to align conservation planning climate change objectives, and the Sacramento Area Council of Governments' (SACOG) is promoting integrated, multivariable conservation and land use planning that includes climate mitigation.

To build on, leverage, and improve all this precedent and concurrent work, SMUD engaged stakeholders from each of these communities to form a workgroup that met several times over the course of approximately six months to inform the methodology, discuss findings, and provide recommendations. The Workgroup consisted of members of SMUD, the Environmental Council of Sacramento County (ECOS), SACOG, and TNC as described in Chapter 1. The County of Sacramento was also invited to participate.

In addition to estimating the current (2014) landscape carbon storage of Sacramento County, this study sought to forecast landscape carbon storage under various development scenarios to understand the impact of land use planning on GHG emissions. Further, while understanding GHG impacts is important, SMUD recognized that impacts cannot be and should not be evaluated in isolation. Leveraging work being done for SACOG, the landscape carbon storage data was incorporated into a Marxan-based model that seeks efficient solutions for

[1] Sacramento Municipal Utility District (SMUD). Our Board of Directors. Available at: https://www.smud.org/en/about-smud/company-information/board-of-directors/

[2] More information can be found online at: http://resources.ca.gov/wp-content/uploads/2017/01/CALAND-Technical-Description_9.22.17.pdf

meeting multiple spatially-explicit carbon goals. This study had five goals with corresponding outcomes, as summarized in **Figure 1**.

	Project Goals		Project Outcomes
1	Quantify the current landscape carbon storage in Sacramento County, prioritizing existing and available data	→	GIS-based model that incorporates soil and biomass carbon densities and quantifies landscape carbon storage
2	Forecast Sacramento County landscape carbon storage under varied land use projections	→	Model incorporating forecast data based on land use constraints and population dynamics
3	Develop and test method for incorporating carbon as an explicit conservation benefit in land use decision-making frameworks	→	Marxan-based model that optimizes conservation designs using carbon as an input variable
4	Explore the potential for landscape carbon sequestration projects in Sacramento	→	Three project concept reviews assessing suitability, carbon potential, and cost considerations
5	Expand understanding of the technical potential for increasing landscape carbon storage in Sacramento County	→	Quantified technical potential based on land use outcomes and incorporating conservation actions

Figure 1. SMUD technical goals and outcomes for landscape carbon assessment

RESULTS AND FINDINGS

Each of the five technical goals and its corresponding outcomes are discussed below.

1 In order to evaluate landscape carbon storage and scenarios in Sacramento County, the team constructed a GIS-based model that leveraged existing public data assets, and incorporated best practice. The model draws land classification data from USGS's LANDFIRE program, soil carbon densities from the NRCS's gSSURGO database, and biomass carbon densities from the California Air Resources Board. These data were selected on the basis of their availability, broad use, update schedules, and suitability to the Sacramento County region. Data manipulations focused on, for example, adapting soil data to reflect losses from agricultural and urban development, and were based on literature reviews. The methodology for this study required the review of multiple data sources and methods through consultation with the Workgroup, many of which – though not used in this model – have great merit. The selected data and processing algorithms were imported and built into a spatially explicit model and used to estimate a current landscape carbon inventory for the county. Based on an evaluation of current land use in Sacramento County, the current landscape carbon storage totals approximately 36.3 million metric tons carbon dioxide-equivalent ($MTCO_2e$). The urban, general agriculture and shrubland categories dominate the land area and landscape carbon storage in Sacramento County (**Figure 2**). This chart illustrates how the land category-specific carbon densities impact carbon stored in the landscape. For example, forests only account for 2 percent of the land area in Sacramento County but represent 8 percent of the carbon stored in the landscape. This idea will be important for land use planners to consider as developing over certain land covers without enhanced management or supportive policy development, even if the land area is small, will have a higher carbon impact than others.

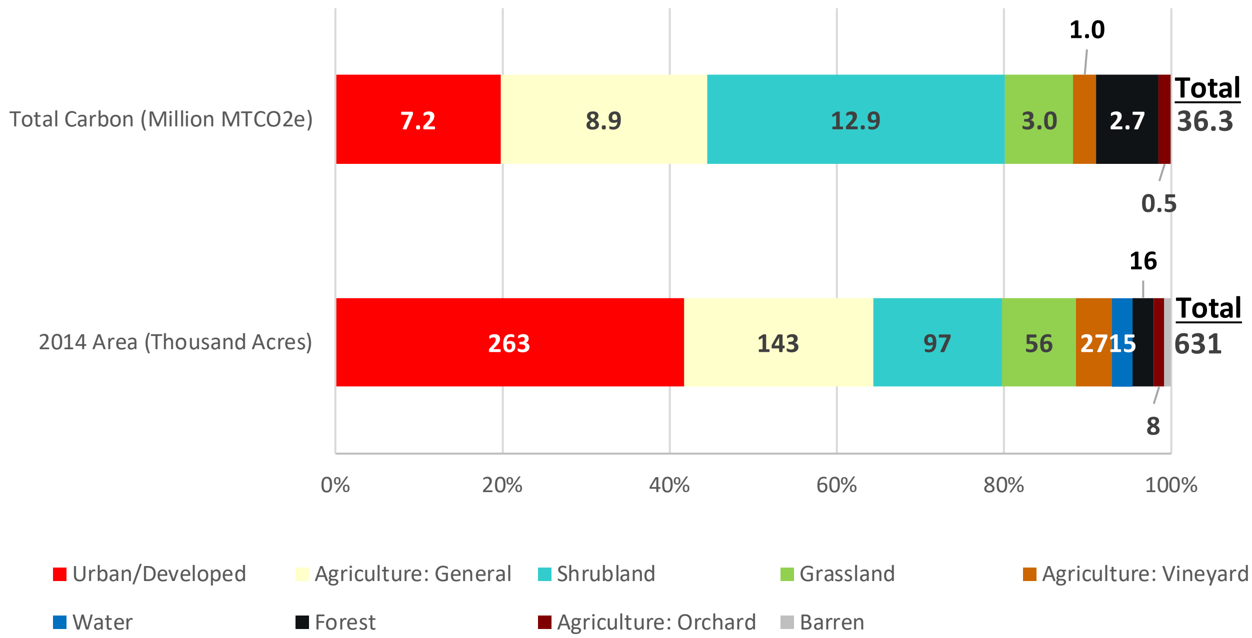

Figure 2. 2014 land area and landscape carbon storage by percentage of totals for each of the land uses and land covers evaluated in this project.

2

To forecast landscape carbon under varying development scenarios, this study used the UPlan urban growth development scenarios to evaluate three distinct growth patterns: business-as-usual, compact new growth, and infill. These 2050 scenarios were used to illustrate how landscape carbon stocks could change as a result of land-use planning in the coming decades. New growth was incorporated into our model to reflect how various land use and land covers may shift into the urban footprint, as shown in **Figure 3**. There was relatively little overall difference between the footprints of the business-as-usual and compact new growth scenarios, but the infill scenario retained a higher share of landscape carbon (**Figure 4**). The business-as-usual scenario would result in new emissions of 5.2 million $MTCO_2e$ (via a reduction in the 2014 baseline stored carbon estimate), which exceeds the 2015 emissions of unincorporated Sacramento County.[3]

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[3] Ascent Environmental. November, 2016. Sacramento County Communitywide CAP, Technical Memo #1 -2015 GHG Emissions Inventory. Available at: http://www.per.saccounty.net/PlansandProjectsIn-Progress/Pages/CAP.aspx

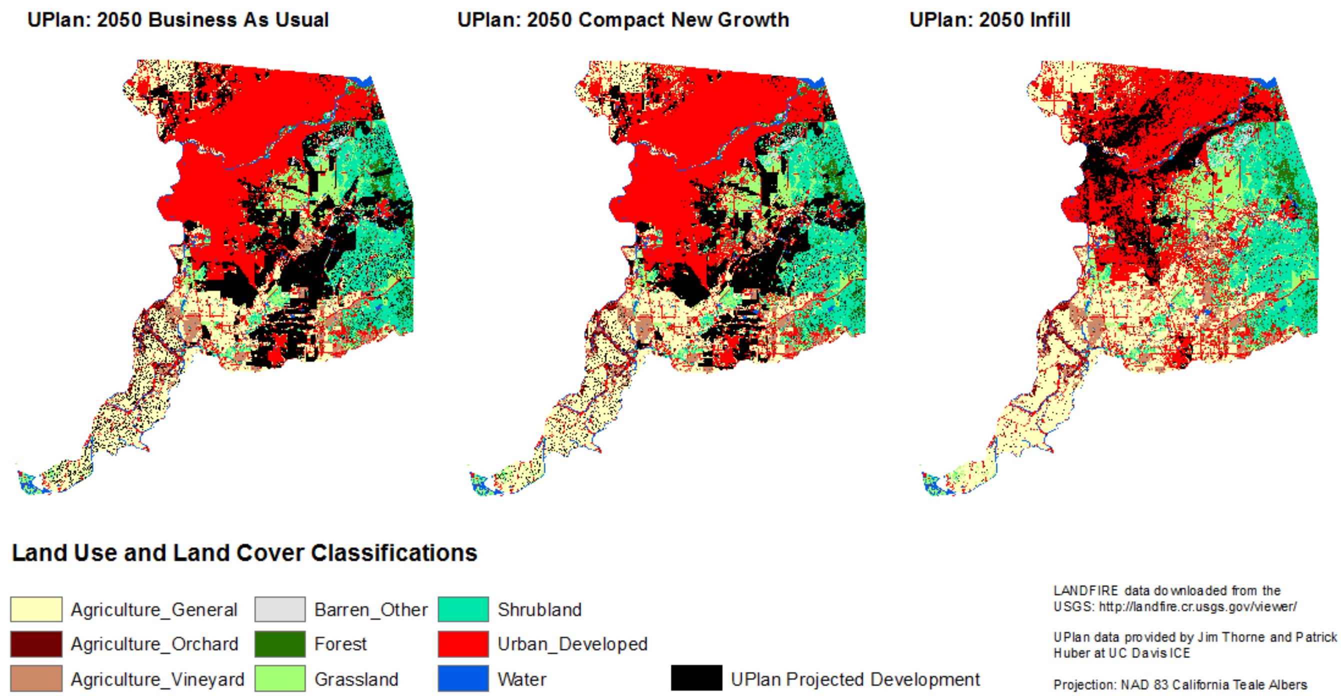

Figure 3. Projected 2050 urban development under UPlan's Business as Usual, Compact New Growth and Infill scenarios.

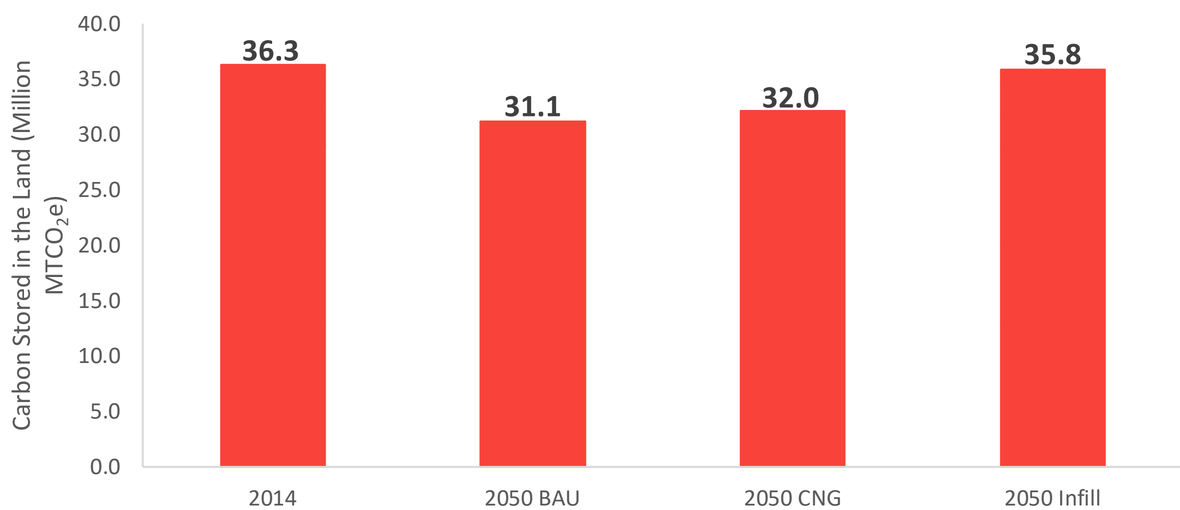

Figure 4. Carbon contained in Sacramento County land for 2014 and the 2050 scenarios.

3 While evaluation of the UPlan data does showcase an opportunity to leverage land use planning to maintain and expand landscape carbon stocks in Sacramento County, it does not provide a mechanism to actively do so. Using a modeling framework currently under development for SACOG, this study incorporated landscape carbon data into Marxan, a software platform that optimizes land use for multiple conservation benefits. Using Marxan in a policy-informative manner requires extensive stakeholder input to set

priorities and targets. However, as a proof-of-concept and precursor to an active policy discussion, multiple Marxan test runs were used to demonstrate how landscape carbon can drive conservation and land use planning both as a single variable and in combination with additional priorities such as farmland preservation. While the Marxan outputs in this study were developed with arbitrary targets both to demonstrate the capability, and assess the sensitivity of the model to parameter variability, Marxan did successfully identify high priority areas based on the input conditions. The outputs themselves should not be construed as recommendations or used to inform any planning decision at this time, but the successful integration of landscape carbon data into the framework removes a significant barrier to integrated, multi-variable planning that reflects a focus on landscape carbon. The outcomes from this type of assessment can be used to identify the locations most susceptible to the tradeoff between the carbon and agricultural preservation goals of the region and the expansion of urban areas.

4 Proactive planning that considers and maximizes landscape carbon can be an important climate mitigation strategy, but there are also opportunities to improve carbon storage through specific new or expanded practices. These practices include well-established strategies like hedgerow planting, riparian forest buffers, windbreak/shelterbelt establishment, and silvoplasture[4] that are being incentivized through the California Department of Food and Agriculture (CDFA) Healthy Soils Program, and more novel techniques like biochar application. We evaluated three sample project concepts to understand the suitability and potential climate benefit of these activities in Sacramento County.

1 **Urban Forestry**: planting of additional urban trees is highly aligned with Sacramento's General Plan and SMUD's shade tree program, can greatly achieve meaningful carbon sequestration, and provides significant co-benefits to the communty.

2 **Nutrient Managment**: optimizing fertilizer application rates and sources can reduce nitrous oxide emissions and bolster soil carbon. With agriculture being the second largest land use in the county behind urban development, there is significant opportunity to work with agricultural stakeholders to promote nutrient management and other agricultural activities that reduce emissions or sequester carbon.

3 **Biochar**: Biomass that has undergone pyrolisis or gasification results in a charcoal that stabilizes carbon for extended periods of time and can be applied to agricultural and other lands to improve soil carbon. However, the impact on agricultural productivity – particularly in a region with rich soils like Sacramento County – is uncertain and potentially adverse, and requires further study.

These three activities are examined in greater detail, but are not exhaustive nor fully representative of the opportunities in Sacramento County.

5 By combining the findings from the development scenarios with opportunities from specific activities, we can begin to see the potential not only to reduce emissions from landscape carbon, but to use community lands as a vehicle for reversing the forecasted loss. Relative to the business-as-usual scenario, pursuing a development future consistent with the infill scenario can reduce emissions by approximately 4.7 million $MTCO_2e$ (see **Figure 5**), resulting in losses from 2014 of only 0.5 million $MTCO_2e$ rather

[4] https://www.nrcs.usda.gov/wps/portal/nrcs/detailfull/national/technical/cp/ncps/?cid=nrcs143_026849

than 5.2 million $MTCO_2e$ for the BAU scenario. However, as additional activities like expansion of urban forests and improving nutrient management are layered in, total landscape carbon storage may increase relative to current levels (**Figure 6**).

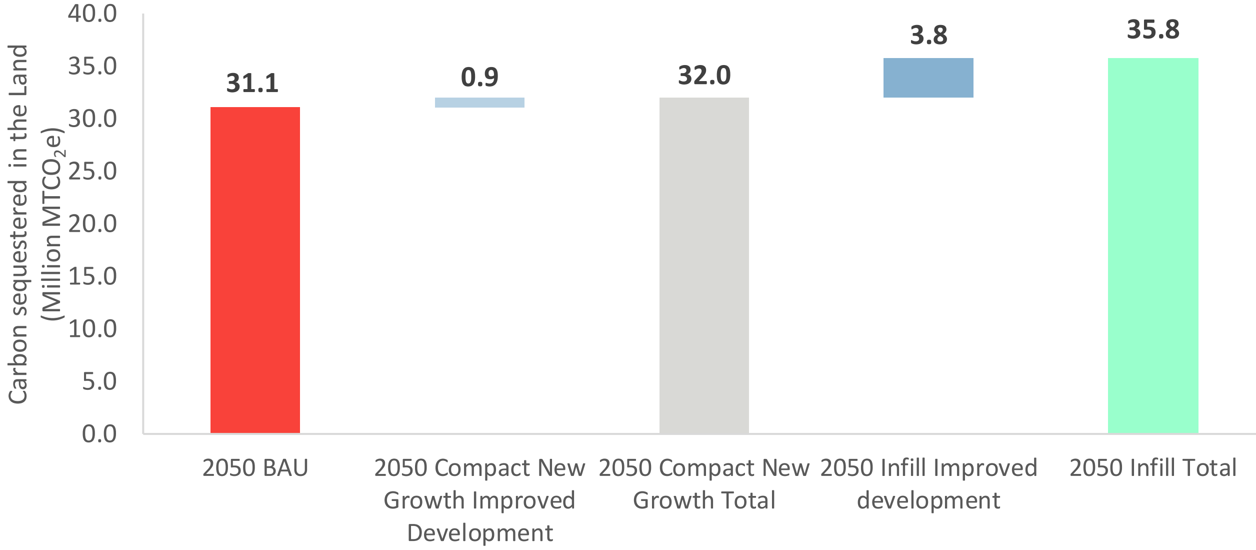

Figure 5. Technical potential to reduce landscape carbon losses associated with a business-as-usual development future through compact new growth and infill strategies.

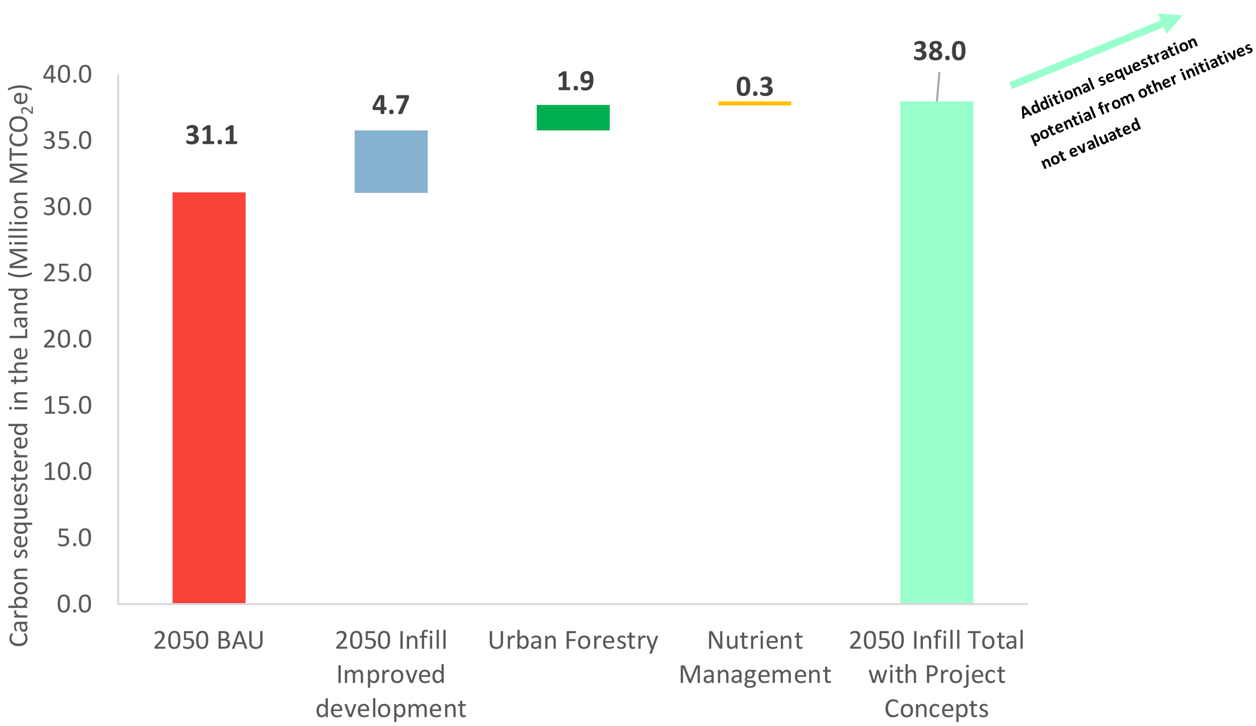

Figure 6. Technical potential to reduce landscape carbon losses and increase sequestration through land-use planning and mitigation activities on community lands.

CONCLUSION AND NEXT STEPS

Through this initial study, SMUD facilitated a dialog with key stakeholders in the Sacramento region, which fostered further interest around embedding climate change mitigation in general, and landscape carbon sequestration improvements in particular into land use and conservation planning. We developed models and analytic tools that demonstrated not only that there is a meaningful opportunity to take climate action through this type of integrated planning, but also tested and proved the tools that can enable it in practice.

During this study, additional data was released that could not be fully reviewed and incorporated, and additional data resources are being developed presently. Further, there are opportunities to refine the methodology with additional time and resources, and the study region of Sacramento County is too limited to fully embed our findings in the SACOG process. Throughout the chapters that follow, we document these opportunities, but note that while they may improve resolution and accuracy, they are unlikely to change in a meaningful way the overall conclusion: **planning for landscape carbon storage can make a meaningful mitigation contribution, and the analytical tools to do so in a spatially-explicit manner exist today for the Sacramento region.** To expand and improve on this study, we recommend that SMUD, the workgroup, and stakeholders:

- Brief key stakeholders and policymakers on the current work, and build appetite for a conceptual framework that incorporates climate mitigation as a key conservation and land-use planning variable
- Expand the study area to align with the SACOG six-county region to allow the data to be fully integrated into the Marxan modeling framework and planning process
- Evaluate additional project concepts to identify and quantify their carbon sequestration potential
- Update methodology and datasets used for this study based on continued collaboration with technical experts and further review of additional resources and evolving datasets, including, but not limited to, those identified in this study
- Incorporate additional economic metrics to understand the costs in addition to GHG and other co-benefits
- Develop tools, guidance, and resources for the implementation of this framework for use by county and regional planners.

1 INTRODUCTION

The Sacramento Municipal Utility District (SMUD) is the sixth-largest community-owned electric service provider in the country. SMUD generates, imports, transmits and distributes electricity to a 900-square-mile service area with a population of 1.5 million that includes Sacramento County and a small portion of Placer County.

