Natural & Working Lands Inventory Improvements: A Guide for States

Prepared by the World Resources Institute for US Climate Alliance states
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CHAPTER 1: OVERVIEW

Guide at a Glance

Chapter	Topic	Purpose
1	**Overview**	**Understand basic concepts and identify inventory priorities for your state *(designed for state policymakers and agency staff)***
2	Trees & Forests	Deep dive into inventory improvement options across land use classes *(designed for agency staff)*
3	Croplands & Grasslands	Deep dive into inventory improvement options across land use classes *(designed for agency staff)*
4	Land Use Change	Deep dive into inventory improvement options across land use classes *(designed for agency staff)*
5	Wetlands	Deep dive into inventory improvement options across land use classes *(designed for agency staff)*
6	Baselines	Deep dive into options for creating a historical or projected inventory baseline *(designed for agency staff)*
7	Federal Action	Overview of inventory improvement options that require action by Congress or federal agencies *(designed for state policymakers)*

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Executive Summary: About This Project

Improving inventory methods for land-based sources and sinks of greenhouse gases (GHG) is a core tenet of the Natural and Working Lands (NWL) Challenge. Over the last two years, the World Resources Institute (WRI) has provided technical support to states pursuing that objective through working group webinars and discussions, individual state outreach, and engagement with federal agencies on state inventory priorities. WRI is now releasing this Guide to NWL Inventory Improvements in order to advance states' progress toward this NWL Challenge objective. This Guide evaluates current NWL inventory methods among US Climate Alliance states, identifies gaps, and provides information and resources to advance improvements to data and methods that satisfy key objectives for NWL inventories.

The Guide to NWL Inventory Improvements builds on WRI's findings from state engagement, expert interviews, and literature review. The Guide is structured as a "fact pack" of reference slides divided into chapters that each cover a discrete topic area related to NWL inventories. Major issues and recommendations from the Guide will be presented at a virtual Learning Lab session on NWL inventories on September 22, 2020.

Executive Summary: The Issue

NWL already play a major role in mitigating the United States' contribution to climate change. According to the Inventory of U.S. GHG Emissions and Sinks (the "National GHG Inventory"), which is published annually by the Environmental Protection Agency (EPA) based on methodological guidelines from the Intergovernmental Panel on Climate Change (IPCC), the land use, land use change and forestry (LULUCF) sector removes the equivalent of 11% of annual economy-wide GHG emissions. Further measures to enhance LULUCF carbon sinks and reduce other GHG emissions associated with NWL could reduce net GHG emissions from business-as-usual projections by approximately 1 billion tons of CO2, equivalent to over 20% of annual economy-wide GHG emissions. Globally, NWL activities could contribute a significant share of the GHG reductions required to limit temperature rise to 1.5^0C.

Including NWL in GHG inventories is critical to realizing the sector's potential for climate change mitigation. Regularly reporting GHG fluxes in NWL can help governments measure progress toward GHG reduction goals, inform policymaking and program management, track performance of existing GHG reduction programs and projects, and demonstrate the importance of NWL to key stakeholders.

Of the US Climate Alliance states that currently publish NWL inventories, half rely on the EPA State Inventory Tool (SIT)—an interactive spreadsheet model that covers all major inventory sectors—as their primary data source. SIT estimates state-level GHG fluxes using similar methods to the National GHG Inventory. SIT is considered the default method for state NWL inventories because it is free and easy to use off-the-shelf, updated annually by EPA, and flexible enough to allow states to either use pre-loaded state-level NWL data derived from federal datasets or input their own data sources.

Using SIT brings significant limitations, however. Many of the NWL data sources underlying SIT are significantly older than the corresponding data in the National GHG Inventory: the 2019 release of SIT, for example, only includes forest carbon data through 2014, while its data on