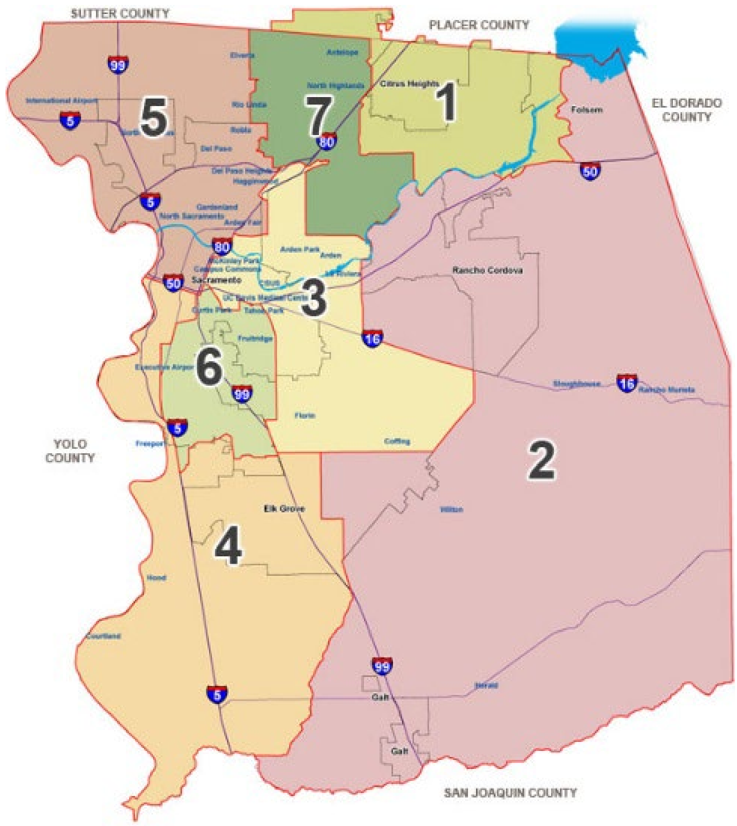

Figure 7. Map of SMUD's service territory. The territory is divided into seven wards (numbered above), each of which is represented by a board member elected to SMUD's Board of Directors. Source: SMUD

SMUD is owned by its customers, who elect a seven-member Board of Directors every four years. Each director represents a different geographic area, or "ward," seen in **Figure 7**. During their four-year terms, the directors' job is to establish policies and values that guide how SMUD serves its customers and the long-term direction SMUD will take moving forward.[5]

The board has been early in understanding the risks posed by climate change, and proactive in setting a long-term path towards decarbonization. Strategic Direction (SD) 7 sets out a broad direction for the utility in aligning with policymakers to promote climate mitigation, instructing SMUD to "*provide leadership in the reduction of the region's total emissions of greenhouse gases through proactive programs in all SMUD activities and development and support of national, State, and regional climate change policies and initiatives.*" More specifically, SD-9 commits SMUD to reduce GHG emissions to 10% of 1990 emissions by 2050, achieve energy efficiency equal to 15 percent of retail load, and meet 33 percent of SMUD's load by 2020 with renewable resources, and 50 percent by 2030.

In its path towards achieving these targets, SMUD was the first large California utility to receive more than 20% of its energy from renewable resources and currently provides electricity from varied sources including natural-gas-fired generators, carbon-free and renewable energy such as hydropower, solar and wind power, and power purchased on the wholesale market. Currently, 50% of SMUD's power comes from non-carbon-emitting resources, and 26% of SMUD's power meets the Renewable Portfolio Standard (RPS) outlined by the state of California.

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[5] Sacramento Municipal Utility District (SMUD). Our Board of Directors. Available at: https://www.smud.org/en/about-smud/company-information/board-of-directors/

While SMUD's SD-9 commitments and actions promote renewable energy and distributed energy resources, there are additional opportunities to support policies and initiatives consistent with SD-7. The California Climate Strategy pillars shown in **Figure 8** place clear emphasis on efficiency, renewables, and even vehicle electrification – all areas closely aligned with SMUD programs. Through its Climate Readiness Assessment and Action Plan, and work with the Department of Energy's Partnership for Energy Sector Climate Resilience SMUD is actively safeguarding California and its customers through improving resilience of energy infrastructure to extreme weather and climate change impacts and strengthening energy security. However, SMUD's strategies around carbon sequestration in the land base and reducing short-lived climate pollutants (SLCP) are more nascent. The Pilot Natural Refrigerant Incentive Program is a first-of-its-kind offering that provides incentives to customers for the direct emission reductions associated with use of natural refrigerants in place of high-global warming potential hydrofluorocarbons. However, SMUD's efforts to promote carbon sequestration in the land base have been limited, with shade trees being the primary program through which SMUD directly promotes carbon sequestration.

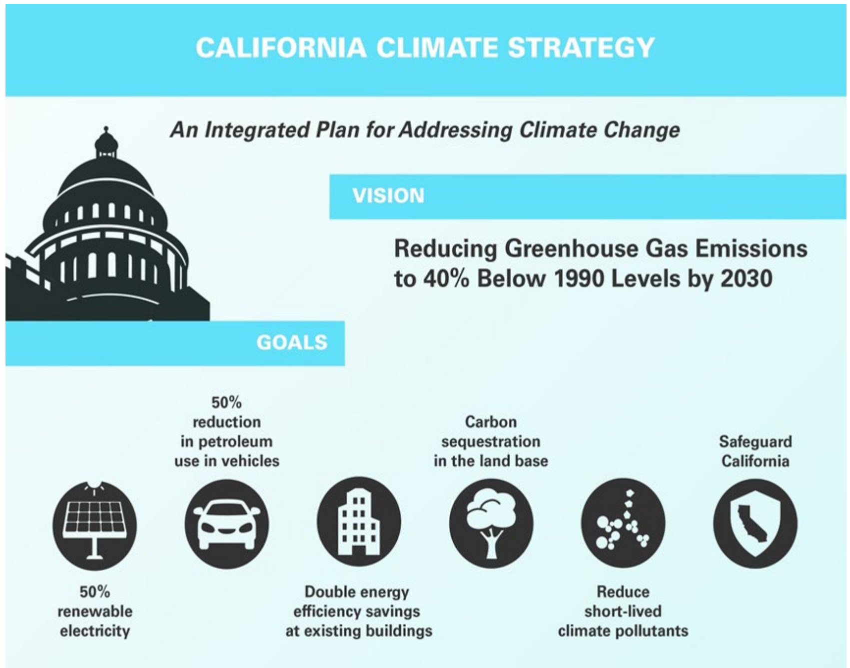
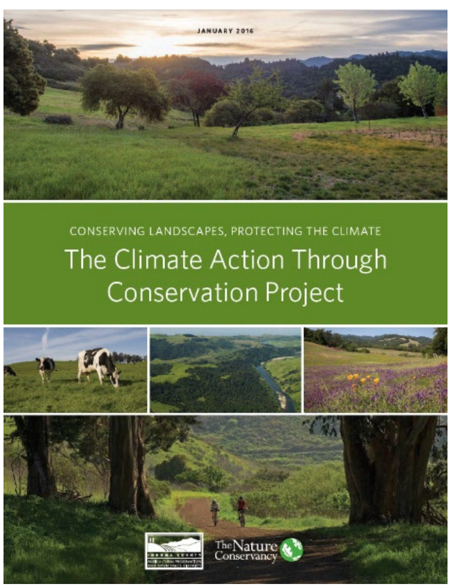


Figure 8. California Climate Strategy Pillars



In addition to the focus on maximizing landscape carbon at the state level through initiatives such as the Proposed Natural and Working Lands Climate Change Implementation Plan and the CALAND model[6], there are two key work streams underway in the region that make a focus on landscape carbon and biosequestration timely. First, The Nature Conservancy (TNC) has been working with partners in both Sonoma and Merced County to improve understanding of the role that carbon storage and sequestration can play in conservation planning. Published with the Sonoma County Agricultural Preservation and Open Space District in January, 2016 *The Climate Action Through Conservation Project* through work established TNC's framework "for local governments, land managers, and planners to understand the links between climate benefits and conservation values and incorporate that knowledge into

[6] Information on the most recent (October 13, 2017) workshop materials on these two items can be found here: https://www.arb.ca.gov/lispub/rss/displaypost.php?pno=10594

decisions about land use and land management."[7] The effort developed a county-wide inventory of landscape carbon, and projected future changes in that carbon reservoir based on baseline scenarios, in addition to evaluating scenarios in which conservation treatments are used to promote carbon sequestration. TNC found that that conservation could sequester an additional 4 million metric tons carbon dioxide-equivalent ($MTCO_2e$) by 2050 relative to the baseline scenario. TNC is expanding upon this framework through similar work in Merced County, incorporating more robust modeling of agricultural lands and soils.

Locally, a two year project undertaken in collaboration with the Sacramento Area Council of Governments (SACOG) and Environmental Council of Sacramento (ECOS) assembled a large amount of natural resource data in the six-county Sacramento region in order to investigate the potential complementarity, co-benefits, and trade-offs associated with sustainability planning in the region. In addition, a project funded by U.S. EPA is just being launched that will use this spatial framework to incorporate human health factors and ecosystem service valuation into priority setting for regional sustainability. This effort aims to incorporate carbon sequestration data into its analysis using the same framework.

Figure 9. Alignment of Landscape Carbon Assessment Study with State and Regional policy priorities

The current work situates SMUD squarely in line with policy priorities and efforts at the state, regional, and local level, and as a contributor in particular to the SACOG and ECOS sustainability planning efforts. The data generated through this work will inform the SACOG and ECOS work, and support broader implementation of landscape carbon analysis at the county level.

[7] The Nature Conservancy and Sonoma County Agricultural Preservation and Open Space District. 2015. Conserving Landscapes, Protecting the Climate: The Climate Action through Conservation Project. San Francisco and Santa Rosa, CA. 28 pages plus appendices.

1.1 OBJECTIVES

While recognizing the conceptual value that community lands can play in mitigating climate change is not novel, the goals of this study are to push that conceptual understanding further by quantifying the mitigation potential in Sacramento County, and understanding how that mitigation can be maximized and prioritized alongside other ecosystem services. Through improved data and a demonstrated methodology for integrating landscape carbon into conservation planning, carbon can become an actionable variable in conservation and land use planning. This study has not attempted to quantify the co-benefits of conservation on water quality, biodiversity, fire prevention, promotion of native vegetation, or resiliency. Instead, the data developed on landscape carbon will serve as one input to broader integrated conservation and land use planning. A key component of this work was to test and demonstrate the viability of coupling this data with additional conservation priorities, the data for which was independently developed. The five technical objectives of this study include:

	Project Goals		Project Outcomes
1	Quantify the current landscape carbon storage in Sacramento County, prioritizing existing and available data	→	GIS-based model that incorporates soil and biomass carbon densities and quantifies landscape carbon storage
2	Forecast Sacramento County landscape carbon storage under varied land use projections	→	Model incorporating forecast data based on land use constraints and population dynamics
3	Develop and test method for incorporating carbon as an explicit conservation benefit in land use decision-making frameworks	→	Marxan-based model that optimizes conservation designs using carbon as an input variable
4	Explore the potential for landscape carbon sequestration projects in Sacramento	→	Three project concept reviews assessing suitability, carbon potential, and cost considerations
5	Expand understanding of the technical potential for increasing landscape carbon storage in Sacramento County	→	Quantified technical potential based on land use outcomes and incorporating conservation actions

In addition to the technical outcomes, an important methodological priority is to leverage existing data, and align with prior and planned efforts. To this end, the team coordinated closely with The Nature Conservancy, the state agency staff, and others who have developed methodology and data and were able to share insights into best practice. This priority was important for two reasons. In addition to providing cost efficiencies, leveraging and aligning with prior and concurrent efforts helps to build consistency, compatibility and comparability. Sacramento, Sonoma, and Merced counties can achieve meaningful climate mitigation through proactive land use and conservation planning, but to avoid the worst impacts of climate change will require widespread adoption of similar frameworks and thinking not just across California, but the planet. This effort is one contribution to that dialog and ongoing work.

This project covers the geographic area of Sacramento County. This region was selected due to its general alignment with SMUD service territory, availability of data, and appropriate scale. In order to support future SACOG work, it is anticipated that this exercise may need to be expanded and refined to extend to the six-county region. Accordingly, while the outcomes of this project include estimates of landscape carbon inventories and potentials, these are intended as initial results subject to further refinement. Results should be treated with due care, recognizing that they are directionally reliable, but, due to data limitations, are not as spatially precise as would be required to make specific planning decisions. The results, as shown in Chapter 5, do highlight regions that are high priorities, but these results should not be used at the parcel level, nor used without further on-the-ground validation for funding or planning decision-making.

In order to promote the ongoing refinement of this methodology, throughout the report we document opportunities to improve the methodology and data. Some of these opportunities were not pursued due to the initial scope of this study, and some because there remains uncertainty about the relative benefit. Nonetheless, to be fully transparent these are discussed and documented in Chapter 6 of the report.

Finally, this work is intended to educate policy and decision makers on the opportunities that landscape carbon and biosequestration provide for the region. The groundswell of activity in Sonoma, Merced, and Sacramento counties, combined with efforts at the state level, provide a wealth of data that, if properly leveraged, can help to align economic, social, and environmental sustainability priorities.

1.2 ORGANIZATION OF THE REPORT

This report is organized into four chapters. Chapter 2 outlines the methodology that was developed to model landscape carbon inventories and forecast scenario-based biosequestration potential for Sacramento County. The methodology documents data sources, processing, and analyses. Through transparent discussion of the methodology and its limitations, our goal is that it may serve as a resource for future practitioners.

Chapter 3 summarizes the findings of the current landscape carbon inventory and potential future inventories based on projected land use scenarios. The results demonstrate that the model is responsive to future land use scenarios, and capable of representing the carbon implications of development paths.

Chapter 4 explores how to move from reactive modeling – i.e., how do potential scenarios translate into carbon impacts? – to proactive planning. Through integration into a Marxan model that considers multiple conservation priorities, the data is used to inform development and conservation planning. This chapter documents the process and preliminary results. We emphasize that these results are preliminary and based on simplified modeling, but also highlight that the intent of this exercise was as a proof-of-concept to demonstrate that there is a viable method to consider carbon as a key conservation input alongside other priorities.

In Chapter 5, we document three distinct project concepts that have the potential to increase landscape carbon. While the scenarios modeled previously consider the impact of land use or land cover change, the project concepts explore how improved management can increase landscape carbon without shifts to land use and land cover. The three concepts are evaluated on the basis of their technical potential and maturity, their suitability to Sacramento, and potential cost effectiveness. While these are not an exhaustive list of management opportunities, they are intended to highlight the existing research and breadth of opportunities to positively impact landscape carbon in the region. Similarly, they highlight the fact that any discussion of landscape carbon must be local, and that opportunities must be evaluated in a geographically distinct framework.

Chapter 6 discusses opportunities to expand and refine the methodology with additional time and resources, recognizing that new datasets, methodologies and models are being developed in parallel to this work. This section includes suggestions from the workgroup and the technical experts involved in this project in the hopes of informing a future phase 2 of this work.

1.3 WORKGROUP AND ACKNOWLEDGEMENTS

As a key component of this landscape carbon evaluation, SMUD composed a small workgroup of stakeholders with prior experience working to integrate landscape carbon into conservation and planning prioritization frameworks, who were currently engaged in prioritizing carbon as a decision criteria, or whose work could be informed by the outcomes of this effort. The following organizations and their representatives shared their experiences, insights, priorities, and time throughout this process, and their guidance helped improve the methodology and findings, as well as point the direction for future improvements and next steps. The County of Sacramento was also invited to participate and was provided periodic updates and draft materials.

Environmental Council of Sacramento
The Environmental Council of Sacramento (ECOS) is a coalition of environmental and social organizations working for social equity, public health and environmental sustainability in the Sacramento region, through land use and transportation planning, and habitat and agricultural preservation. ECOS's Conservation Committee, Habitat 2020, has worked for over a decade in developing a comprehensive regional conservation strategy, including partnership with UC Davis, SACOG, Sacramento County, and TNC for the construction of a regional natural resources data inventory.

The Nature Conservancy
The Nature Conservancy has been developing and advancing the role of nature as a key part of climate mitigation strategies in California and globally for over 25 years. In California, this includes the development of greenhouse gas reduction estimates and accounting methods for natural and working lands at the landowner, county and state scales.

Sacramento Area Council of Governments
The Sacramento Area Council of Governments (SACOG) is an association of local governments in the six-county Sacramento Region. Its members include the counties of El Dorado, Placer, Sacramento, Sutter, Yolo, Yuba and the 22 cities within. SACOG provides transportation planning and funding for the region, and serves as a forum for the study and resolution of regional issues.

This workgroup was further supported by a technical advisory committee, whose members each brought specific domain expertise and insights. Their review of initial findings provided additional clarity, refinement, and identified opportunities for pursuing future work. Throughout this effort, additional experts were also generous with their time, knowledge and expertise, and contributed to the methodology and data used in this study. This was a data intensive exercise with a priority on leveraging best practice and existing data sources. Each was instrumental in helping the team understand existing methodologies and data, and exploring best practice to integrate prior work and evolve appropriate methods for this effort.

The project team is grateful for the contributions of the following workgroup members, technical reviewers, and experts: *Matthew Baker, Environmental Council of Sacramento; Michelle Passero, The Nature Conservancy; David Shabazian, Sacramento Area Council of Governments; Jason Ko, United States Forest Service; Jeffrey Onsted, California Department of Conservation; Brian Shobe, California Climate & Agriculture Network; David Marvin, The Nature Conservancy; John Nickerson, Climate Action Reserve; Klaus Scott, California Air Resources Board; Mark Tukman, Tukman Geospatial*

2 METHODOLOGY

This section documents the methodology that was developed and used to estimate the current (data year 2014) landscape carbon inventory in Sacramento County as well as inventories under three future land use scenarios. The methodology can be broadly broken into several steps as shown in Figure 10, beginning with an assessment of relevant land use and land cover (LULC) classifications, and ending with LULC-specific carbon factors for relevant pools applied to the spatial distribution of each LULC across the county. To evaluate future land use scenarios, new LULC layers were created and carbon pool estimates were calculated. Each step is described in further detail in the sections below.

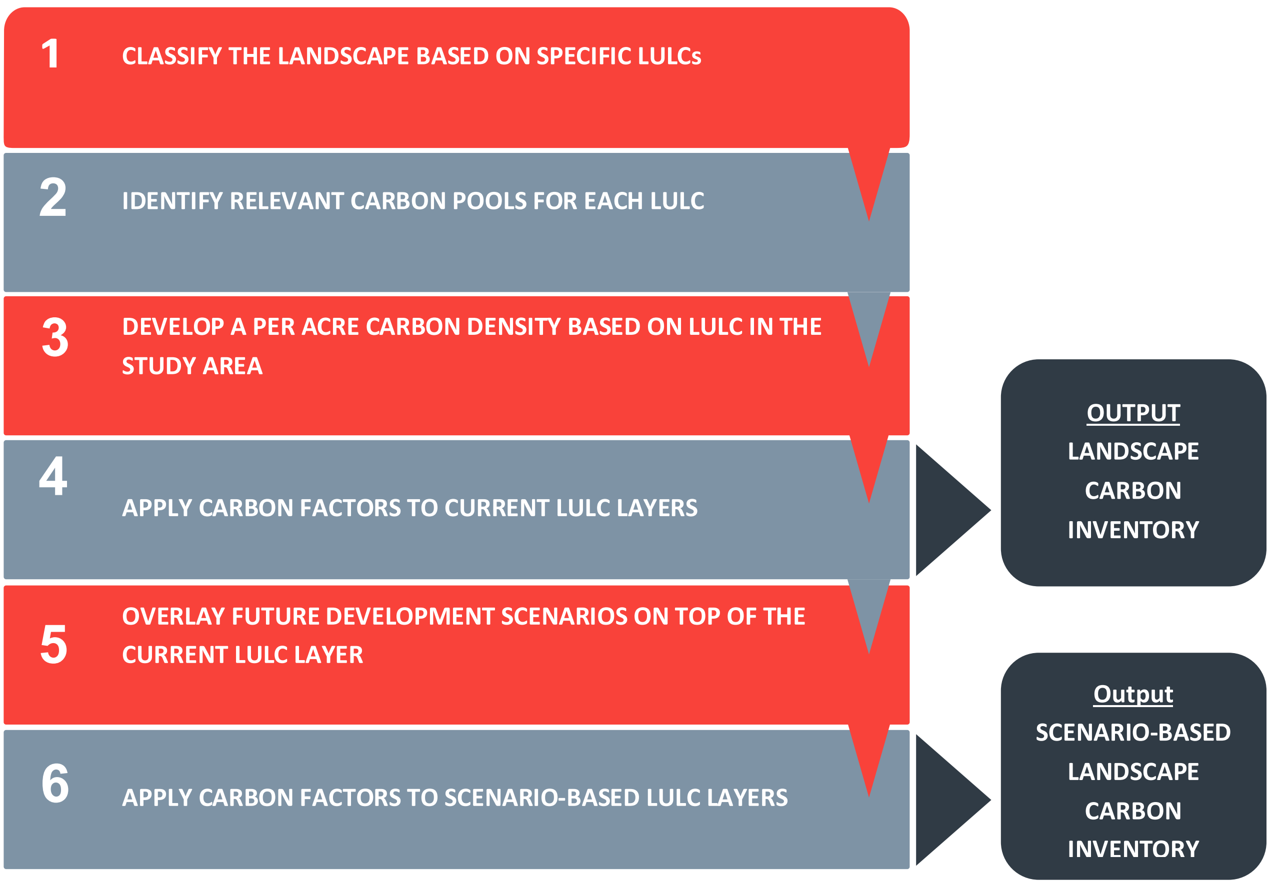


Figure 10. Overview of landscape carbon inventory process

2.1 LAND USE AND LAND COVER CLASSIFICATIONS

Land in Sacramento County was mapped into land cover classes using U.S. Geological Survey LANDFIRE 2014 data for vegetation type, height and cover.[8] The LANDFIRE program, supported by the U.S. Department of Agriculture Forest Service and U.S. Department of the Interior, is a long-term, satellite-based land cover mapping program that differentiates land into general (e.g., water, developed and forest, among others) and specific (e.g., development density and forest type, among others) land use and land cover (LULC) classes. Furthermore, with multiple years of data and a standardized classification system, the datasets are versatile and applicable to multiple types of analyses. The Workgroup agreed that LANDFIRE datasets would be appropriate for this analysis given that LANDFIRE is a well-established data product and had been used for TNC's Sonoma County land carbon project[9] with relative success.

Given this past project success and in an effort to build upon existing knowledge and experience, multiple experts from the Sonoma County project were contacted to discuss the technical aspects of getting to the most appropriate LULC classes for Sacramento County. This classification process is particularly important because it impacts how carbon densities are applied to each LULC class later in the workflow of the project. During our discussions, the following two major themes emerged:

- **Agriculture:** Properly classifying agriculture is important given that various types of agriculture have very different carbon densities based on their dissimilar biomass characteristics.[10] For example, orchards are perennial plants with woody biomass and higher carbon densities than crops that are grown annually. Based on this knowledge and in order to align with TNC's Merced County project, agriculture was separated into the following three categories to account for the carbon sequestration differences: general agriculture (agriculture that excludes all orchards and vineyards, for example, cropland and pasture), orchards, and vineyards.
- **Urban Forest:** LANDFIRE classifies urban or developed areas into multiple categories including low, medium and high density developed areas, roads and urban vegetation (e.g., shrubs, grassland and forest). Although it is possible that the various development densities have different tree canopy area, it is difficult to collect this resolution of data. Consequently, smoothing out the urban areas into one class is an appropriate classification given data availability. This approach was used in the Sonoma County project[11], and was also applied to this Sacramento County project.

These discussions and emerging trends were particularly applicable to Sacramento County given that urban centers and agriculture dominate the land area of the county. Several data collection and processing steps were

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[8] LANDFIRE Existing Vegetation Type, Height and Cover Layers. Data year 2014, released in 2017. U.S. Department of Interior, Geological Survey. Online at: http://landfire.cr.usgs.gov/viewer/

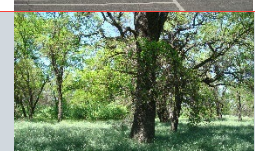
[9] The Nature Conservancy and Sonoma County Agricultural Preservation and Open Space District. 2015. Conserving Landscapes, Protecting the Climate: The Climate Action through Conservation Project. San Francisco and Santa Rosa, CA. 28 pages plus appendices.

[10] Personal communications with John Nickerson (July 25, 2017 and September 7, 2017) and Dave Marvin (August 1, 2017).

[11] Personal communication with Mark Tukman (August 15, 2017).

performed to prepare the 2014 LANDFIRE existing vegetation type (EVT), height (EVH) and cover (EVC) datasets (rasters with 30m x 30m pixel resolution) [12] for further landscape carbon analysis[13]. In order to align with

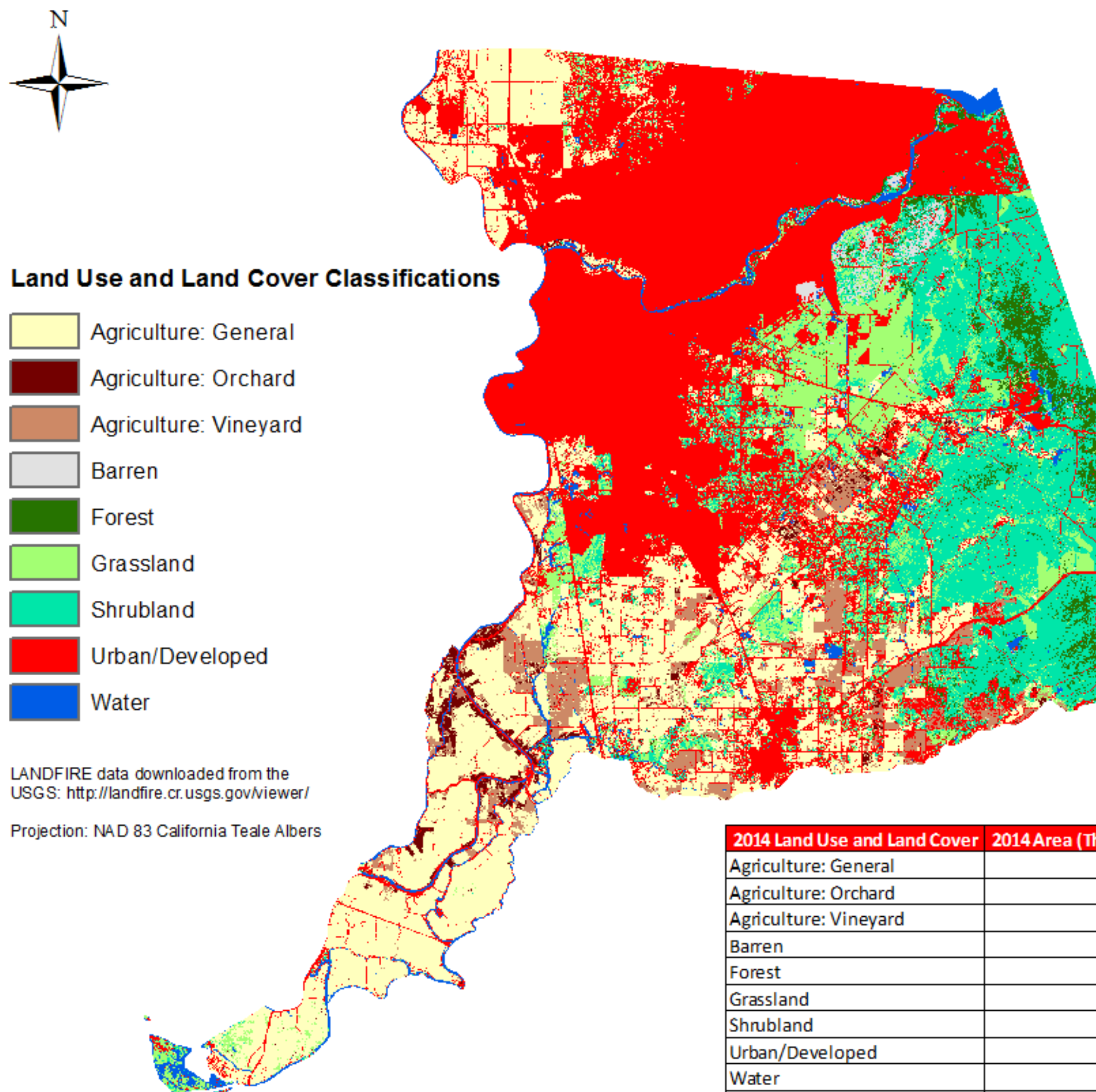
Table 1. Descriptions of how LULC classes were defined for the Sacramento County study area.

LULC Designation	Description	
Agriculture: General	This category includes all agriculture except orchards and vineyards, specifically row crops, close grown crops, wheat, fallow/idle cropland and pasture and hayland as defined in LANDFIRE.	
Agriculture: Orchard	This includes all Western Warm and Western Cool Temperate Orchards as defined in LANDFIRE.	
Agriculture: Vineyard	This includes all Western Warm and Western Cool Temperate Vineyards as defined in LANDFIRE.	
Barren	This designation includes all barren lands with sparse vegetation cover.	
Forest	Forest includes all deciduous and coniferous tree-dominated landscapes as defined by LANDFIRE. The majority forest cover in Sacramento County includes foothill pine woodland and savanna followed by oak forests and woodlands.	
Grassland	This category accounts for herbaceous landscapes as defined in LANDFIRE. Introduced upland vegetation-perennial grasslands and annual grassland make up a majority of the grassland land cover in Sacramento County.	
Shrubland	Shrublands accounts shrub-dominated landscapes as defined by LANDFIRE. Shrublands in Sacramento County were mainly mesic chaparral.	
Urban/Developed	Urban areas included low, medium and high density development, roads, and areas designated as urban or developed forest, shrubland, grassland or herbaceous.	
Water	This included all open water categories.	

[12] LANDFIRE Existing Vegetation Type, Height and Cover Layers. Data year 2014, released in 2017. U.S. Department of Interior, Geological Survey. Online at: http://landfire.cr.usgs.gov/viewer/
[13] The Sacramento County shapefile used to set the study area for all datasets was downloaded from the following source: U.S. Geological Survey. The National Map Small Scale Dataset. Online at: https://nationalmap.gov/small_scale/index.html

carbon densities delineated by the California Air Resources Board (ARB)[14], EVT, EVH and EVC datasets were combined in ArcGIS to get multiple combinations of each within Sacramento County. This process resulted in over 2,000 unique combinations in Sacramento County that were later matched with specific carbon densities that ARB created for the entire State of California. From these unique combinations and based on the discussions documented above, each EVT, EVH and EVC combination was classified into the following general land cover classes for further analysis: Agriculture: General, Agriculture: Orchard, Agriculture: Vineyard, Barren, Forest, Grassland, Shrubland, Urban/Developed, Water. **Table 1** provides further information on how these categories were defined. The final LULC classes and associated 2014 acreage for this analysis are shown in **Figure 11**.

[14] Battles, J.J., Gonzalez, P., Robards, T., Collins, B.M. and D.S. Saah. 2014. California Forest and Rangeland Greenhouse Gas Inventory Development: Final Report. Produced for the State of California Air Resources Board. Online at: https://www.arb.ca.gov/cc/inventory/pubs/battles%20final%20report%2030jan14.pdf



2014 Land Use and Land Cover	2014 Area (Thousand Acres)
Agriculture: General	143
Agriculture: Orchard	8
Agriculture: Vineyard	27
Barren	5
Forest	16
Grassland	56
Shrubland	97
Urban/Developed	263
Water	15
Total	**631**

Figure 11. Land use and land cover classifications derived from the LANDFIRE 2014 data for Sacramento County.

The Sacramento landscape is dominated by urban/developed and agricultural LULCs, with approximately 42 percent and 28 percent of the county's acreage, respectively. While conversion to urban/developed generally reduces landscape carbon, there are opportunities to store additional carbon in this cover class through urban forestry and other activities, as discussed in Chapter 5. Opportunities related to agricultural practices are also discussed. Forests, grasslands, and shrublands each have lower coverage than urban/developed and agriculture, but as discussed later in this chapter, the carbon densities in these cover classes can be significantly higher.

ALTERNATIVE LULC DATASETS EVALUATED

- **FVEG Dataset:** Along with the LANDFIRE dataset, the California Fire and Resource Assessment Program recently released a 2015 FVEG land use and land cover dataset that compiles the "best available" land cover data available for California into a single comprehensive statewide data set. The data span a period from approximately 1990 to 2014, so there are multiple data years that make up a single dataset.[15] This dataset is very similar to the LANDFIRE data, but was not chosen for the following reasons:

   — LANDFIRE datasets represent one year of land use and land cover. There are multiple years of LANDFIRE datasets, so they can be compared to see change over time if necessary.
   — The ARB carbon densities described below align directly with LANDFIRE classes, facilitating less uncertainty in aligning factors with land cover classes and developing inventory calculations.

— **Agriculture Classifications:** LANDFIRE resolution limits the ability to accurately classify different types of agriculture at a county or local level. The following options were considered for detailed agriculture land classifications[16]:
   — TNC is currently developing detailed agricultural classifications which could be used by applying crop/commodity-specific factors from Saah et al. 2015. However, the detailed classifications were not available at the time of this study, so we used the LANDFIRE classifications.
   — The California Department of Water Resources recently released a dataset with detailed agricultural classifications. This dataset was not released in time to be included in this study, but may be another consideration for granular agriculture classifications to which the Saah et al. 2015 crop/commodity specific carbon densities could be applied.

2.2 CARBON POOLS AND DENSITY FACTORS

Carbon is stored in multiple places in landscapes, whether it be in live biomass like trees, grasses or shrubs or in deadwood and litter and duff produced by live biomass. **Table 2** outlines the assessment boundaries used to quantify carbon in Sacramento County. Consistent with prior work in other counties, certain carbon pools were excluded because they are likely to have a negligible contribution to the overall carbon inventory and are not expected to materially impact the outcome of the landscape carbon analyses completed for this study. While Sonoma County's assessment was used as a guide, discussions with individuals engaged in that work indicated the importance of breaking out vineyards and orchards from agriculture given their carbon storage potential and economic importance to the region. The following subsections outline the carbon density data collection and development process.

Table 2. Carbon assessment boundaries for the Sacramento County study area.

		Land Cover Classes						
	● = Included ● = Excluded	**Forest**	**Grasslands**	**Shrublands**	**Agriculture**	**Urban**	**Barren Lands**	**Water**
C	**Soil organic carbon**	Included	Included	Included	Included	Included	Included	Excluded

[15] California Fire and Resource Assessment Program. FRAP Vegetation (FVEG15_1). Online at: http://frap.fire.ca.gov/data/statewide/FGDC_metadata/fveg15_1.xml

[16] Personal communication with Dave Marvin (August 1, 2017).

Standing live and deadwood (trees)	●	○	○	○	●	○	○
Litter and duff	●	○	○	○	○	○	○
Lying dead wood	●	○	○	○	○	○	○
Shrubs (Forests)	●	○	○	○	○	○	○
Shrubs	○	○	●	○	○	○	○
Grasses	○	●	○	○	○	○	○
Crops and Pastures	○	○	○	●	○	○	○
Orchards	○	○	○	●	○	○	○
Vineyards	○	○	○	●	○	○	○
Harvested wood products and landfill	●	○	○	○	○	○	○

2.2.1 SOIL ORGANIC CARBON

The U.S. Department of Agriculture Natural Resources Conservation Service publishes a spatial soil survey that includes California.[17] The gridded Soil Survey Geographic (gSSURGO) Database is intended for national, regional, statewide and local resource planning and analyses, and provides soil organic carbon densities (grams of carbon per m^2) for specified soil types and associated depths.

After resampling the gSSURGO data from 10m x 10m pixels to 30m x 30m pixels to align with the LANDFIRE pixel size, the 2014 LANDFIRE datasets were combined with the gridded SSURGO data in order to match soil types with the existing vegetation type, height and cover classes. After the area of these combinations was calculated, the corresponding soil organic carbon density (grams of carbon per square meter) was applied. Soil carbon was evaluated at the 0-30cm depth range consistent with TNC's Sonoma County analysis.[18] Soil carbon totals were then aggregated to the nine land covers specified above. Because the resolution of the SSURGO soil organic carbon data does not account for soil carbon impacted by landscapes modified by urban development or agricultural activity,[19] soil organic carbon estimates were adjusted to 48 percent of the original SSURGO calculations for urban, agricultural (Agricultural: General, Agricultural: Orchard, Agricultural: Vineyard) and barren land classes to reflect the decomposition of soil converted from natural land cover types to modified types. The 48 percent factor was selected based on a 2014 paper[20] that compared data from 453

A NOTE ABOUT THE UNITS USED IN THIS STUDY

Landscape carbon and carbon densities are often expressed in units of mass carbon/unit land area, rather than as CO_2e/land area. The latter is standard for expressing exchange with the atmosphere (flux). All units in this report are presented in $MTCO_2e$ in order to avoid confusion, and emphasize the potential impact that the landscape carbon would have if released to the atmosphere. $MTCO_2e$ can be converted to metric tons of carbon by dividing the $MTCO_2e$ by 3.67 (ratio of the molecular weight of carbon dioxide to carbon or 44/12).

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[17] United States Department of Agriculture, Natural Resources Conservation Service. Released November 29, 2016. Gridded Soil Survey Geographic (gSSURGO) Database for California. Online at: http://datagateway.nrcs.usda.gov/.
[18] The Nature Conservancy and Sonoma County Agricultural Preservation and Open Space District, 2015, Appendix B p. 49.
[19] The Nature Conservancy and Sonoma County Agricultural Preservation and Open Space District, 2015, Appendix B p. 49.
[20] Wei, X., Shao, M., Gale, W. and L. Li. 2014. Global pattern of soil carbon losses due to the conversion of forest to agricultural land

sites globally and determined there to be 52 percent loss in soil carbon in temperate regions when converting forest to agriculture land. A 70 percent soil carbon loss factor (30 percent of the carbon would be lost from the soil due to conversion) presented in VandenBygaart et al. 2003[21] and referenced in TNC's Sonoma County report was also considered, but the 48 percent value was selected as it yields a more conservative soil carbon estimate. Furthermore, while the conversion to agricultural lands is not the same as conversion to urban areas and may have a different soil carbon loss factors, research on the conversion to agricultural lands is more prevalent, so the same loss factor was used for both agriculture and urban conversions. A second phase of this Sacramento County study should further refine the soil carbon loss factor assumptions for these various land conversions to understand the differences in factors.

After all of the 2014 carbon estimates were aggregated to LULC classes and the 48 percent factor applied to urban, agriculture and barren land areas, soil organic carbon densities (metric tons CO_2e per acre) that could be used to evaluate current LULC and projected LULC based on development scenarios were calculated. Given the uncertainty of how the landscape will change in the future, carbon density factors for all LULCs were kept constant in the 2050 estimates, thus assuming no further degradation associated with development or agricultural uses. **Table 3** provides the soil organic carbon sequestration factors calculated from the LANDFIRE 2014 and SSURGO data.

Table 3. Soil organic carbon density factors used for calculations for the Sacramento County study area.

Land Use or Land Cover	$MTCO_2$e/Acre
Agriculture: General	54
Agriculture: Orchard	36
Agriculture: Vineyard	30
Barren	4
Forest	25
Grassland	43
Shrubland	28
Urban/Developed	14
Water	0

2.2.2 BIOMASS CARBON

A majority of the pools listed in **Table 2** – including standing live and dead trees (forests and urban forests), forest litter and duff, forest lying deadwood, forest shrubs, shrublands, grasslands, and agriculture (crops and pasture, orchards, and vineyards) – are comprised of biomass carbon. TNC's Sonoma County project compiled multiple methods to quantify carbon for these pools, all of which were reviewed and evaluated. Through consultation with ARB, a database[22] ARB has developed on biomass and carbon densities for combinations of LANDFIRE vegetation types, heights and cover classes for wildlands in the entire State of California was selected instead.

In the context of the ARB data, wildlands are generally all areas within California except for land classified as agricultural or urban. Furthermore, the database also provides factors for agriculture vegetation types and

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[21] VandenBygaart, A.J., Gregorich, E.G., and D.A. Angers. 2003. Influence of agricultural management on soil organic carbon: A compendium and assessment of Canadian studies. Canadian Journal of Soil Science, 83: 363-380. Online at: http://www.nrcresearchpress.com/doi/abs/10.4141/S03-009
[22] Personal communication with Klaus Scott (August 22, 2017).

county-specific urban forests, allowing for a comprehensive set of factors to be used for Sacramento County calculations. **Table 4** maps the ARB classifications, general land cover classifications and associated carbon pools used in this study. These datasets are a result of work completed[23] and updated[24] by ARB in recent years for the Forest and Natural Lands portion of California's Greenhouse Gas (GHG) Inventory[25]. Given that these datasets and carbon factors align with LANDFIRE, are California-specific, and were integral in ARB's recent GHG inventory work, the workgroup agreed that using these data would be relevant and applicable to Sacramento County for this analysis.

Table 4. Relationships between LULC classifications defined for this study, carbon pools and ARB classifications.

LULC Classification Used in this Study	ARB Classification	Carbon Pool
Agriculture: General	Agriculture	Crops and pastures
Agriculture: Orchard	Agriculture	Orchards
Agriculture: Vineyard	Agriculture	Vineyards
Barren Land	Wildlands	Shrubs and grasses*
Forest	Wildlands	Standing live and deadwood (trees), litter and duff, lying dead wood, shrubs (Forests)
Grassland	Wildlands	Grasses
Shrubland	Wildlands	Shrubs
Urban/Developed	Urban	Standing live and dead wood (trees)
Water	Wildland	Excluded from this analysis

*Barren lands generally have no or sparse vegetation. The ARB factors account for a minimal amount of aboveground biomass likely to be shrubs or grasses, so barren lands contribute a small quantity of carbon storage on the landscape.

This analysis applied the wildland, agricultural and urban forest densities to the LANDFIRE 2014 vegetation type, height and cover class combinations[26] aforementioned in the Land Use and Land Cover Classifications section as follows:

- **Wildlands:** Carbon factors (metric tons of carbon per hectare) that accounted for above and belowground biomass were multiplied by the land area of each combination of vegetation type, height and cover class, converted to CO_2e, and the totals were aggregated to the LULC classifications used in this study.
- **Agriculture:** The ARB data provided carbon factors (metric tons of carbon per hectare) by LANDFIRE's existing vegetation type category. This granularity allowed for the separation of orchards and vineyards from other types of agriculture. Carbon factors were multiplied by the land area of each agricultural

[23] Gonzalez et al. 2014.
[24] Saah, D., Battles, J., Gunn, J., Buchholz, T., Schmidt, D., Roller, G., and S. Rosmos. 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. Online at: https://www.arb.ca.gov/cc/inventory/pubs/arb_pc173_v004.pdf
[25] California's Forest and Other Natural Lands Inventory can be found online at: https://www.arb.ca.gov/cc/inventory/sectors/forest/forest.htm
[26] There were a few instances where Sacramento County combinations did not match those of the ARB data so no carbon factors matched. In these cases, a weighted average of that specific LULC class's factors was applied that to these unmatched combinations. When excluding the water land class, this accounted for roughly 2% of the land area in Sacramento County and is likely due to the precision and resolution of the LANDFIRE data.

vegetation type, converted to CO_2e, and the totals were aggregated to the Sacramento County LULC classifications. Saah et al. 2015 describes the methodology to derive the carbon factors in detail, but a quick summary of the methods is below:

- **Crops and Pasture:** For crops, Saah et al. 2015 weighted biomass and carbon values based on statewide acreage allocation of multiple crop types where data were available. A single weighted statewide carbon stock value for aboveground biomass was then calculated from these multiple crop types.[27]
- **Orchards and Vineyards:** A literature review of biomass and above and below ground carbon estimates for orchards and vineyards yielded data for almonds avocadoes, oranges and grapes. Saah et al. 2015 calculated carbon content by using published data on tree or vine biomass estimates and the typical planting density of each species.[28]

- **Urban:** The ARB data contained urban forest carbon densities (metric tons of carbon per hectare) by county, so the Sacramento County factor was applied to all Urban/Developed area and converted to CO_2e. Saah et al. calculated this single factor from urban forest biomass stock data that consisted of multiple data inputs including but not limited to tree plot data, itree canopy cover data, parcel and land use data, and climate zone data as described in Bjorkman et al. 2015.[29]

After all 2014 carbon estimates were aggregated to LULC classes, carbon densities (metric tons CO_2e per acre) were calculated on the aggregate data and applied to the LULC land areas for the 2050 development scenarios described in the Future Land Use Scenarios section below. Given the uncertainty of how the landscape will change in the future, sequestration factors for all LULCs were kept constant in the 2050 estimates to provide an order of magnitude emissions figure. **Table 5** provides the biomass carbon sequestration factors used for this study.

Table 5. Biomass carbon density factors used for calculations for the Sacramento County study area.

Land Use and Land Cover	$MTCO_2e$/Acre
Agriculture: General	9
Agriculture: Orchard	27
Agriculture: Vineyard	6
Barren	3
Forest	145
Grassland	10
Shrubland	106
Urban/Developed	14
Water	0

[27] Saah et al. 2015, p. 18-21.
[28] Saah et al. 2015, p. 13, 16-17.
[29] Bjorkman, J., J.H. Thorne, A. Hollander, N.E. Roth, R.M. Boynton, J. de Goede, Q. Xiao, K. Beardsley, G. McPherson, J.F. Quinn. 2015. Biomass, carbon sequestration and avoided emission: assessing the role of urban trees in California. Information Center for the Environment, University of California, Davis.

ALTERNATIVE DATASETS EVALUATED

Forests

- The 2013 FIA forest carbon raster layer could be used to calculate carbon for forest sources . Given that the ARB dataset incorporates FIA data into its forest calculations and has detailed factors for each LANDFIRE combination of existing vegetation type, height and cover class in California, it was selected as a comprehensive dataset for all biomass sources.[30]
- The Oregon State University Landscape Ecology, Modeling, Mapping, and Analysis (LEMMA) program dataset likely has more refined classifications than LANDFIRE, but does not align as well with the ARB carbon densities provided by ARB. LEMMA could be used for future analyses, but its advantages must be weighted against alignment with ARB.[31]

Forest Litter and Duff, Lying Deadwood, Shrubs

- The Sonoma County study used the US Forest Service's Carbon Online Estimator (COLE) to calculate carbon from these sources. COLE uses continuously updated data from regional and local forest to provide tons of carbon per hectare for specific forest types and species. The COLE methodology was established prior to the ARB dataset being complete. While these COLE factors could be mapped to LANDFIRE classes, as specified in the Sonoma County methodology, ARB's dataset included these carbon sources in their aboveground and belowground carbon factors.[32]

Grasslands

- In its Sonoma County work, TNC applied a 1 $MTCO_2e$/acre aboveground biomass carbon density for grasslands due to the fact that it is very difficult to quantify carbon factors for grassland. The ARB dataset used in this study did contain grassland density factors that were similar to the TNC factor.

2.2.3 HARVESTED WOOD PRODUCTS AND LANDFILL

Carbon persists in solid form for extended periods of time as wood products in use and as decomposing discards in landfills. Carbon from this source was calculated following the Climate Action Reserve's Harvested Wood Products Calculation Worksheet as described in the TNC Sonoma County methodology[33] using annual timber harvest data from the State of California's Board of Equalization[34] by converting harvest volume, reported in board feet log volume, into sawtimber CO_2e (**Table 6**).

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[30] Wilson, B.T., Woodall, C.W., and D.M. Griffith. 2013. Imputing forest carbon stock estimates from inventory plots to a nationally continuous coverage. Carbon Balance and Management, 8 (1). Online at: https://cbmjournal.springeropen.com/articles/10.1186/1750-0680-8-1

[31] Oregon State. Landscape Ecology, Modeling and Mapping Analysis: GNN Structure (Species-Size) Maps. Data posted August 2014. Online at: https://lemma.forestry.oregonstate.edu/data/structure-maps

[32] FIA COLE data can be found online at: https://www.fs.usda.gov/ccrc/tools/cole

[33] Table adapted from The Nature Conservancy and Sonoma County Agricultural Preservation and Open Space District, 2015, Appendix B p. 57.

[34] California State Board of Equalization: Timber Yield Tax Harvesting Statistics. California Timber Harvest by County 1994-2015. Online at: http://www.boe.ca.gov/proptaxes/timbertax.htm

Table 6. Data conversions used to convert harvested log volume into metric tons of CO_2e stored.[35]

Data unit in	Conversion*	Data unit out
Log volume in thousand board feet (scribner long volume)	145	Log volume in cubic feet
Log volume in cubic feet	0.0283	Log volume in cubic meters
Log volume in cubic meters	0.675	Sawtimber in cubic meters. Conversion is a measure of mill efficiency.
Sawtimber in cubic meters	0.3990	Sawtimber biomass. Conversion is the specific gravity in softwoods.
Sawtimber biomass	0.5	Sawtimber carbon
Sawtimber carbon	3.67	Sawtimber CO_2e
Sawtimber CO_2e	0.76	Sawtimber remaining long-term (100 years) in wood products and/or in landfill.

*All conversion units based on guidance from Climate Action Reserve from Harvested Wood Products Calculation Worksheet guidance (http://www.climateactionreserve.org/how/protocols/forest/).

Timber yields for the past decade indicate that Sacramento County has had zero or negligible yield, so after thorough evaluation this carbon pool is considered to be *de minimis* and set equal to zero.

2.3 CALCULATING LANDSCAPE CARBON IN SACRAMENTO COUNTY

Based on the LULC classifications and LULC-specific carbon pool densities developed, calculating the landscape carbon inventory is a relatively straightforward exercise, applying a carbon density to the acreage of each LULC. Biomass carbon and soil carbon quantities are then aggregated to calculate a total carbon sum for each LULC in study area, as shown in **Figure 12**.

[35] Table adapted from The Nature Conservancy and Sonoma County Agricultural Preservation and Open Space District, 2015, Appendix B p. 57.

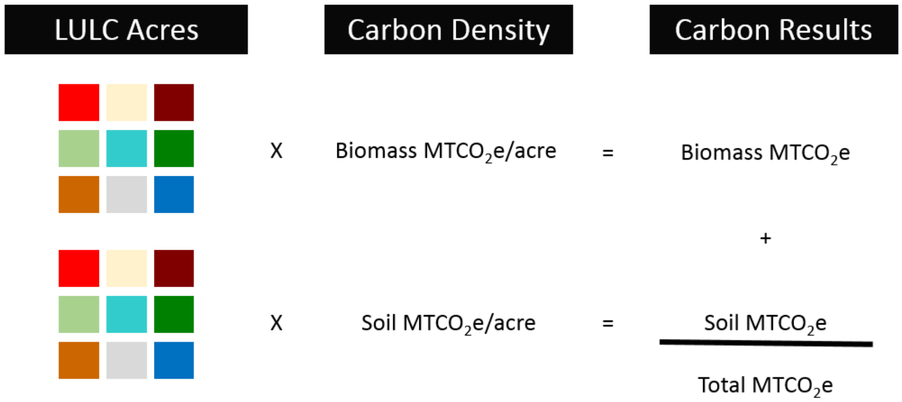

Figure 12. Conceptual landscape carbon quantification methodology

2.4 FUTURE LAND USE SCENARIOS

2.4.1 UPLAN URBAN GROWTH MODEL BACKGROUND

Development scenarios modeled out to 2050 were used to understand how future development may impact landscape carbon quantities in Sacramento County. Modeling to 2050 aligns with SMUD's Board objectives, California's Climate Action Plan, and prior work by TNC in Sonoma County and Merced County. Three methodologies were considered for projecting land carbon densities under business-as-usual. The first method, aligned with jurisdictional accounting, evaluates a historical trend and extrapolates it linearly to estimate future land use and emissions. This method is useful in carbon crediting regimes because it helps to provide an accounting backstop to manage leakage. However, it does not consider existing land use constraints or zoning, and was therefore not selected. The second method considered would use Sacramento County's full build out scenario from the South Sacramento Habitat Conservation Plan (SSCP)[36]. When compared to UPlan, which is a development scenario for the State of California, the SSCP plan has the advantage of being Sacramento-specific and accounts for conservation; however, at the time of this report, the data granularity needed for this analysis was not available. The final option uses the UPlan Urban Growth Model developed by the UC Davis Information Center for the Environment (ICE). The UPlan method was selected because it provides, in addition to a business-as-usual scenario, several alternative land use scenarios. UPlan is a rule-based, spatially explicit urban growth model that:

- Is based on a population projections, existing infrastructure and factors that would attract or discourage development,
- Accounts for various urban growth and development policies,
- Is intended for regional or county level modeling, and
- Projects development to 2050.[37]

[36] Sacramento County. The South Sacramento Habitat Conservation Plan. Online at: http://www.southsachcp.com/
[37] UC Davis Information Center for the Environment. UPlan: Urban Growth Model. Online at: http://ice.ucdavis.edu/project/uplan

It is important to note that actual patterns of development are also influenced by factors other than those specified above, and consequently, the UPlan model does not forecast exact development patterns, but rather estimates the magnitude and spatial pattern of growth under different policies.[38] These estimates are useful in understanding where development might occur and the land uses and land covers that it could affect. Furthermore, UPlan's multiple land use policy scenarios provide an opportunity to compare future scenario-specific landscape carbon estimates to the 2014 base year inventory. This study evaluated the following land use scenarios from the UPlan model for Sacramento County[39]:

- **Business as Usual (BAU):** This scenario simulates legally permissible urban sprawl, and represents no change in current California policy. The percentage of population placed in each residential density class is similar to current residential patterns as outlined by the 2010 US Census. The model also assigns new population to lower density residential classes that require more land area, creating more of a sprawling effect than other scenarios.
- **Compact New Growth (CNG):** This scenario increases the density of new growth and situates it closer to existing urban areas. For example, much of the new population is situated in new, high density living areas, and urban growth is concentrated around existing towns and cities. High density development has a higher percentage of new households than low density development when compared to the BAU scenario.
- **Infill (IF):** This is a redevelopment scenario that adds a proportion of new growth inside existing urban centers. New population is placed in urban areas, causing some places to become denser than the BAU and CNG scenarios. Given these conditions, this scenario, amongst the three used in this study, represents the least expansive urban sprawl.

2.4.2 APPLYING UPLAN TO SACRAMENTO COUNTY

Sacramento County UPlan data from the UC Davis Information Center for the Environment consists of 50m x 50m raster layers for the business-as-usual, compact new growth and infill scenarios.[40] These data reflect urban area by land use and density class (e.g., low and high density commercial, industrial, and multiple densities of residential areas). This detail of data clarifies the types of urban land uses being projected; however, for this study, all urban land use and density categories were reclassified to represent one urban class so that the county-specific soil carbon and biomass carbon factors mentioned previously could be applied to urban area.

Before being able to apply this urban forest carbon density, UPlan data was overlaid on LANDFIRE data to create new LULC layers, effectively replacing certain areas of the LANDFIRE data with development data. UPlan rasters were also resampled to a pixel size of 30m x 30m to align with the LANDFIRE resolution, and then a UPlan mask was created by reclassifying the data into urban areas and non-urban areas. Using raster calculator, this mask was added to the 2014 LANDFIRE layer and data were reclassified into the LULC classes defined previously in order to create final data layers for each scenario. **Figure 13** depicts the final layers for 2014 and each 2050 scenario, clearly showing the impact that projected development may have on the landscape. Areas for each

[38] Thorne, J.H., Santos, M.J., Bjorkman, J., Soong, O., Ikegami, M., Seo, C., and L. Hannah. 2017. Does infill outperform climate-adaptive growth policies in meeting sustainable urbanization goals? A scenario-based study in California, USA. Landscape and Urban Planning (157), p. 483-492.
[39] Scenario definitions from: Thorne et al., 2017, pp. 484 - 485.
[40] Personal communication with Patrick Huber (August 16 and August 21, 2017).

LULC class were tabulated in ArcGIS, exported to Microsoft Excel and multiplied by the biomass and soil organic carbon factors to get landscape carbon totals for each scenario.

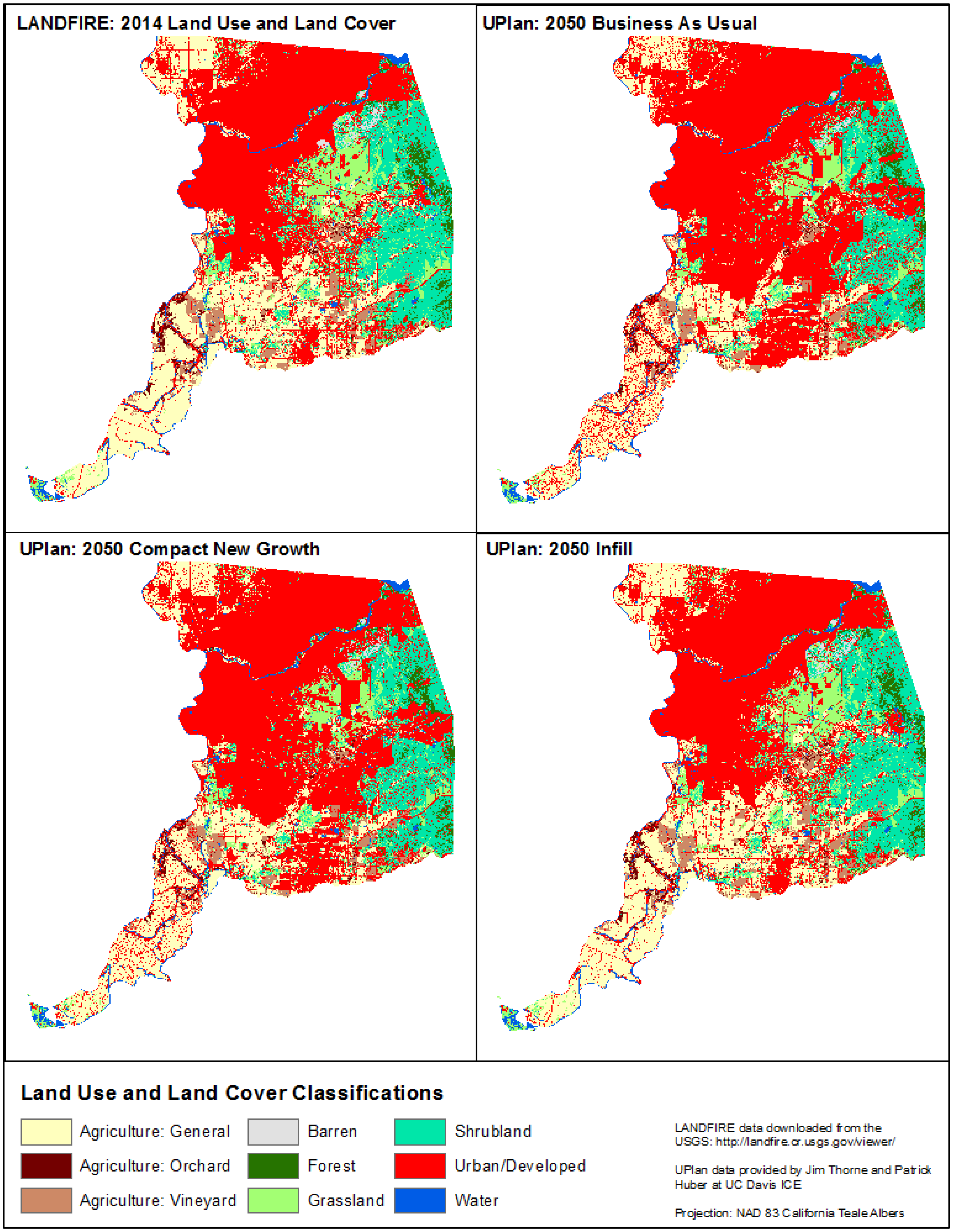

Figure 13. Land use and land cover in Sacramento County for 2014 historical data and the 2050 UPlan projections.

3 LANDSCAPE CARBON INVENTORY FINDINGS AND DISCUSSION

3.1 CURRENT INVENTORY AND FORECAST SCENARIOS

The results of the carbon inventory reflect that there is a substantial quantity of carbon sequestered by lands in Sacramento County. Based on LANDFIRE 2014, Sacramento County lands held roughly 36.3 million $MTCO_2e$ in aboveground biomass, belowground biomass, and soils. General agriculture, shrublands and urban areas make up a majority (approximately 80 percent) of landscape carbon in the 2014 inventory (**Figure 14**). Forests and grasslands consist of about 16 percent of the landscape carbon in the county with the rest of the LULCs accounting for approximately 3 to 4 percent of the inventory. These results are intuitive given that urban, agriculture and shrubland areas dominate the acreage of the county. Furthermore, although forests only make up approximately 3 percent (**Figure 15**) of county acreage, their high biomass and soil carbon sequestration rates cause them to account for 8 percent of the 2014 inventory (**Figure 14**).

When comparing 2014 inventory results to those of the 2050 scenarios, the 2014 inventory aligns closely with the infill scenario while the BAU and compact new growth scenarios show similar trends (**Figure 14**). About 0.5 million $MTCO_2e$ are lost in the infill scenario when compared to the 4 to 5 million $MTCO_2e$ lost in the BAU and compact new growth forecasts (**Table 7**). These results support the definitions of these scenarios in that the infill scenario mainly increases existing urban density with little additional sprawl while the BAU and CNG scenarios increase development outside of existing urban areas. Development from the BAU and CNG scenarios has the largest impact on general agriculture land area, reducing acreage in that category considerably. Development from these scenarios also significantly reduce the landscape carbon of both the general agriculture and shrubland categories. Projected development that replaces shrubland and general agriculture exacerbates the carbon impacted because shrublands have a high biomass carbon density and general agriculture has a high soil carbon density. This trend will be important to consider when planning for future development as developing over certain land covers without enhanced management or supportive policy development, even if the land area is small, will have a higher carbon impact than others. Carbon storage can be maintained and even enhanced with awareness of its potential and supportive policy development.

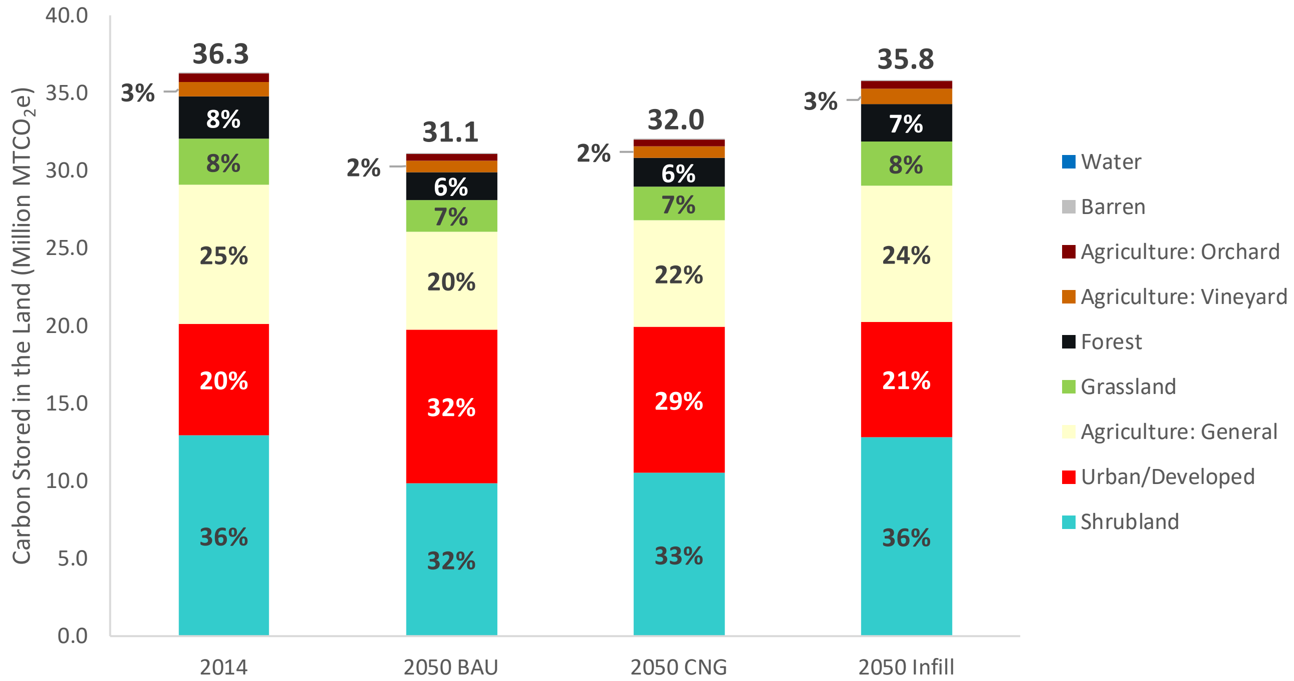

Figure 14. Carbon contained in Sacramento County land by category for 2014 and the 2050 scenarios.

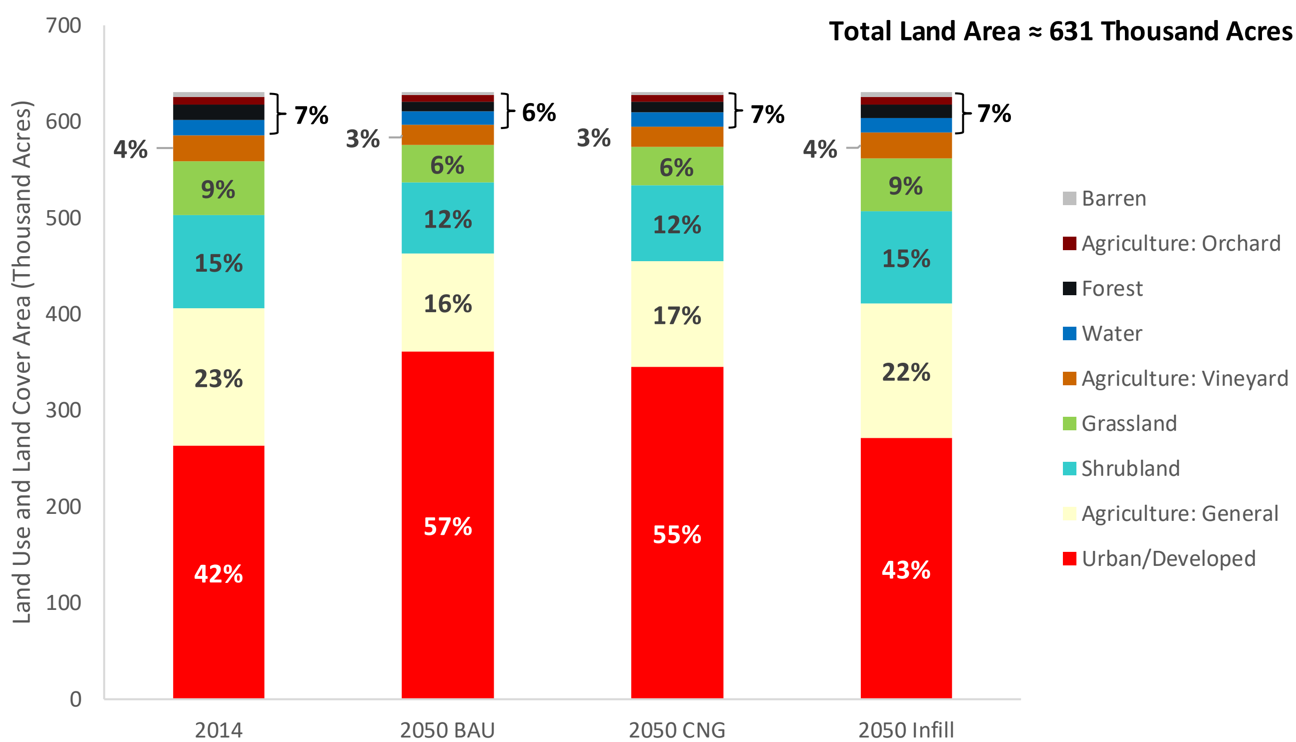

Figure 15. Land area by land use and land cover in Sacramento County for 2014 and the 2050 scenarios.

Table 7. 2050 UPlan scenario net change in acreage and landscape carbon from 2014 for Sacramento County.

	2050 BAU		2050 CNG		2050 Infill	
Land Use and Land Cover	**Thousand Acres**	**Net Carbon Change (Million $MTCO_2e$)***	**Thousand Acres**	**Net Carbon Change (Million $MTCO_2e$)***	**Thousand Acres**	**Net Carbon Change (Million $MTCO_2e$)***
Agriculture: General	-42	-3	-33	-2	-3	-0.2
Agriculture: Orchard	-2	0	-1	0	0	0.0
Agriculture: Vineyard	-6	0	-6	0	0	0.0
Barren	-2	0	-2	0	0	0.0
Forest	-6	-1	-5	-1	-2	-0.3
Grassland	-17	-1	-16	-1	-1	-0.1
Shrubland	-23	-3	-18	-2	-1	-0.1
Urban/Developed	99	3	82	2	8	0.2
Water	-1	0	-1	0	0	0.0
Total	0	-5	0	-4	0	-0.5

* Carbon accounts for carbon stored in aboveground and belowground biomass and soils. Numbers may not add up to the total due to rounding.

3.2 TECHNICAL POTENTIAL

For the purposes of this study, the technical potential for improved carbon storage is defined as the difference between the BAU scenario and alternative outcomes. The technical potential is an important consideration because it represents the carbon value that can be generated from the landscape, either to supplement or allow tradeoffs with alternative climate mitigation alternatives. For example, holistic planning should consider landscape carbon in the context of transportation, energy, and short-lived climate pollutant emissions, allowing each lever to be used in a cost-effective manner aligned with community, economic, and social needs.

The BAU UPlan scenario can be compared both to the current landscape carbon inventory as well as the compact new growth and the best-performing infill scenario. When considering only development scenarios as a variable, the current inventory has the highest technical potential because there has not been additional urban area added to the county, and landscape carbon storage is 5.2 million $MTCO_2e$ greater than the BAU scenario, as shown in **Figure 16**. Furthermore, an infill scenario that densifies urban areas and reduces development outside of urban boundaries provides an applicable approach to realizing the sequestration potential of the current inventory, increasing landscape carbon by about 4.7 million $MTCO_2e$ relative to the BAU scenario with the compact new growth scenario performing less well, as shown in **Figure 17**.

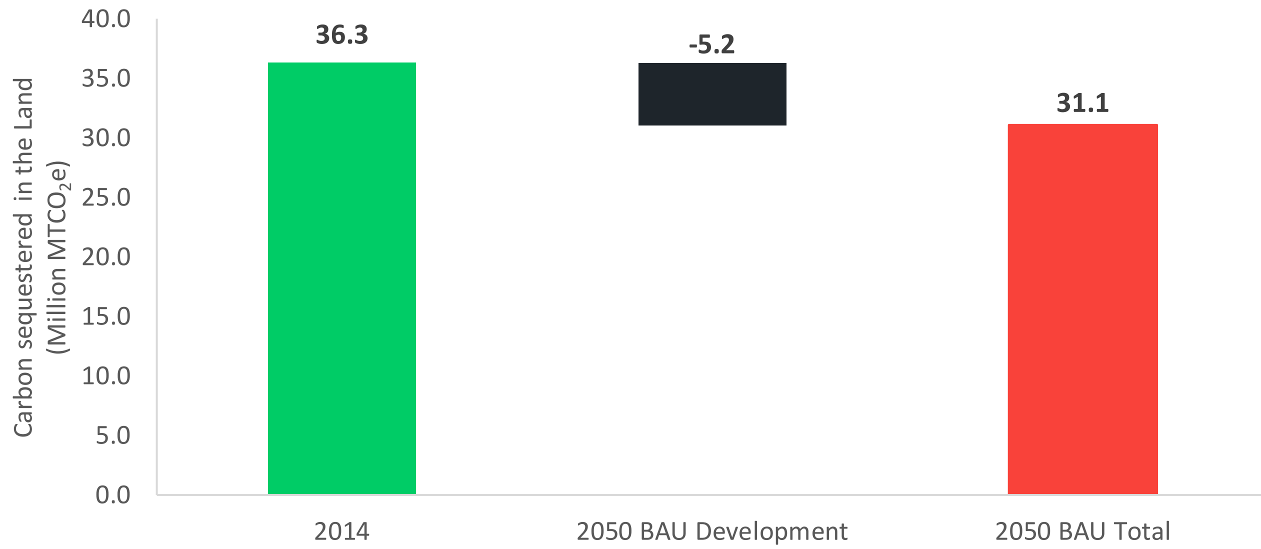

Figure 16. Technical potential for landscape carbon in Sacramento County, showing the differences between the 2014 inventory and the BAU scenario.

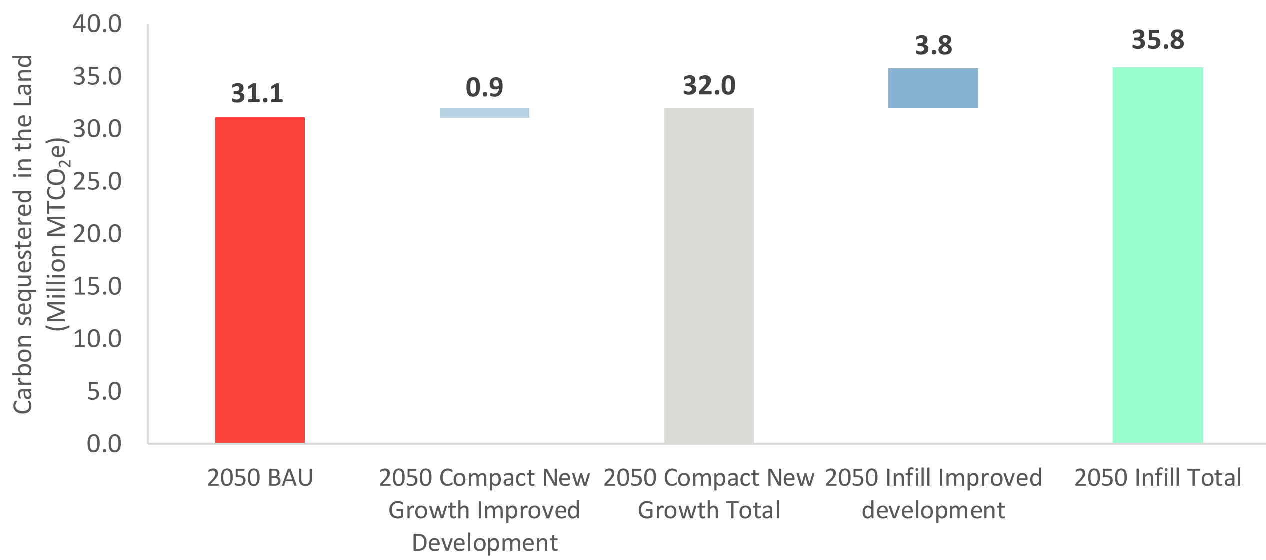

Figure 17. Technical potential for landscape carbon in Sacramento County, showing the differences between the BAU, compact new growth and infill scenarios.

These technical potentials are conservative estimates because they consider only the avoidable emissions from conversion to urban/developed land use. However, there are additionally opportunities to increase landscape carbon through improved practices within land use and land cover types. In Chapter 5, we evaluate in greater detail several project concepts among many similar opportunities. Two project concepts in particular demonstrate scalable opportunities: manure application and urban forestry. Based on COMET-Planner, a nutrient management regime that replaces synthetic fertilizer with beef feedlot manure[41] can sequester 0.21 $MTCO_2e$ per acre per year. If half of croplands in Sacramento County improved nutrient management regimes, this could equate to an additional cumulative technical potential of nearly 278 thousand $MTCO_2e$[42] by 2050 across Sacramento County. Similarly, improving and expanding urban forests increases carbon in biomass. If the General Plan goal of doubling urban forest canopy cover was achieved by 2050, this would effectively double the biomass carbon in urban/developed land uses. Based on current sequestration rates, this would equate to an additional 1.9 million $MTCO_2e$ by 2050.[43]

The potential sequestration from these opportunities is intended to be indicative of how specific management strategies can increase the technical potential beyond the values shown in **Figure 16** and **Figure 17**. Adding these two opportunities would bring the technical potential relative to BAU up to 6.9 million $MTCO_2e$, as seen in **Figure 18**. Additional management practices not researched in this study would likely bring this estimate higher, and should be explored through future work. In its efforts in Merced County, TNC is developing a series of such activity sheets that document specific opportunities, important considerations, and their sequestration potential. These papers will be an important contribution, and should be evaluated closely upon their release to understand how those opportunities may change the technical potential calculated here for Sacramento County.

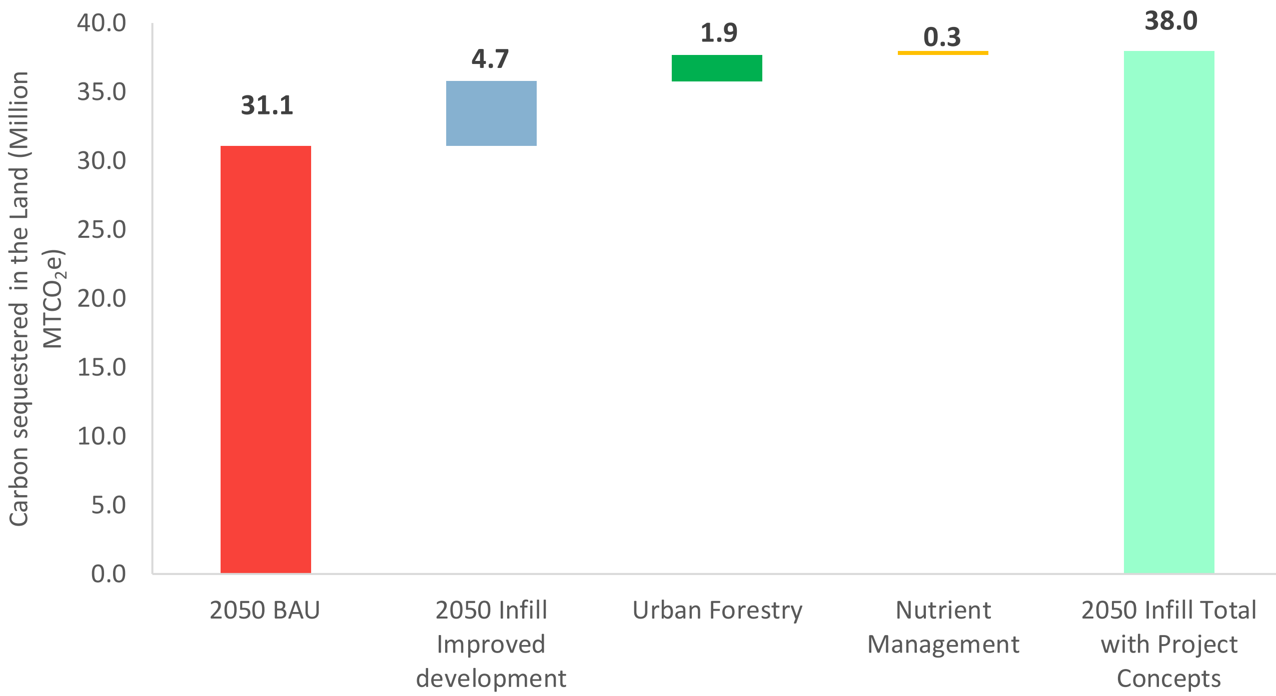

Figure 18. Technical potential for landscape carbon in Sacramento County, employing the infill development scenario, doubling urban forestry canopy and improving nutrient management on 50% of general agriculture.

[41] Beef feedlot manure was chosen because it has the highest sequestration factor of accessible manure in Sacramento County.

[42] Assumes 50% of Agriculture: General adopts cow manure fertilization between 2014 and 2050.

[43] Refer to the Urban Forestry section in Chapter 5 below for this estimate.

4 MARXAN INTEGRATION

4.1 MARXAN OVERVIEW

Marxan is optimization software designed for use in conservation reserve design.[44] It was originally designed for use in selecting marine reserves and, more generally, in designing spatially-explicit conservation reserve networks. It is a widely used conservation planning tool, used globally in a wide variety of reserve planning contexts. More than 100 peer reviewed papers describe some of the projects in which it was used by scientists or planners in support of conservation decisions.

Marxan works by using a simulated annealing algorithm to explore many configurations of planning units, incrementally moving towards solutions that meet inputted conservation objectives in "low cost" ways. "Cost" is defined by the user; it can refer to monetary cost but more generally refers to the suitability of a given planning unit for inclusion in a final conservation network. While it is unlikely that simulated annealing will produce an absolute lowest cost solution, it will identify multiple sets of planning units that comprise relatively low cost, or most suitable, solutions to meeting a user's conservation objectives.

The outcomes from this assessment can be used to identify the locations most susceptible to conflict between the carbon and agricultural preservation goals of the region and the expansion of urban areas.

4.1.1 INPUTS

Marxan uses three fundamental input tables (files) for an optimization analysis. The first is the "planning units" table file. This table is a list of all the objects that could potentially be selected for inclusion in a planning process. Typically, these would be land parcels. Each planning unit is given: 1) a unique ID; 2) a "cost" for inclusion in a final conservation network; and 3) a status (i.e. whether eligible to be selected, "locked in" a final Marxan solution, or "locked out" of a solution).

The second required input file is the "species" file. This table lists every conservation target in an analysis as well as the goal for inclusion of that target. Typically, these could be species occurrences, land cover types, etc.

The final input table in Marxan is the "planning unit vs. species" file. This table details the amount of each conservation target present in each planning unit.

In future iterations of the analyses presented here, stakeholder input will be used to set these values

[44] Ball, I.R., H.P. Possingham, and M. Watt. 2009. Marxan and relatives: software for spatial conservation prioritisation. Chapter 14: Pages 185-195 in *Spatial conservation prioritisation: quantitative methods and computational tools.* Eds Moilanen A., Wilson KA, and Possingham HP. Oxford, UK: Oxford University Press.

4.1.2 MODEL PARAMETERS

Marxan has a number of parameters that can be adjusted to best capture the conservation goals of the user. Some of the typically used parameters are “runs”, “iterations”, and the “boundary modifier”.

While Marxan is not designed to identify a true lowest cost solution to a given conservation problem, it does generate multiple low cost solutions. To do this, an input file is created that tells Marxan how many runs to undertake. At the end of each run a set of potential planning units is identified that meets the targeted conservation goals. Generally, Marxan analyses use multiple runs in order to fully explore the range of potential solutions.

The input file also includes the number of iterations (i.e. combinations of planning units) to assess in the course of each run. The greater the iterations, the closer is Marxan’s approach to an optimum solution. However, computing time increases as well, so a balance between optimization and computing time is typically sought.

The boundary modifier is a multiplier applied to the total boundary length of the conservation network identified during a run. The higher this modifier is set, the greater clumping of planning units in the solution occurs. This modifier requires calibrating in every analysis to achieve the desired clumping because it simply acts as a multiplier to other costs.

4.1.3 OUTPUTS

Marxan generates two types of output tables. The first is the “best” solution, i.e. the single lowest cost set of planning units identified for all of the runs. The value is binary, a unit is either included in the set or not.

The second output table is the “summed solution” table. This file describes the number of runs in which the planning unit was included as part of a low-cost solution. Here, each planning unit is scored 0 to n, with n equal to the total number of runs Marxan performed. This score can be thought of as an “irreplaceability” metric for the planning units. Those with a higher score are likely more critical in addressing the conservation goals in a low-cost manner, while those with a lower score are generally more substitutable.

4.2 METHOD OF INTEGRATION

Eight scenarios were developed to demonstrate the use of Marxan in assessing carbon sequestration opportunities in Sacramento County.

The first four scenarios exclusively used carbon sequestration potential as a conservation target (**Table 8**, Scenarios 1-4), with the conservation goal set at 33% of the current estimated stock in Sacramento County. Scenarios 5-8 also used carbon exclusively; however, the carbon conservation goal was set at 50% of the total. The latter four also included prime farmland conservation goals (Scenarios 9-12). Farmland Mapping and Monitoring Program (FMMP) data were used to represent prime agricultural land and agricultural land of statewide importance. Farmland goals were set at 25% of the county total. These goals were selected to be large enough that relatively large hotspots could be identified while not being too large and forcing Marxan to simply select most of the planning units containing the conservation features. Within this range, however, the goals were arbitrarily set.

Table 8. Scenarios used to demonstrate the use of Marxan in assessing carbon sequestration opportunities in Sacramento County

Scenario	Target	Goal (%)	Cost	Boundary
1	Carbon	33	Equal	0.001
2	Carbon	33	BAU	0.001
3	Carbon	33	Smart growth	0.001
4	Carbon	33	Infill	0.001
5	Carbon	50	Equal	0.001
6	Carbon	50	BAU	0.001
7	Carbon	50	Smart growth	0.001
8	Carbon	50	Infill	0.001
9	Carbon, prime ag	33, 25	Equal	0.001
10	Carbon, prime ag	33, 25	BAU	0.001
11	Carbon, prime ag	33, 25	Smart growth	0.001
12	Carbon, prime ag	33, 25	Infill	0.001

Within each of these three sets of conservation goals, scenarios were also developed that took into consideration future urban growth models developed through the UPlan modeling tool. One scenario used the current urban context (Scenarios 1, 5, 9), while the other three scenarios used either: 1) a "business-as-usual" growth model (BAU, Scenarios 2, 6, 10), 2) a compact new growth model (CNG, Scenarios 3, 7, 11), or 3) an infill-focused model (INF, Scenarios 4, 8, 12). These urban growth models were used to discourage the selection of planning units to meet conservation goals that also were likely to experience future urbanization. This was accomplished through altering the Cost scores in the planning unit input files. Scenarios 1, 5, and 9 assumed all planning units would have an equal cost. Costs in the other scenarios were adjusted to fit a 0.5-1.0 scale, with planning units with no expected urban growth having a score of 0.5 while those expected to be fully urbanized having a cost score of 1.0.

All 12 scenarios were run using a boundary modifier (BLM) of 0.001. This value was chosen after running a number of sample analyses to calibrate the outputs to a pattern that may possibly be the most useful for identifying future land management areas. The BLM was large enough that it forced some clumping of the selected planning units into larger potential management areas without being so large that planning units were simply being selected to reduce the overall boundary length of the outputs.

We designated as locked those planning units whose centroids were located within existing public or private conservation areas (as denoted by CPAD: California Protected Area Database). These currently existing conservation areas can serve as "seeds" around which new conservation areas may be identified, leading to larger and potentially easier to manage future conservation areas. Planning units comprised of 50% or greater urban land use (as represented in the FRAP land cover dataset: Forest and Range Assessment) were locked out of consideration in Marxan. The decision was made in order to steer identified areas of conservation emphasis away from the immediate vicinity of developed areas.

Each scenario was run 100 times, using 100,000,000 iterations for each run. Outputs included a table of the planning units selected during the single highest scoring run as well as scores (0-100) for each planning unit representing the number of runs in which it was selected as part of an "efficient" solution.

4.3 FINDINGS

Results from the Marxan analyses included eight "best solution" output tables and eight "summed solution" output tables. **Figure 19** shows the summed solution results from Scenarios 1-4. The outputs are similar across the urban growth scenarios, demonstrating that much of the high carbon value portions of the county are not likely to experience a large amount of urbanization. These areas are largely comprised of relatively natural shrubland and woodland ecosystems.

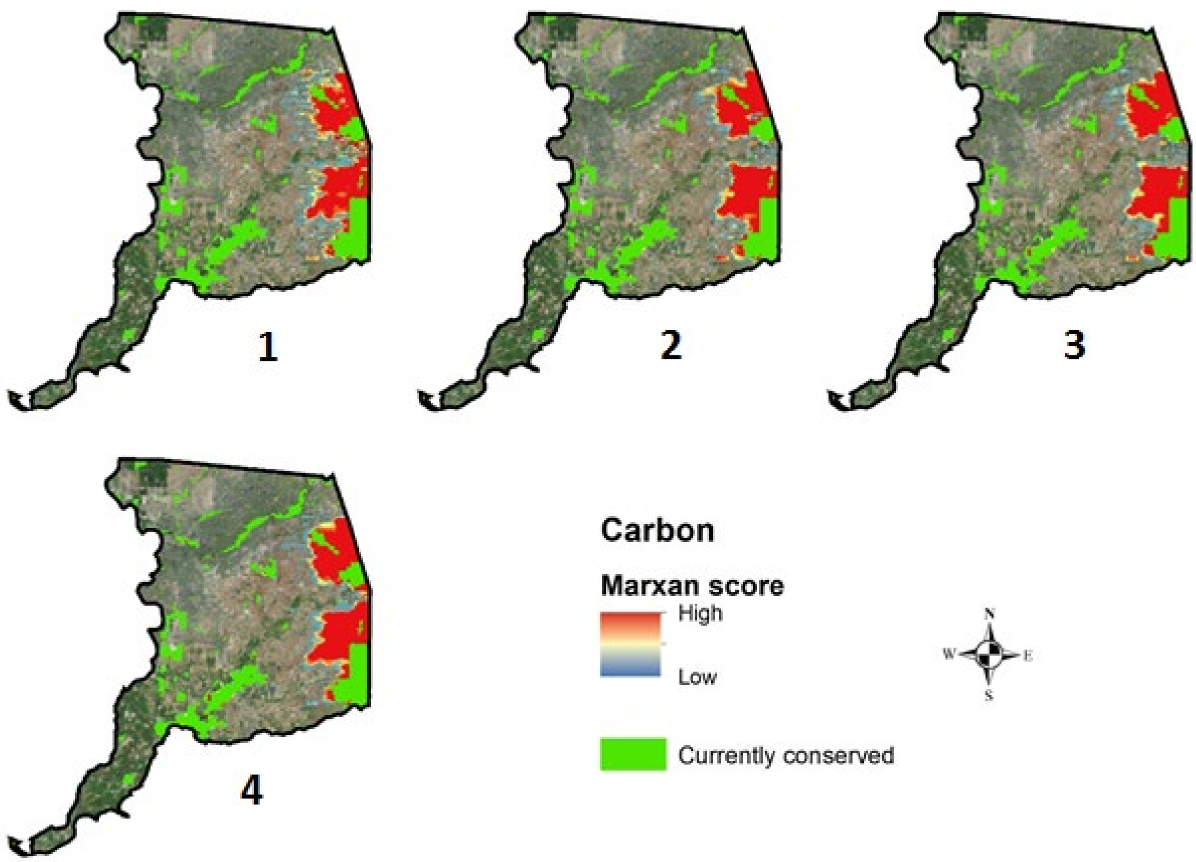

Figure 19. Summed solution outputs for Scenarios 1-4 .The color ramp for summed solution scores ranges from red (high value) to blue (lower value). Areas without colored planning units were not selected in any of the 100 Marxan runs. Green areas are existing conservation lands (fee title or easement).

Figure 20 shows the results of increasing the conservation goal for carbon. Additional areas closer to Sacramento, in the southeastern portion of the county, and in the low elevation farmland in the southwestern portions of the county were selected in addition to the shrublands and woodlands that dominated the first four scenarios.

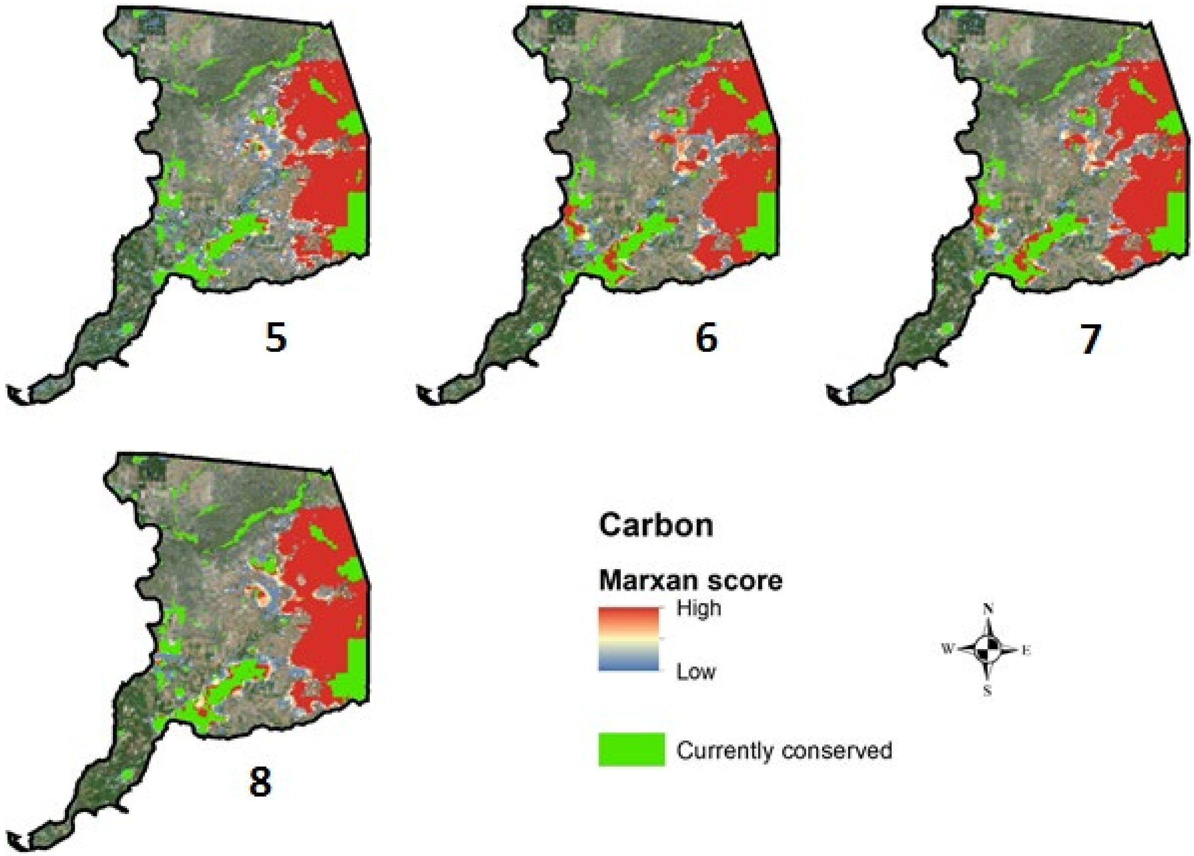

Figure 20. Summed solution outputs for Scenarios 5-8. For these scenarios, the carbon conservation goal is set to 50%. The color ramp for summed solution scores ranges from red (high value) to blue (lower value). Areas without colored planning units were not selected in any of the 100 Marxan runs. Green areas are existing conservation lands (fee title or easement).

Figure 21 shows the summed solution results from Scenarios 5-8. Including prime agricultural land as a conservation target leads to planning units in the lower elevation areas along the Cosumnes River, in the Sacramento Delta, and in Natomas Basin being selected as high value. Again, there are similar patterns regardless of urban growth scenario. However, there are some differences in planning units selected in the Rancho Murrieta area, along the Cosumnes River, and in the Sacramento Delta.

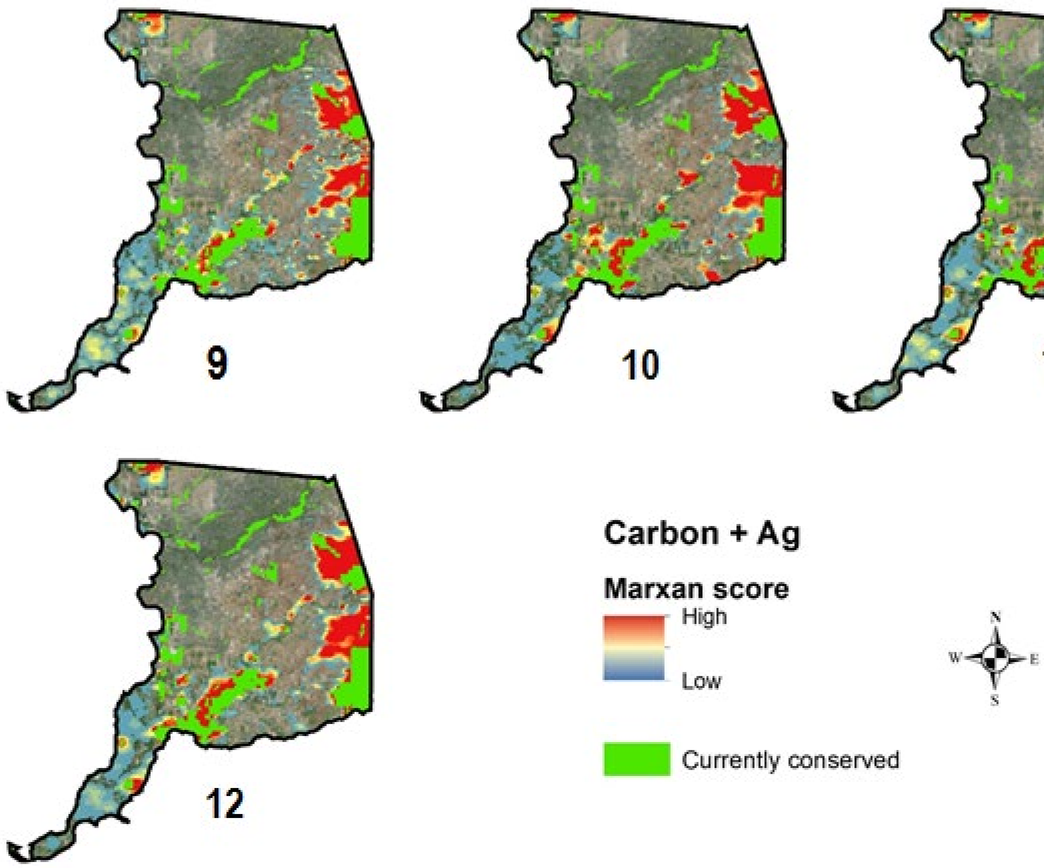

Figure 21. Summed solution outputs for Scenarios 9-12, which use both carbon and farmland conservation goals. The color ramp for summed solution scores ranges from red (high value) to blue (lower value). Areas without colored planning units were not selected in any of the 100 Marxan runs. Green areas are existing conservation lands (fee title or easement).

The urban growth models can be used to assess threat to current carbon sequestration potential in addition to being used to guide future conservation planning. To demonstrate this approach, we used the urban growth model under the BAU scenario to assess threat in Scenario 5 (**Figure 23**). Scenario 5 did not take into regard future urbanization potential in selecting planning units. We identified planning units that were selected in at least 50% of the Marxan runs and assessed the projected area of future development under the BAU urban growth scenario. We classified the hexagons into three categories: x=0; 0<x≤20; and x>20 (where x=acres of projected development within a hexagon) (**Figure 23**). The red color ramp illustrates differing levels of threat due to future projected urbanization.

The combination of conservation value (i.e. Marxan score) and threat (i.e. UPlan outputs) are depicted in the conceptual diagram in **Figure 22**. The colored circles refer to the red color ramp in the previous figure. The locations where particular hexagons fall in this matrix can suggest different conservation strategies. For example the “high value”/”high threat” hexagons in the upper right could be selected for future conservation action (e.g. protection through fee title or easement acquisition), while those in the upper left may be considered relatively secure even without explicit conservation action.

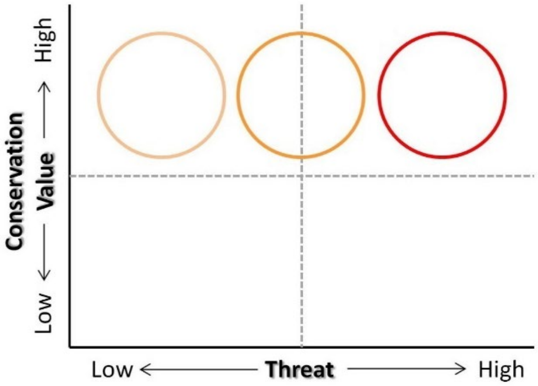

Figure 22. "Conservation value" vs. "threat" matrix. All of the planning unit hexagons can be placed into the matrix based on their Marxan and UPlan scores. Their location in this matrix can suggest appropriate future management strategies. The colored circles refer to the colored hexagons in the following figure.

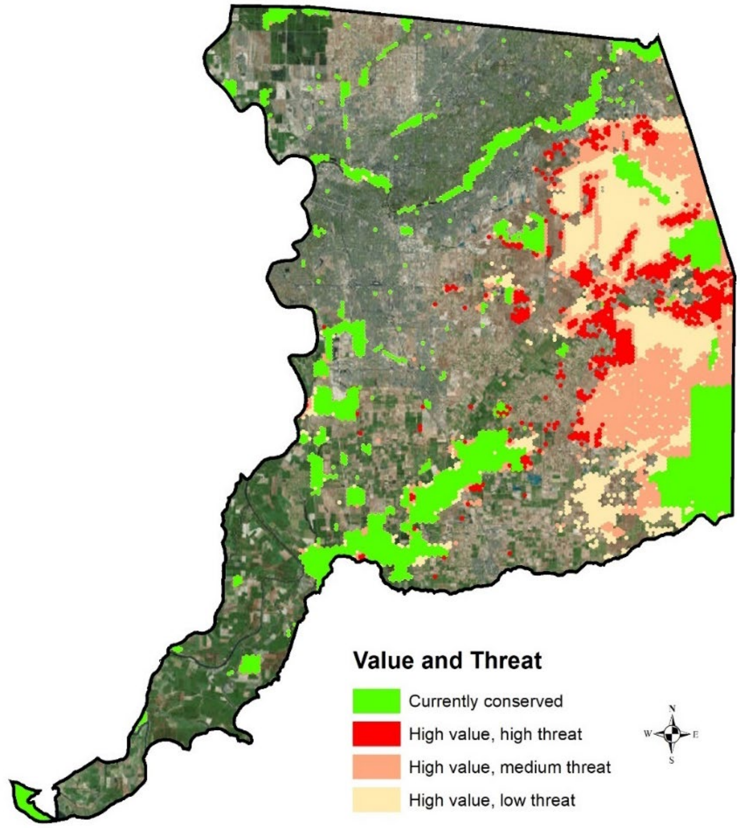

Figure 23. A comparison of conservation value and potential threat. All hexagons shown on the red color ramp are those that were selected in at least half of the Marxan runs (using a 50% target for carbon) using the "no UPlan" cost score (Scenario 5). The hexagons are classified into three "threat" categories: x=0; 0<x≤20; and x>20 (where x=acres of projected development within a hexagon) and displayed accordingly.

Using Marxan in a policy-informative manner requires extensive stakeholder input to set priorities and targets. However, as a proof-of-concept and precursor to an active policy discussion, multiple Marxan test runs demonstrated how landscape carbon can drive conservation and land use planning both as a single variable and in combination with additional priorities such as farmland preservation. While the Marxan outputs in this study were developed with arbitrary targets both to demonstrate the capability, and assess the sensitivity of the model to parameter variability, Marxan did successfully identify high priority areas based on the input conditions. High priority areas generally aligned with areas of shrublands and forests, which have the highest biomass carbon densities. The outputs themselves should not be construed as recommendations or used to inform any planning decision at this time, but the successful integration of landscape carbon data into the framework removes a significant barrier to integrated, multi-variable planning that reflects a focus on landscape carbon. The outcomes from this type of assessment can be used to identify the locations most susceptible to the tradeoff between the carbon and agricultural preservation goals of the region and the expansion of urban areas.

4.4 OPPORTUNITIES AND LIMITATIONS

Marxan outputs can be very useful in decision support. The software allows for simultaneous consideration of many factors that affect conservation strategy. However, it can never capture all of the nuanced and important information that land managers are likely to have about a given area. For example, any conservation actions undertaken are very likely to involve willing land owners; however this information is not available and is not part of the analysis. No Marxan output should be considered a conservation plan, but rather as a valuable input to a robust decision-making process.

The analyses here are not meant to be comprehensive conservation assessments of the region, but rather as demonstrations of investigations that can be undertaken in future planning efforts. These efforts are likely to include regional biodiversity, wildlife connectivity, riparian protection, and other ecosystem service goals in addition to carbon sequestration and agricultural protection. Marxan is a flexible, powerful tool for bringing these multiple types of information to bear in a given planning process and the outputs shown in this chapter are meant as a starting point for assessments that integrate carbon sequestration with other conservation goals in Sacramento County.

5 PROJECT CONCEPTS

While Chapters 2 and 3 focus on developing countywide landscape carbon inventories and forecasts, and Chapter 4 explores the potential to use that data to inform conservation and land use planning, these top-down analyses do not explicitly capture the potential benefits from improved practices within existing land uses. In agricultural, urban, and wildland setting, there are numerous opportunities to improve landscape carbon and reduce emissions through practices including urban forest expansion, nutrient management, and myriad others. This section outlines three such potential opportunities, evaluating the practices on the basis of suitability to Sacramento County, technical potential, and cost concern. Evaluating these concepts in the specific context of Sacramento County also highlights the importance of local consideration, and the fact that concepts are not consistently suitable due to local advantages and disadvantages in the natural environment or political landscape.

5.1 URBAN FORESTRY

5.1.1 STRATEGY SUMMARY

Urban forests remove and store CO_2 from the atmosphere and store it as carbon in above and below-ground biomass. CO_2 is acquired through photosynthesis and converted into cellulose and other materials to create wood and leaves. The trunk contains about half of the stored CO_2, while branches and stems account for 30% of storage and roots 18-24%. Foliage accounts for just 3% of CO_2 storage[45]. The sequestration is not necessarily permanent except in aggregate; however, when a tree dies and decays, the carbon stored is released back into the atmosphere. Though fast-growing trees uptake CO_2 at a faster rate, they tend to live fewer years than their slow-growing counterparts, releasing CO_2 back into the atmosphere sooner upon their decay.

The expansion and management of urban forests creates an opportunity for carbon sequestration. It is important to choose native species that are better adapted to the climate, as well as choosing a variety of species to prepare for unforeseen tree disease. Furthermore, the age of the forest should be managed to provide continual sequestration. Trees release carbon upon decay, so new trees should be planted in their wake to counteract this release. Comprehensive expansion and management of urban forests has great carbon sequestration potential, as described in the corresponding section below.

Urban forestry also improves air quality through the uptake of pollutants. The Sacramento Tree Foundation (STF) estimates that every 100 trees will remove 1,000 pounds of pollutants per year, including 400 pounds of ozone and 300 pounds of particulate matter, two criteria pollutants of particular concern to Sacramento County[46].

Trees also reduce energy costs by minimizing heating and air conditioning needs through the provision of shade and acting as wind blocks, a benefit recognized by SMUD and promoted through its shade tree program.[47] Shade

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[45] Ravin, Amelia and Raine, Teresa. Best Practices for Including Carbon Sinks in Greenhouse Gas Inventories. CDM Cambridge, MA and Irvine, CA.

[46] Sacramento Tree Foundation 2017. “Air Quality.” Last updated 2017. Accessed September 13 2017. http://www.sactree.com/pages/88

[47] SMUD. “Cool and beautify your home – naturally” Accessed October 2, 2017

and evapotranspiration from trees reduces the heat island effect found in cities by lowering surface and air temperatures. Urban forests also help manage stormwater by intercepting rain and reducing runoff[48].

Urban forests are recognized as improving quality of life. Aside from the aesthetic benefits, neighborhoods with trees tend to be safer and more sociable. Economic benefits have also been recognized in the form of higher property values and increased commercial business in tree-lined areas.

5.1.2 SACRAMENTO COUNTY SUITABILITY

Sacramento currently has 22% tree cover and has 25.2% non-tree, plantable land cover[49]. The Sacramento climate is well-suited for maximizing the benefits of urban forestry. Deciduous shade trees reduce heating and cooling costs year round and enhance stormwater management during the region's typical winter storms by reducing runoff. Slow growing trees with higher wood density increase the amount of carbon that can be stored; trees native to Sacramento, such as oaks, have high wood density, increasing the amount of carbon storage potential per tree[50].

There are multiple existing urban forestry programs within Sacramento County from both the government and nonprofit sectors. These programs include:

1. **The Sacramento Tree Foundation (STF)**
   a. Save the Elms Program (STEP): management of American and English elm trees of Sacramento that are vulnerable to Dutch elm disease (DED).
   b. Neighborwoods: Community Foresters work directly with neighborhoods to plant trees for free, providing their expertise on species, location, and maintenance.
   c. Community Shade: an initiative to plant trees in the community's schools, parks, streets, and open spaces.
   d. Sacramento Shade: a collaboration with SMUD to provide up to 10 free shade trees to Sacramento residents.
2. **CalFire's Urban and Community Forestry Program**: an initiative under the Urban Forestry Act to expand and manage urban forests, including coordination with the U.S. Forest Service.
3. **California ReLeaf**: a nonprofit with the mission of preserving, protecting, and enhancing California's urban and community forests, often through grant giving for planting programs, such as CalFire's Urban and Community Forestry Program

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[48] U.S. Environmental Protection Agency (EPA) 2016. "Using trees and Vegetation to Reduce Heat Islands." Last updated August 12 2016. Accessed September 13 2017. https://www.epa.gov/heat-islands/using-trees-and-vegetation-reduce-heat-islands

[49] i-Tree Canopy. i-Tree Software Suite v6.1. Web. Accessed 28 September.2017. https://forums.itreetools.org/viewtopic.php?p=1381

[50] McPherson, E. G., Xiao, Qingfu, and Aguaron, Elena 2013. A new approach to quantify and map carbon stored, sequestered and emissions avoided by urban forests. Elsevier B.V., Landscape and Urban Planning 120(2013)70-84. August 14.

The presence of existing urban forestry organizations already supports the biosequestration through urban forestry, and would ease further implementation. These programs can be expanded and built upon rather than starting from scratch.

In addition, Sacramento County has outlined two major objectives in the 2030 General Plan that support the expansion of urban forestry:

1. **Urban Forestry Management Objective:** A coordinated, funded Urban Tree Management Plan and program sufficient to achieve a doubling of the County's tree canopy by 2050 and promote trees as economic and environmental resources for the use, education, and enjoyment of current and future generations. This objective has been implemented through the Greenprint Initiative, managed by STF.

2. **New Urban Trees Objective:** One million new trees planted within the urban area between now and 2030.This objective is being met by the efforts of private tree foundations. This includes SMUD's efforts to increase shade cover near buildings.

The California Air Resources Board (ARB) issues credits to Offset Project Operators (OPOs) that undergo projects to reduce and remove GHGs. OPOs must adhere to the ARB urban forest projects compliance offset protocol to receive credits, including the completion of monitoring and reporting annually[51].

5.1.3 SEQUESTRATION POTENTIAL

The gross average annual carbon sequestration of urban forestry in Sacramento is 0.377 kilograms carbon per square meter of tree cover per year (kg C m^{-2} $year^{-1}$). However, because of the release of carbon upon decay of trees, the net average annual carbon sequestration is 0.327 kg C m^{-2} $year^{-1}$[52]. The ARB estimates total carbon densities for urban forests in Sacramento at 9.16 Metric Tons Carbon (MTC) or 13 $MTCO_2e$[53] per hectare. For 22% tree cover, this translates to 1.903 million $MTCO_2e$ sequestered. Doubling the tree canopy as per the Urban Forestry Management Objective would bring this sequestration up to 3.807 million MT CO_2e.

Several tools already exist that can help quantify the impact of urban forests. The USDA Forest Service has created the i-Tree tool to analyze a wide scope of urban and rural forest characteristics, including carbon sequestration (see i-Tree website at www.itreetools.org). The specific i-Tree Eco tool offers carbon sequestration quantification at the species level. Tree species and diameter are required inputs for the tool. Tree height and canopy are additional input that can enhance the quality of the estimate. Sequestration is measured as tons per tree as an annual average and lifetime total. Generated reports break this output down by both tree and per unit area. i-Tree also offers additional ecosystem service measurements such as avoided runoff and air pollutant removal.

In addition to the sequestration potential, urban forests and shade trees can reduce energy use for cooling. SMUD's existing shade tree program recognizes this benefit, and the i-Tree Eco tool also provides approximate estimates of tree-related energy savings.

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[51] California Air Resources Board 2015. Offset Project Operators. Last updated December 21 2015. Accessed September 22 2017. https://www.arb.ca.gov/cc/capandtrade/offsets/operators/operators.htm

[52] Nowak, David J., Greenfield, Eric J., Hoehn, Robert E., and Lapoint, Elizabeth 2013. Carbon storage and sequestration by tees in urban and community areas of the United States. Elsevier Ltd., Environmental Pollution 178 (2013) 229-236. March 10.

[53] Saah, David, et. al. 2016. Technical Improvements to the Greenhouse Gas (GHG) Inventory for California Forests and Other Lands. California Air Resources Board. Sacramento, CA. May.

CASE STUDIES

Three case studies were identified for urban forestry projects in the western U.S. The studies focused on ecosystem services as a whole, including carbon sequestration.

Boulder City, Nevada

10,000 trees were planted in Boulder City over a 5-year period. Fifty percent of the trees were planted near residences. The total cost of the project was $1,000,000: $900,000 for planting and $100,000 for administrative costs. Total CO_2 sequestration was 31,535 MT while net CO_2 savings were 47,746 MT. This came out to a cost of $21/MT CO_2 saved[54].

Tucson, Arizona

The Cool Communities Demonstration Project monitored the impact of 299 trees planted to shade 104 homes between 1993 and 1997. Species varied, but over half were deciduous medium-sized trees. The total cost of the project was $111,589. Total CO_2 sequestration was 1,123 MT while net CO_2 savings were 5,966 MT. This came out to a cost of $19/MT CO_2 saved (USDA 1999)[8].

Corvallis, Oregon

The EPA conducted a quantitative assessment of ecosystem services provided by trees in the City of Corvallis and the campus of Oregon State University. i-Tree Streets and i-Tree Eco were used to analyze the more than 17,500 trees (more than 13,200 in the city and 4,300 on the university). Factors measured included reduction in air pollutants, carbon sequestration, aesthetic (as property value), stormwater runoff reduction, and energy savings. City trees were valued at $68/tree annually for ecosystem services, including 1,080 MT of net carbon sequestration, for a total of $900,000. University trees were valued at $44/tree for annual ecosystem services, including 600 MT of net carbon sequestration, for a total of $190,000[55].

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[54] McPherson, E.G. and Simpson, James R. 1999. Carbon Dioxide Reduction through Urban Forestry: Guidelines for Professional and Volunteer Tree Planters. Pacific Southwest Research Station, Forest Service, USDA, Albany, California. January.

[55] Phillips, Donald L., Burdick, Connie, Merja, Becky, and Brown, Norm 2013. Urban forest ecosystem services: A case study in Corvallis, Oregon. U.S. Environmental Protection Agency, Minneapolis, MN. August 4.

5.1.4 COSTS AND MAINTENANCE

Initial and maintenance activities for urban forests include planting, purchasing, irrigation, pruning, and pest control. Initial costs are high to establish the tree correctly, but drop significantly after the first five years. Other costs include infrastructure repair and administrative costs for public trees. Tree and stump removal are

also considered for the end of the tree life. For large, public trees, the average annual maintenance cost of a 40-year old tree in an inland valley, such as Sacramento, has been estimated at $20 by the USDA. This cost includes

purchase, planting, pruning, irrigation, pest control, removal, and even administrative costs. The gross environmental benefits, including carbon sequestration and others, are estimated at $68, making the net average benefit $48 annually for one large public tree over 40 years[56]. In the urban forestry applications found in case studies in Boulder City and Tucson, costs were reported to be \$21/MTCO$_2$ saved and \$19/MTCO$_2$ saved, respectively.

5.1.5 URBAN FORESTRY CONCLUSION

Urban forestry would be an effective and applicable solution to achieve biosequestration in Sacramento County. Existing programs and county objectives would support urban forestry initiatives, and the U.S. Forest Service is a potential partner to promote carbon sequestration in the urban footprint. Focusing on large, woody native trees would maximize the potential for biosequestration. Urban forestry provides a variety of additional benefits, including energy savings and air pollutant removal, and has been shown to be successful in other western cities. However, newer housing developments in Sacramento County favor higher density housing with less homeowner individual space for planting trees. Therefore, some of the programs may need to be adjusted to accommodate newer style development plans. Overall, urban forestry would be an environmentally practical and economically efficient solution to increase carbon sequestration. Opportunities for SMUD to contribute to urban forestry as a biosequestration strategy could be by expanding their existing Sacramento Shade program or becoming involved in other programs by providing their expertise or funding.

5.2 NUTRIENT MANAGEMENT

5.2.1 STRATEGY SUMMARY

Agriculture and working lands provide myriad opportunities to reduce GHG emissions and increase carbon sequestration, ranging from tillage practice, crop rotations, grazing, and sundry other activities. Tools like COMPET-Planner allow for simple estimates of GHG mitigation potential. One set of agricultural activities with GHG emissions benefits is nutrient management.

Nutrient management refers to a suite of activities that change the amount, source, placement, and/or timing of nutrient application (primarily nitrogenous fertilizers) on agricultural lands to increase carbon sequestration, reduce nitrous oxide (N_2O) emissions from soil and irrigation canals, and/or improve soil health. Nutrient

[56] Unites States Department of Agriculture (USDA) 2011. Trees Pay Us Back in the Inland Valleys Region. Accessed September 7 2017. https://lgc.org/wordpress/docs/events/calfire/CaUFC%20forestry%20flyer.pdf

management practices are also referred to as the Four R's: right amount, right form, right place, and right time. These practices, presented in **Table 9**, can sequester CO_2 and reduce other GHGs, notably N_2O.

Carbon sequestration occurs through the replacement of synthetic fertilizer with organic alternatives, such as compost or manure, which put carbon in the form of organic matter back into the soil. Other GHG benefits result from reducing N_2O emissions. This can have a meaningful impact because N_2O has a global warming potential 298 times that of CO_2 and N_2O emissions from agriculture accounted for 7.3 million metric $MTCO_2e$ in California in 2015[57]. N_2O emissions are the result of nitrification, the conversion of ammonia to nitrate, and denitrification, the conversion of nitrate to N_2O and subsequently to nitrogen gas (N_2). These conversions are not fully efficient, however, so some nitrogen is lost as N_2O in the atmosphere before being converted to N_2. Fertilizers increase nitrogen concentration in soil, which encourages nitrification. However, excess nitrogen leads to increased N_2O emissions. Thus, reducing the nitrogen concentration in soil can prevent the release of carbon equivalents into the atmosphere.

Table 9. Nutrient Management Practices

Management Type	Activity	Impact
Right Amount	Reduction in fertilizer volume	Directly reduces the amount of nitrogen available for nitrification and release into the atmosphere[58]
Right Form	Addition of nitrification inhibitors Substitution of organic fertilizer for synthetic fertilizer	Reduces the nitrification rate by blocking the bacteria responsible for this conversion[59] Puts organic matter back into soil, increasing soil organic carbon and gradually releases nutrients as needed to the crop over a season (slow-release)[2]
Right Place	Optimizing location of fertilizer application	Increases the uptake of nutrients by plants and minimizes runoff of nutrients[2]
Right Time	Split fertilizer application into smaller portions at essential points of plant development	Reduces nutrient loss from runoff/leaching and improves nitrification efficiency[2]

In addition to sequestering carbon and reducing N_2O emissions, nutrient management has the potential to improve the quality of surface and ground waters, as well. Nitrogen and phosphorous runoff from fertilizers can impair water quality. Reducing fertilizer volume, applying fertilizers in the proper amount, and applying at the appropriate time of year can prevent nutrient pollution in the watershed[60] .

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[57] California Air Resources Board (ARB) 2017. Nitrous Oxide (N_2O). Last updated June 6 2017. Accessed September 22 2017. https://www.arb.ca.gov/cc/inventory/background/n2o.htm

[58] California Ag Water Stewardship Initiative 2017. Nutrient Management. Accessed September 14 2017. http://agwaterstewards.org/practices/nutrient_management/

[59] International Plant Nutrition Institute (IPNI). Nutrient Source Specifics: Nitrification Inhibitors. IPNI, Peachtree Corners, Georgia.

[60] US Environmental Protection Agency (EPA) 2017. Nutrient Pollution: The Sources and Solutions: Agriculture. Accessed September 14, 2017. https://www.epa.gov/nutrientpollution/sources-and-solutions-agriculture.

Fertilizers are a high input cost for farmers, so nutrient management by fertilizer reduction can produce savings for farmers. Depending on the farm and availability of manure, replacing synthetic fertilizers with manure has the potential to provide savings, but is not guaranteed (see Cost & Maintenance).

5.2.2 SACRAMENTO COUNTY SUITABILITY

California is a national leader in agriculture, and in Sacramento County, agriculture is the second largest land cover at 28%, the majority of which is non-orchard, non-vineyard agriculture. In 2015, the gross value of agricultural production in Sacramento County was $470 million[61]. Within agriculture, manure is responsible for 25% of N_2O emissions in California or 2.9 million $MTCO_2e$[62]. As such, there is a lot of potential for GHG control through nutrient management in Sacramento County.

The California Department of Food and Agriculture (CDFA) leads two existing programs that promote nutrient management among other agricultural practices: the Fertilizer Research and Education Program (FREP) and the Healthy Soils Initiative.

FREP is a research initiative started in 1990 to advance the environmentally safe and agronomically sound use and handling of fertilizing materials. FREP's comprehensive approach to achieve this goal includes outreach, education, research, funding, and fertilization guidelines[63].

The Healthy Soils Initiative promotes innovative farm and ranch practices to build soil organic matter that in turn sequesters carbon and reduces GHGs. Action 1 of the Healthy Soils Initiative is to "Protect and restore soil organic matter in California's soil," which includes the expansion and balance of soil amendments to manage carbon storage[64]. It's FY16-FY17 funding will be funding approximately 12-15 demonstration projects and approximately 75-150 direct farmer incentive projects over the three years beginning January, 2018. While the FY17-FY18 budget was not renewed, the program continues to implement existing projects and anticipates future funding, for example through the SB-5 Parks and Water Bond of 2018. The Sustainable Agricultural Lands Conservation (SALC) Program has a mission to reduce GHG emissions and promote conservation.

Cattle and chicken are the main animals raised in Sacramento County. As such, replacement of synthetic fertilizer with manure would focus on beef and chicken manure despite the superior performance of swine manure (see Sequestration Potential).

5.2.3 SEQUESTRATION POTENTIAL

The U.S. Department of Agriculture (USDA) and Natural Resources Conservation Service (NRCS) have created COMET-Planner, an online tool for estimating GHG emission reductions through conservation practices. COMET-Planner calculates GHG reductions by pollutant and CO_2e for a variety of conservation practices, including nutrient management through reduced fertilizer volume, nitrification inhibitors, and alternative fertilizers.

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[61] Sacramento County 2015. Sacramento County 2015 Crop and Livestock Report. Agriculture- Weights and Measures. Sacramento, California.

[62] California Air Resources Board (ARB) 2017. nitrous Oxide (N_2O). Last updated June 6 2017. Accessed September 22 2017. https://www.arb.ca.gov/cc/inventory/background/n2o.htm

[63] California Department of Food and Agriculture (CDFA) 2017. Fertilizer Research and Education Program. Accessed September 14 2017. https://www.cdfa.ca.gov/is/ffldrs/frep/

[64] CDFA 2016. Health Soils Action Plan. CDFA, Sacramento, CA. September.

Calculations are based on county level data and acreage input. A more detailed level of analysis can be achieved using the sister tool, COMET-Farm, designed for enhanced farm-level estimates.

According to COMET-Planner, reducing fertilizer application rates by 15% in Sacramento County reduces N_2O emissions 0.019 $MTCO_2e$ per acre per year. Use of nitrogen inhibitors reduces 0.034 $MTCO_2e$ per acre annually[9]. However, replacing synthetic fertilizer with manure can have a potentially larger impact by increasing carbon sequestration in soils, while replacing synthetic fertilizer with compost can have an even larger impact. Swine manure produces higher sequestration rates than beef, chicken, or sheep manure. Unfortunately, swine manure is not readily available in Sacramento County, and chicken and beef manures have the highest availability. Carbon sequestration from fertilizer replacement is also more effective on irrigated rather than non-irrigated crops. For example, for compost application to irrigated crops in Sacramento County, CO_2e sequestration is 0.2-0.5 $MTCO_2e$/year, while it is 0.2-0.3 $MTCO_2e$/year for non-irrigated crops[65].

A summary of sequestration rates of various nutrient management practices on irrigated crops for Sacramento County is presented in **Table 10**. Rates are displayed in $MTCO_2e$ per acre per year. Negative rates indicate release of GHGs into the atmosphere. For replacement of synthetic fertilizer with compost or manure, landscape carbon is improved through increased soil organic carbon. While there may be some increased N_2O emissions associated with manure, the overall climate impact is positive.

Table 10. Sequestration Rates for Nutrient Management on Irrigated Crops in Sacramento County (MTCO2e/acre/year)

Activity	CO_2	N_2O	Total CO_2e
Reduce fertilizer application rate by 15%	(0.005)*	0.019	0.014
Use of nitrification inhibitors	0.0	0.034	0.034
Use of slow-release fertilizers	0.0	0.02	0.017
Replace synthetic fertilizer with manure (varies by manure type)	0.17-0.24	(0.03)* - 0.06	0.21-0.34
Use of other manure	0.24	- 0.03	0.21
Replace synthetic fertilizer with compost	0.2-0.5	0	0.2-0.5

Source: COMET-Planner 2017

*Negative rates indicate the emission of the pollutant into the atmosphere

For each 10% (14,296 acres) of Sacramento County general agriculture (non-orchard, non-vineyard) that implemented nutrient management the carbon sequestration would be as displayed in **Table 11**. While these annual numbers are modest, the impact at scale could be significant. For example, if 50% of acreage used manure, the total impact could be almost 280 thousand MTCO2e cumulative by 2050.[66]

Table 11. Sequestration Rates for 10% of Agriculture Sacramento County (MTCO2e/year)

Activity	CO_2	N_2O	Total CO_2e
Reduce fertilizer application rate by 15%	- 68	270	200
Use of nitrification inhibitors	0	490	490
Use of slow-release fertilizers	0	240	240
Use of beef feedlot manure	3420	-380	3040
Use of chicken manure	2380	-500	188

[65] COMET-Planner 2017. COMET-Planner Carbon Sequestration and Greenhouse Gas Estimation Report. September 15.

[66] Assumes 50% of acreage adopts beef feedlot manure fertilization at linear implementation rate between today and 2050

Source: COMET-Planner 2017

5.2.4 COSTS AND MAINTENANCE

Nutrient management is an ongoing practice at the individual farm level. Farmers will need to manage fertilizer for their specific setting, and calculating the optimal rate of nitrogen application is difficult, a fact that has historically led to over-fertilization. Nutrient management tools do exist to aid in this process, such as CropManage, an online tool for irrigation and nutrient management.

Reductions in fertilizer volume can produce savings for farmers because they simply purchase less fertilizer. Replacing synthetic fertilizers with manure has variable return, depending on each unique farm and crop type. Local availability of organic fertilizer is key, otherwise transportation costs can create a burden. The variable nutrient concentration of manure poses a challenge to farmers. Assuming average nutrient rates when determining application quantities risks lower crop yield while avoiding over-application. Applying excess manure guarantees crop yield, but brings higher costs and water quality concerns. Furthermore, manure storage and management is a concern because nutrient concentration varies over time and can force farmers to apply manure at sub-optimal times[67]. Professors Ray Massey and John Lory of the University of Missouri summarized "manure has value only if it offsets the need to purchase other nutrient or soil amendments…. actual economic value of manure must be negotiated between the manure seller and the buyer."[68] Management practices must be balanced at the farm-specific level to maximize the benefits of nutrient management.

Agricultural protocols for carbon offsets are gaining momentum. The California Air Resources Board (ARB) has implemented their first agricultural protocol, focused on rice farming. This opens the door for other agricultural protocols[69], potentially including the voluntary offset protocols for nutrient management.

5.2.5 NUTRIENT MANAGEMENT CONCLUSION

Nutrient management has modest potential for carbon sequestration in Sacramento County. Existing programs by the CDFA could integrate and expand nutrient management. However, responsibility for nutrient management practices is at the farm-level and would require adequate support and incentives to encourage farmers to implement these practices. Aside from GHG reduction, nutrient management can improve water quality and potentially reduce farmer's cost. One program that could benefit from support is the Healthy Shoils Initiative which currently has a funding gap for FY17-FY18, and SMUD could encourage new funding through the Parks and Water Bond. For more hands-on involvement, SMUD could consider developing an agricultural position or department to provide community expertise and subsidies, similar to their tree programs.

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[67] Lory, John, Massey, Ray, and Joern, brad 2008. Using Manure as a Fertilizer for Crop Production. Pp. 105-116 in Final Report: Gulf Hypoxia and Local Water Quality Concerns Workshop. September 26-28, 2005, Ames, Iowa. Sponsored by Iowa State University and EPA. Organized by the MRSHNC, Upper Mississippi River Sub-basin Hypoxia Nutrient Committee. St. Joseph, Michigan: ASABE

[68] Massey, Ray and Lory, John 2013. Calculating the Value of Manure as a Fertilizer Source. University of Missouri. Last updated June 2013. Accessed September 29 2017. http://extension.missouri.edu/p/G9330

[69] Environmental Defense Fund. Greenhouse Gas Markets for Agriculture. Accessed September 22 2017. https://www.edf.org/ecosystems/greenhouse-gas-markets-agriculture

5.3 BIOCHAR

5.3.1 TECHNOLOGY SUMMARY

Biochar is biomass (i.e. plant material, compost, manure, etc.) that has been partially combusted in a limited oxygen setting through pyrolysis or gasification. The resulting charcoal stabilizes carbon in the biomass in an inert form for long term carbon sequestration and greenhouse gas emission reduction, and the biochar can be applied to the soil as an amendment. Biomass not treated through pyrolysis or gasification undergoes decomposition at a faster rate than biochar and biomass carbon is converted to atmospheric CO_2. Partial combustion does not prevent the conversion of biomass carbon to atmospheric CO_2; however, the process is retarded. Studies regarding the length of time the carbon is held in this inert form in biochar are ongoing with current estimates placing long term stability from decades to millennia. Factors affecting this stability in soil include the type of feedstock used, the depth at which the feedstock is buried, the soil biological and chemical characteristics, and the rate of soil cultivation of the land. In addition to stabilized carbon, biochar may also contain phosphorus, potassium, sulfur, magnesium, calcium, and lime among other elements which can alter soil chemistry and impact crop yields. [70]

Application of biochar to the soil can be conducted in a variety of ways, such as broadcasting by any plowing method, mixing the biochar with solid amendments (manure, compost, lime, etc.), and targeted biochar application for poor soils.[71]

Beyond GHG mitigation, there are multiple identified additional benefits with the application of biochar. In agricultural settings biochar has the capacity to increase water holding capacity of the soil and can improve the productivity of the soil. The productivity of the soil after application appears to depend on the existing conditions of the soil (e.g. soil acidity and texture), the biochar feedstock, and regional environmental conditions. There is some ongoing discrepancy concerning these additional benefits and the role biochar plays in increasing crop yields and improving soil health. Positive effects of biochar appear in studies conducted in the tropics where the soils are highly weathered, nutrient poor, and acidic. This is because biochar has alkaline properties that improve soil pH and the addition of carbon to the soil. However, results in fertile soil regions, such as California's Central Valley, regarding improvement of crop yield and soil health are not as positive and in some cases either have no statistical effect or a negative effect.[72]

UC Davis researchers examined the productivity in the Central Valley of corn and tomato crops with and without application of biochar with a feedstock of walnut shells from an orchard in Winters, California. An increase in crop yield was not observed until the second year after application and these benefits were short lived (limited to one year). Additionally, the study noted that as the biochar degrades, there is uncertainty as to the interaction with the native soil and if the crop yield is maintained.[73]

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[70] Terra Global Capital LLC. 2010. Evaluation of the Opportunities for Generating Carbon Offsets from Soil Sequestration of Biochar. Climate Action Reserve.

[71] Major, Julie. 2010. Guidelines on Practical Aspects of Biochar Application to Field Soil in Various Soil Management Systems. International Biochar Initiative.

[72] Griffin DE, Wang D, Parikh SJ, and Scow KM. 2016. Short-lived effects of walnut shell biochar on soils and crop yields in a long-term field experiment. Agriculture, Ecosystems & Environment. 236 (2017) pgs. 21-29.

[73] Griffin et al, 2016.

A study in San Mateo County indicated that biochar had a neutral or negative effect on crop yields of Brussel sprouts. While the cause of this effect is unknown, the study suggested that the pH of the soil prior to biochar application was already favorable for Brussel sprout cultivation and thus precluded the effect of biochar.[74]

Pyrolysis and gasification systems to produce biochar vary considerably, and can be stationary or mobile. Systems can be built and operated on a small residential scale that provides heat and decreases biomass of a single residence up to large scale industrial systems that require tonnes of biomass per day to operate effectively. At the farm level, large farms could operate a pyrolysis or gasification system that harvests excess biomass to convert to biochar and then apply directly to the fields. [75]

5.3.2 SACRAMENTO COUNTY SUITABILITY

Sacramento County land cover and land use provides multiple opportunities to employ biochar as a carbon sequestration method. As the second largest land cover in the county, agriculture land cover and more specifically row crops is an area in which biochar may be well suited for biochar application. Dominant row crops in Sacramento that may be candidates for biochar application include corn (~25,000 harvested acreage in 2015) and hay (~21,000 harvested acreage in 2015). Other row crops in Sacramento County that may be candidates include rice, oats, wheat, and ryegrass.[76] A large concern regarding the application of biochar to Sacramento County's alkaline agricultural soils is the lack of benefits biochar could have on soil health of an already fertile region.

There are local biochar suppliers in Willows, California (Pacific Biochar) and Merced, California (Phoenix Energy) that produce a variety of biochar and biochar blends. Pacific Biochar also offers consultation to optimize biochar application rates.[77] [78]

There is support in the State government to address GHG emissions and climate change from a soils perspective. California Department of Food and Agriculture (CDFA) has developed the Healthy Soils Program (HSP) that's objective is "to build soil carbon and reduce agricultural greenhouse gas emissions." The program has issued a request for grant applications for pilot projects that examine methods to reduce GHG emission from agricultural soils.[79] This request does not include funding for projects that incorporate biochar. Based on the program's mission statement, it seems biochar projects would be candidates for studies in the future; however, the budget for the Healthy Soils Program was cut for the 2017-2018 fiscal year.[80]

In examining other agricultural lands, such as rangeland, there are some obstacles to biochar application on rangeland that do not make rangeland an ideal land cover type to apply biochar. For instance, the increase of

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[74] San Mateo Resource Conservation District. February1, 2016. Biochar Field Trials in San Mateo County. Accessed September 17 2017. http://www.sanmateorcd.org.
[75] US Biochar Initiative. Biochar Production. Accessed September 17 2017. http://biochar-us.org/biochar-production.
[76] County of Sacramento. 2016. 2015 Sacramento County Annual Crop and Livestock Report. Accessed September 27 2017. http://www.agcomm.saccounty.net/Pages/CropandLivestockReports.aspx.
[77] Phoenix Energy. Biochar from Phoenix Energy. Accessed September 17 2017. Available from: http://www.phoenixenergy.net/bulk_biochar.
[78] Pacific Biochar. Biochar Price Sheet. Accessed September 17 2017. Available from: https://pacificbiochar.com/biochar-price-sheet.
[79] California Department of Food and Agriculture. Healthy Soils Program. Accessed September 17 2017. https://www.cdfa.ca.gov/oefi/healthysoils/.
[80] Merrill J. 19 September 2017. "No Funding for Healthy Soils and SWEEP Programs in Cap-and-Trade Budget Deal." California Climate and Agriculture Network. Accessed September 25 2017. https://www.calclimateag.org.

developments in the county is decreasing the acreage of rangeland. Additionally, rangelands in Sacramento County contain vernal pools and vernal pool complexes that are highly sensitive habitats requiring a narrow range of environmental conditions. Any application of biochar in this county would require wetland delineations and vernal pool surveys to identify the locations of these habitats within rangeland. Additionally, the effect on vernal pools of biochar addition to these habitats or the rangeland habitat surrounding vernal pools is not well studied and the impacts are not understood. As a result, this summary does not recommend application of biochar to rangeland in Sacramento County at this time and the remainder of this summary will not address rangeland application.

5.3.3 TOOLS

The total or per acre carbon sequestration potential depends on the source of the biochar and the application rate of the biochar to the soil.

The Pacific Northwest Biochar Atlas (Atlas) provides tools that encompass a Biochar selection evaluation and Biochar Cost-Benefit Analysis Tool. The Selection Evaluation is based on soil characteristics, biochar goals (sequester carbon, improve soil fertility, increase water retention, etc.), and crop type. The selection tool requires inputs of the following soil characteristics: percent organic matter carbon, phosphorous (parts per million [ppm]), potassium (ppm), sulfur (ppm), magnesium (ppm), pH, cation exchange capacity, and texture. Results from the Biochar Selection Tool provide users with the option to explore various biochar types and amendment rates and assess the average stable carbon by weight and acre. [81] The Atlas is a program funded jointly by the DOI Northwest Climate Science Center and the USDA Northwest Climate Hub and developed by the USDA Agricultural Service Forage Seed and Cereal Research Unit and the Department of Crop and Soil Science at OSU. Other tools provided by the Atlas include a cost benefit analysis tool that assesses the predicted harvest yield and the net economic benefit. This tool requires the user to estimate the biochar application rate in ton per acre, the cost of the biochar per ton, as well as transport and application costs. The changes in crop margin are also required (price of crop per acre, average yield in ton per acre, and expected change in yield) as well as any changes to the fertilizer, lime, and irrigation costs.[82]

While these tools are tailored to regions in the Pacific Northwest, they allow the user to enter site specific soil characteristics and can likely be adapted for use in Sacramento County. For example, the biochar recommendations are specific to biomass feedstock available in the Pacific Northwest, but there is overlap of feedstock that would be available in the Sacramento County or Northern California (e.g. poultry litter, ponderosa pine, Douglas fir, and yard waste). This set of tools provides a rough initial estimate of the amount of stable carbon in a biochar type and the net economic benefit of application (making assumptions concerning projected crop yield). With multiple variables, estimating these outputs would need to occur on an agricultural field scale to produce realistic financial impacts to the growers.

5.3.4 EVALUATION

The volume of carbon sequestered depends on a multitude of factors. The feedstock basis for the biochar, the pyrolysis and gasification procedures, and soil characteristics (soil pH, clay content, etc.) can affect the carbon sequestration potential and stability of the biochar. Biochar can sequester carbon for decades to millennia depending on surrounding conditions and the quality of the initial biochar. While this is longer than non-

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[81] Pacific Northwest Biochar Atlas. Biochar Selection Tool. Accessed October 2 2017. http://www.pnwbiochar.org/tools/selector/.
[82] Pacific Northwest Biochar Atlas. Cost-Benefit Analysis Tool. Accessed October 2 2017. http://www.pnwbiochar.org/tools/cba/.

charcoal organic matter in soil, biochar does degrade and the carbon is eventually released. The International Biochar Initiative has developed a biochar classification system that estimates the quantity of organic carbon (grams per kilogram) sequestered in a biochar for at least 100 years (sBC_{+100}) (**Table 12**).[83] The Atlas has evaluated biochar feedstock types used in its tools based on this classification system.

Table 12. Carbon Storage Classification System and application of System by Pacific Northwest Biochar Atlas.

Carbon Storage Classes	Carbon Storage Value	Pacific Northwest Biochar Atlas: Biochar Feedstock
5	$sBC_{+100} \geq 600$ g/kg	Douglas fir (500°C & 700°C), Ponderosa pine, Yard debris (700°C)
4	500 g/kg $\leq sBC_{+100} <$ 600 g/kg	*(no applicable biochar feedstock to Sacramento County)*
3	400 g/kg $\leq sBC_{+100} <$ 500 g/kg	Yard debris (500°C)
2	300 g/kg $\leq sBC_{+100} <$ 400 g/kg	Poultry litter (500°C & 700°C) Yard debris (500°C)
1	$sBC_{+100} <$ 300 g/kg	Poultry litter (350°C)

Generally, the biochar application rate is based off of site specific characteristics and aims to maximize the improvement of crop yield. Due to variability of soils, climate, and biochar characteristics, application rates vary and studies have observed positive crop yield effects from the application of 5 to 50 tonnes of biochar per hectare. However, in arid temperate areas of the west with quality soils, such as the climate in the California Central Valley, studies have suggested mixed results regarding crop yield.

To calculate the amount of carbon sequestered for the largest row crop type in Sacramento County (corn), 2015 harvested corn acres[84] and pounds per acre of stable carbon present in poultry litter (combusted at 700°C)[85] were used to provide a rough estimate. As an example, exercise, an application rate of 0.5 ton of biochar per acre was used. The estimate yielded approximately 21,600 pounds of sequestered carbon.

5.3.5 COSTS AND MAINTENANCE

The International Biochar Initiative has assessed average wholesale prices of 28 US biochar producers to be $1,360/ton of biochar in 2014[86]; however, the cost varies widely depending on the feedstock and operating costs of the facility. Assessing the cost for nearby producers, wholesale pure biochar from Pacific Biochar is currently $1,000 /ton and can be blended with compost or biologically active culture at an increased cost. The feedstock is debris from high fire risk areas in California. No information was provided concerning the carbon sequestration potential. In the Sacramento County region, due to the lack of clear benefits, the cost to apply the biochar may be a sunk cost that does not generate increased profit yield.

Biochar can be a one-time application (one-time cost) or biochar may be incorporated into fertilizers and composts and reapplied at the rate required by the fertilization application rate (application rate dependent on

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[83] International Biochar Initiative. IBI Biochar Classification Tool. Accessed October 1 2017. http://www.biochar-international.org/classification_tool.
[84] County of Sacramento, 2016.
[85] Pacific Northwest Biochar Atlas, Biochar Selection Tool.
[86] Jirka S. and Tomlinson T. 2015. '2014 State of the Biochar Industry: A Survey of Commercial Activity in the Biochar Sector', International Biochar Initiative report. Accessed October 2 2017. http://www.biochar-international.org/node/8367.

crop and soil type).[87] Additional costs and maintenance can be associated with biochar. Due to fine particle size of some biochar, wind and water erosion are concerns for maintaining biochar on site. To address these concerns the International Biochar Initiative has developed guidelines for implementation of best management practices.[88] To address wind erosion that occurs during application, moistening the biochar or pelleting the biochar is recommended. To address water erosion that may impact off site areas or local waterways, proper and full incorporation of the biochar into the soil is recommended.[89] In addition, it is likely that implementation of traditional row cropping management practices that reduce offsite runoff from agricultural sites would be beneficial (e.g. vegetation buffers).

5.3.6 BIOCHAR CONCLUSIONS

While the application of biochar to the agricultural field landscape offers an opportunity to sequester carbon on the second largest land cover type in Sacramento County, the field of study is limited and effect on crop yields have not produced positive results in the long term for this region. At its current state, biochar would likely be difficult to implement as a carbon sequestration method due to unknown effects to crop yield, the fact that negative or neutral results would affect grower's livelihood, and the fact that biochar remains in the soil for an extended period of time and could impact the region's already fertile soil. To further the understanding of the effects biochar has on agricultural land in the region, SMUD may be able to fund studies of fields and crop types of willing growers in the County. Additionally, SMUD may be inclined to partner with Healthy Soils Program and provide funding towards this program. Ultimately, more research on the effect to soil health, crop yield, and farm economics in the region is required prior to recommending widespread funding and application of biochar in Sacramento County.

5.4 DISCUSSION

These three project concepts are illustrative, but by no means exhaustive of the range of opportunities both generally for increasing landscape carbon through biosequestration or specifically in Sacramento County. Work underway by TNC in Merced County is developing a long list of project concepts that will be a wealth of information. While these will not follow precisely the same topics covered here, they will evaluate opportunities on the basis of technical potential, cost, and other considerations.

The project concept biosequestration potentials have not been included in the current, forecast, or MARXAN-based modeling exercises. However, with appropriate spatial resolution and classifications, the areas where each concept could be implemented could be identified. Future work should seek to integrate these concepts more explicitly to understand not only the losses in landscape carbon attributable to development, but also the areas where carbon could be maximized.

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[87] Major, 2010.
[88] Ibid.
[89] Ibid.

6 FUTURE OPPORTUNITIES

The model described in Chapter 2 was developed within the existing scope of this project as an initial study, but there are opportunities for model expansion and refinement in future iterations. The sections below document potential expansions and refinements that may inform future studies in Sacramento County and the surrounding region.

6.1 LAND USE AND LAND COVER CLASSIFICATIONS AND BIOMASS CARBON DENSITIES

6.1.1 AGRICULTURE

Agriculture represents over a quarter of Sacramento County's land area and is an important contributor to the economy in the region. For agriculture, the resolution that LANDFIRE provides is more applicable to a state-level analysis than it is for a county- or local-level analysis. There are resolution issues that impact the delineation of orchards and vineyards as well as grasslands and shrublands. An improvement to this model would be to incorporate more granular agriculture land classes to have a more accurate portrayal of specific crops, orchards and vineyards in the county. Potential datasets include:

- **California Department of Water Resources Statewide Cropping Data:** Recent 2014 statewide cropping data, released in late September 2017, from the California Department of Water Resources and LandIQ is a solution that provides improved granularity of agricultural land uses, and should be considered if this analysis is expanded. According to the metadata, this dataset "represents a statewide, comprehensive, field-scale assessment of agricultural land use, as well as urban and managed wetland boundaries for the 2014 year. This data is prepared by Land IQ, LLC and provided to the California Department of Water Resources (DWR) and other resource agencies involved in work and planning efforts across the state for current land use information. This dataset is meant to provide information for resource planning and assessments across multiple agencies and serves as a consistent base layer for a broad array of potential users and multiple end uses." The data can viewed and downloaded online at: https://gis.water.ca.gov/app/CADWRLandUseViewer/
- **The Nature Conservancy Statewide Agriculture and Grasslands Classifications:** TNC is developing a statewide dataset with the intention of creating a robust granular classification of agriculture and grassland. These data are not yet available, but may provide another option for increased accuracy of agriculture and grassland classes.

Improved granularity would also allow for the application of vineyard-, orchard- and crop-specific carbon factors to calculate sequestration carbon storage to apply to these calculations. Resources for helping to refine orchard carbon densities might include the U.S. Forest Service's CUFR Tree Carbon Calculator[90] to use tree genera as surrogates for orchard species (e.g., walnuts, almonds, pistachios, and citrus) and UC Davis's Agricultural and Resource Economics Department cost and return studies[91] to evaluate tree planting densities.[92] Furthermore,

[90] The CUFR Tree Carbon Calculator is online at: https://www.fs.usda.gov/ccrc/tools/tree-carbon-calculator-ctcc
[91] Cost and return studies can be found online at: https://coststudies.ucdavis.edu/en/current/
[92] Personal Communication with Klaus Scott (October 12, 2017).

more detailed agricultural classifications may also allow for incorporating COMET-PLANNER data into inventory calculations to show carbon sequestration based on various agricultural practices.

6.1.2 URBAN FORESTS

This analysis uses a single county-specific density to calculate carbon from urban forests. While this approach provides a high level estimate of carbon, future studies at the county level should consider more spatially resolved urban forest carbon stock data to obtain a more accurate estimate. This notion is particularly applicable to Sacramento County where canopy cover varies greatly in urban areas. There may be an opportunity to gather more granular data to develop urban forest carbon factors. The LANDFIRE and UPlan datasets both delineate multiple densities for urban areas. Understanding how forest land cover and area change across these urban densities may lead to a more accurate classification and carbon inventory of urban forests within Sacramento County. This process may involve a combination of field work as well as analysis of high resolution geospatial data such as LIDAR data as seen in TNC's Sonoma County report.[93]

6.1.3 FORESTS

This study calculated carbon at the LANDFIRE forest class level, but then aggregated all forest types together to get an aggregated forest carbon density to be applied to all scenarios. Future studies should consider breaking out forest carbon densities into coniferous and deciduous groupings or specific species to more accurately capture their varying carbon densities[94], particularly in counties or regions where forests cover a great percentage of the landscape than they do in Sacramento County.

6.2 SOIL DATA, CLASSIFICATIONS AND SOIL CARBON FACTORS

The gSSURGO database provides geospatial soil survey data that is publicly available and intended to inform resource planning and analyses, but does have its limitations. The following items discuss how future studies in Sacramento County and the SACOG region may refine soil carbon estimates:

- **Soil Classifications:** Per discussion with the technical experts at TNC, the Merced County project is implementing granular agricultural soil classifications based on Intergovernmental Panel on Climate Change (IPCC) soil categories.[95] These classifications are developed by Colorado State University and are aligned with the COMET-PLANNER tools, and may be useful in developing a more accurate soil carbon estimate for agricultural lands.
- **Soil Carbon Loss from Land Conversion:** The resolution of the gSSURGO soil organic carbon data does not account for soil carbon loss impacted by landscapes modified by urban development or agricultural activity[96]. Having the ability to better understand at a county or regional level how landscape modification impacts soil carbon would yield better soil carbon estimates. Furthermore, while the conversion to agricultural lands is not the same as conversion to urban areas and may have a different soil carbon loss factors, research on the conversion to agricultural lands is more prevalent, so the same

[93] The Nature Conservancy and Sonoma County Agricultural Preservation and Open Space District, 2015, Appendix B p. 60-62.
[94] Personal Communication with Jason Ko (October 12, 2017).
[95] Personal Communication with John Nickerson (August 14, 2017).
[96] The Nature Conservancy and Sonoma County Agricultural Preservation and Open Space District, 2015, Appendix B p. 49.

loss factor was used for both agriculture and urban conversions. A second phase of this Sacramento County study should further refine the soil carbon loss factor assumptions for these various land conversions to understand the differences in factors.

- **Soil Carbon Estimations:** Discussion among the workgroup during the October 12, 2017, meeting suggested that the data provided by SSURGO may underestimate soil organic carbon. Preliminary research comparing gSSURGO to other datasets such as SoilGrids[97] indicates that gSSURGO data may underestimate carbon in soils. [98] Further research on this topic is needed and should be considered in future analyses to understand if there is another method or dataset that may help refine carbon estimates in the region.

6.3 FUTURE URBAN DEVELOPMENT SCENARIOS

The UPlan datasets were selected for this study because they provide, in addition to a business-as-usual scenario, several alternative land use scenarios that are intended for regional and county level modeling.[99] There can be limitations to a broad statewide dataset[100], so future studies should also consider if other datasets are more applicable to the county or regional study area. Some options specific to this study include:

- **Sacramento "Full Build Out" Scenario:** It may be useful to compare the full build out model from the South Sacramento Habitat Conservation Plan to the UPlan scenarios to understand the differences in projected development and how that will impact landscape carbon in 2050. To the extent possible and given data availability, using growth scenarios tailored specifically to Sacramento County or the SACOG region could likely provide a more realistic portrayal of future landscape carbon in the region.
- **Datasets that Incorporate State Bill 375 (SB 375):** UPlan does not include SB 375, California's Sustainable Communities and Climate Protection Act of 2008, in its scenarios.[101] SB 375 supports California's climate action goals to reduce GHG emissions through coordinated transportation and land use planning at the regional metropolitan planning organization (MPO) level. Each MPO must prepare a sustainable communities strategy that contains land use, housing and transportation strategies that would allow the region to meet GHG emissions reduction targets if implemented.[102] If available, geospatial datasets that incorporate this region-level information may be useful in better projecting future land use and development patterns in Sacramento County and the SACOG region, further refining technical potential estimates.
- **USGS Land Use and Carbon Scenario Simulator (LUCAS):** A possible opportunity to expand this model or incorporate with another includes considering LUCAS. LUCAS tracks changes in land use (e.g., urbanization and agricultural expansion or contraction), land cover, land management (e.g., forest harvest), and disturbance (e.g., wildfire), and their impacts on ecosystem carbon storage and flux. ARB

[97] SoilGrids data can be found online at: https://soilgrids.org/#!/?layer=TAXNWRB_250m

[98] Personal Communication with Dave Marvin (November 2, 2017).

[99] UC Davis Information Center for the Environment. UPlan: Urban Growth Model. Online at: http://ice.ucdavis.edu/project/uplan

[100] Personal Communication with David Shabazian (October 12, 2017).

[101] Personal Communication with Patrick Huber (November 2, 2017).

[102] The California Air Resources Board. Sustainable Communities. Last updated October 13, 2017. Online at: https://www.arb.ca.gov/cc/sb375/sb375.htm

is exploring the opportunity to adapt LUCAS to support their work[103], and this may be an opportunity for Sacramento County or SACOG to discuss with ARB or the USGS team to understand LUCAS' applicability to the region.

6.4 ECONOMIC ANALYSIS AND STAKEHOLDER ENGAGEMENT

Developing financial cost metrics in addition to carbon densities by land cover type would be very useful in informing planning and policy discussions. Although this study is focused on quantification of landscape carbon in different land cover types and potential for improvement through enhanced management practices or land use changes, this effort could be considered a precursor to an economic analysis as the results and data could help feed into a cost and carbon value assessment. Such an assessment could include analysis of the social cost of carbon as well as the value of co-benefits associated with open space, including groundwater recharge flood protection, and improved health, for example. Co-benefits analysis may also yield an opportunity to engage various stakeholders such as staff at SMUD, land use planners and land owners in the region to communicate the importance of landscape carbon and conservation planning, and to explore additional project concepts. One source of potential funding for this type of analysis may be available through the California Wildlife Conservation Board's allocation from the Greenhouse Gas Reduction Fund.

[103] Personal communication with Klaus Scott (September 13, 2017).

7 CONCLUSION AND NEXT STEPS

The modeling performed for this study estimates that business-as-usual development in Sacramento County will result in a loss of 5.2 million MTCO2e of landscape carbon storage by mid-century. This quantity would exceed the 4.9 million $MTCO_2e$ annual emissions of unincorporated Sacramento County in 2015.[104] These losses would be the result of increased urbanization, and the loss of natural habitats that store carbon in soil and biomass. The largest losses result from conversion of agriculture and shrubland. However, this emissions liability can be limited through proactive and strategic land use planning, and infill development could minimize stored carbon loss to 0.5 million $MTCO_2e$ relative to 2014.

Additional opportunities to leverage the landscape can, in fact, turn this trend around and achieve additional sequestration. The three project concepts considered in this review identified opportunities through urban forestry and nutrient management that could together sequester an additional 2.2 million $MTCO_2e$ in landscape carbon by 2050. Pursuing both an infill development land use pattern and implementation of these activities has the potential to increase landscape carbon and reduce atmospheric carbon by 1.7 million $MTCO_2e$ from the 2014 base year.

The magnitude of the potential emissions associated with loss of landscape carbon and the benefits of responsible development and actions demonstrate a clear imperative to integrate landscape carbon into planning frameworks. The Marxan modeling framework provides a platform for embedding landscape carbon into ongoing planning by SACOG and its stakeholders, and the model was successfully adapted to not only evaluate landscape carbon as a single prioritization variable, but also demonstrate the feasibility of modeling it within a broader set of conservation priorities. While this proof-of-concept is intended to demonstrate the feasibility of such an approach, additional work is recommended to develop the full set of conservation priorities and associated targets.

The results of this study suggest further work is warranted and needed to improve estimates of landscape carbon, identify and evaluate additional sequestration activities, expand the geographic boundaries of the study area, and fully incorporate the results into regional planning frameworks. But this analytic framework and data-driven exercise should be supported by active outreach to engage a diverse group of stakeholders. The agricultural community, in particular, can play a large role in increasing landscape carbon through activities that increase productivity, return economic benefit, and sequester carbon. Programs like Healthy Soils Initiative are essential to provide financial support to build experience and demonstrate action on the ground. Likewise, local policymakers and NGOs can drive change by embracing landscape carbon as a priority, and identifying opportunities to maximize biosequestration in conjunction with not only other environmental efforts, but economic development and social justice as well.

Finally, beyond Sacramento County, SMUD has an opportunity to engage with other California utilities to share these findings, expand the dialog regarding the role of landscape carbon storage in the state's climate strategy, and explore policy and other initiatives that can assist the energy sector in achieving its critical carbon objectives.

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[104] Ascent Environmental. November, 2016. Sacramento County Communitywide CAP, Technical Memo #1 -2015 GHG Emissions Inventory. Available at: http://www.per.saccounty.net/PlansandProjectsIn-Progress/Pages/CAP.aspx

BIBLIOGRAPY

1 Ascent Environmental. November, 2016. Sacramento County Communitywide CAP, Technical Memo #1 - 2015 GHG Emissions Inventory. Online at: http://www.per.saccounty.net/PlansandProjectsIn-Progress/Pages/CAP.aspx

2 Ball, I.R., H.P. Possingham, and M. Watt. 2009. Marxan and relatives: software for spatial conservation prioritisation. Chapter 14: Pages 185-195 in Spatial conservation prioritisation: quantitative methods and computational tools. Eds Moilanen A., Wilson KA, and Possingham HP. Oxford, UK: Oxford University Press.

3 Battles, J.J., Gonzalez, P., Robards, T., Collins, B.M. and D.S. Saah. 2014. California Forest and Rangeland Greenhouse Gas Inventory Development: Final Report. Produced for the State of California Air Resources Board. Online at: https://www.arb.ca.gov/cc/inventory/pubs/battles%20final%20report%2030jan14.pdf

4 Bjorkman, J., J.H. Thorne, A. Hollander, N.E. Roth, R.M. Boynton, J. de Goede, Q. Xiao, K. Beardsley, G. McPherson, J.F. Quinn. 2015. Biomass, carbon sequestration and avoided emission: assessing the role of urban trees in California. Information Center for the Environment, University of California, Davis.

5 California Ag Water Stewardship Initiative 2017. Nutrient Management. Accessed September 14 2017. http://agwaterstewards.org/practices/nutrient_management/

6 California Air Reources Board (ARB) 2017. Nitrious Oxide (N_2O). Last updated June 6 2017. Accessed September 22 2017. https://www.arb.ca.gov/cc/inventory/background/n2o.htm

7 California Air Resources Board 2015. Offset Project Operators. Last updated December 21 2015. Accessed Spetmeber 22 2017. https://www.arb.ca.gov/cc/capandtrade/offsets/operators/operators.htm

8 California Department of Food and Agriculture (CDFA) 2017. Fertilizer Research and Education Program. Accessed September 14 2017. https://www.cdfa.ca.gov/is/ffldrs/frep/

9 California Department of Food and Agriculture. Healthy Soils Program. Accessed September 17 2017. https://www.cdfa.ca.gov/oefi/healthysoils/

10 California Fire and Resource Assessment Program. FRAP Vegetation (FVEG15_1). Online at: http://frap.fire.ca.gov/data/statewide/FGDC_metadata/fveg15_1.xml

11 California State Board of Equalization: Timber Yield Tax Harvesting Statistics. California Timber Harvest by County 1994-2015. Online at: http://www.boe.ca.gov/proptaxes/timbertax.htm

12 California's Forest and Other Natural Lands Inventory can be found online at: https://www.arb.ca.gov/cc/inventory/sectors/forest/forest.htm

13 CDFA 2016. Health Soils Action Plan. CDFA, Sacramento, CA. September.

14 COMET-Planner 2017. COMET-Planner Carbon Sequestration and Greenhouse Gas Estimation Report. September 15.

15 County of Sacramento. 2016. 2015 Sacramento County Annual Crop and Livestock Report. Accessed September 27 2017. http://www.agcomm.saccounty.net/Pages/CropandLivestockReports.aspx .

16 Environmental Defense Fund. Greenhouse Gas Markets for Agriculture. Accessed September 22 2017. https://www.edf.org/ecosystems/greenhouse-gas-markets-agriculture

17 Griffin DE, Wang D, Parikh SJ, and Scow KM. 2016. Short-lived effects of walnut shell biochar on soils and crop yields in a long-term field experiment. Agriculture, Ecosystems & Environment. 236 (2017) pgs. 21-29.

18 International Biochar Initiative. IBI Biochar Classification Tool. Accessed October 1 2017. http://www.biochar-international.org/classification_tool

19 International Plant Nutrition Institute (IPNI). Nutrient Source Specifics: Nitrification Inhibitors. IPNI, Peachtree Corners, Georgia.

20 i-Tree Canopy. i-Tree Software Suite v6.1. Web. Accessed 28 September.2017. https://forums.itreetools.org/viewtopic.php?p=1381

21 Jirka S. and Tomlinson T. 2015. '2014 State of the Biochar Industry: A Survey of Commercial Activity in the Biochar Sector', International Biochar Initiative report. Accessed October 2 2017. http://www.biochar-international.org/node/8367

22 LANDFIRE Existing Vegetation Type, Height and Cover Layers. Data year 2014, released in 2017. U.S. Department of Interior, Geological Survey. Online at: http://landfire.cr.usgs.gov/viewer/

23 Lory, John, Massey, Ray, and Joern, brad 2008. Using Manure as a Fertilizer for Crop Production. Pp. 105-116 in Final Report: Gulf Hypoxia and Local Water Quality Concerns Workshop. September 26-28, 2005, Ames, Iowa. Sponsored by Iowa State University and EPA. Organized by the MRSHNC, Upper Mississippi River Sub-basin Hypoxia Nutrient Committee. St. Joseph, Michigan: ASABE

24 Major, Julie. 2010. Guidelines on Practical Aspects of Biochar Application to Field Soil in Various Soil Management Systems. International Biochar Initiative.

25 Massey, Ray and Lory, John 2013. Calcualting the Value of Manure as a Fertilizer Source. University of Missouri. Last updated June 2013. Accessed September 29 2017. http://extension.missouri.edu/p/G9330

26 McPherson, E. G., Xiao, Qingfu, and Aguaron, Elena 2013. A new approach to quantify and map carbon stored, sequestered and emissions avoided by urban forests. Elsevier B.V., Landscape and Urban Planning 120(2013)70-84. August 14.

27 McPherson, E.G. and Simpson, James R. 1999. Carbon Dioxide Reduction through Urban Forestry: Guidelines for Professional and Volunteer Tree Planters. Pacific Southwest Research Station, Forest Service, USDA, Albany, California. January.

28 Merrill J. 19 September 2017. “No Funding for Healthy Soils and SWEEP Programs in Cap-and-Trade Budget Deal.” California Climate and Agriculture Network. Accessed September 25 2017. https://www.calclimateag.org.

29 Nowak, David J., Greenfield, Eric J., Hoehn, Robert E., and Lapoint, Elizabeth 2013. Carbon storage and sequestration by tees in urban and community areas of the Untied States. Elsevier Ltd., Environmental Pollution 178 (2013) 229-236. March 10.

30 Pacific Biochar. Biochar Price Sheet. Accessed September 17 2017. Available from: https://pacificbiochar.com/biochar-price-sheet

31 Pacific Northwest Biochar Atlas. Biochar Selection Tool. Accessed October 2 2017. http://www.pnwbiochar.org/tools/selector/

32 Pacific Northwest Biochar Atlas. Cost-Benefit Analysis Tool. Accessed October 2 2017. http://www.pnwbiochar.org/tools/cba/

33 Personal communication with Dave Marvin (August 1, 2017).

34 Personal communication with Klaus Scott (August 22, 2017 and September 13, 2017).

35 Personal communication with Mark Tukman (August 15, 2017).

36 Personal communication with Patrick Huber (August 16 and August 21, 2017).

37 Personal communication with John Nickerson (July 25, 2017 and September 7, 2017)

38 Personal communication with David Shabazian (October 12, 2017)

39 Personal communication with Jason Ko (October 12, 2017)

40 Phillips, Donald L., Burdick, Connie, Merja, Becky, and Brown, Norm 2013. Urban forest ecosystem services: A case study in Corvallis, Oregon. U.S. Environmental Protection Agency, Minneapolis, MN. August 4.

41 Phoenix Energy. Biochar from Phoenix Energy. Accessed September 17 2017. Available from: http://www.phoenixenergy.net/bulk_biochar

42 Ravin, Amelia and Raine, Teresa. Best Practices for Including Carbon Sinks in Greenhouse Gas Inventories. CDM Cambridge, MA and Irvine, CA.

43 Saah, D., Battles, J., Gunn, J., Buchholz, T., Schmidt, D., Roller, G., and S. Rosmos. 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. Online at: https://www.arb.ca.gov/cc/inventory/pubs/arb_pc173_v004.pdf

44 Saah, David, et. al. 2016. Technical Improvements to the Greenhouse Gas (GHG) Inventory for California Forests and Other Lands. California Air Resources Board. Sacramento, CA. May.

45 Sacramento County 2015. Sacramento County 2015 Crop and Livestock Report. Agriculture- Weights and Measures. Sacramento, California.

46 Sacramento County. The South Sacramento Habitat Conservation Plan. Online at: http://www.southsachcp.com/

47 Sacramento Municipal Utility District (SMUD). Our Board of Directors. Available at: https://www.smud.org/en/about-smud/company-information/board-of-directors/

48 Sacramento Tree Foundation 2017. “Air Quality.” Last updated 2017. Accessed September 13 2017. http://www.sactree.com/pages/88

49 San Mateo Resource Conservation District. February1, 2016. Biochar Field Trials in San Mateo County. Accessed September 17 2017. http://www.sanmateorcd.org

50 SMUD. “Cool and beautify your home – naturally” Accessed October 2, 2017

51 Terra Global Capital LLC. 2010. Evaluation of the Opportunities for Generating Carbon Offsets from Soil Sequestration of Biochar. Climate Action Reserve.

52 The Nature Conservancy and Sonoma County Agricultural Preservation and Open Space District. 2015. Conserving Landscapes, Protecting the Climate: The Climate Action through Conservation Project. San Francisco and Santa Rosa, CA. 28 pages plus appendices.

53 Thorne, J.H., Santos, M.J., Bjorkman, J., Soong, O., Ikegami, M., Seo, C., and L. Hannah. 2017. Does infill outperform climate-adaptive growth policies in meeting sustainable urbanization goals? A scenario-based study in California, USA. Landscape and Urban Planning (157), p. 483-492.

54 U.S. Environmental Protection Agency (EPA) 2016. “Using trees and Vegetation to Reduce Heat Islands.” Last updated August 12 2016. Accessed September 13 2017. https://www.epa.gov/heat-islands/using-trees-and-vegetation-reduce-heat-islands

55 U.S. Geological Survey. The LUCAS Model. Online at: https://geography.wr.usgs.gov/LUCC/the_lucas_model.php

56 UC Davis Information Center for the Environment. UPlan: Urban Growth Model. Online at: http://ice.ucdavis.edu/project/uplan

57 United States Department of Agriculture, Natural Resources Conservation Service. Released November 29, 2016. Gridded Soil Survey Geographic (gSSURGO) Database for California. Online at: http://datagateway.nrcs.usda.gov/.

58 Unites States Department of Agriculture (USDA) 2011. Trees Pay Us Back in the Inland Valleys Region. Accessed September 7 2017. https://lgc.org/wordpress/docs/events/calfire/CaUFC%20forestry%20flyer.pdf

59 US Biochar Initiative. Biochar Production. Accessed September 17 2017. http://biochar-us.org/biochar-production.

60 US Environmental Protection Agency (EPA) 2017. Nutrient Pollution: The Sources and Solutions: Agriculture. Accessed September 14, 2017. https://www.epa.gov/nutrientpollution/sources-and-solutions-agriculture.

61 VandenBygaart, A.J., Gregorich, E.G., and D.A. Angers. 2003. Influence of agricultural management on soil organic carbon: A compendium and assessment of Canadian studies. Canadian Journal of Soil Science, 83: 363-380. Online at: http://www.nrcresearchpress.com/doi/abs/10.4141/S03-009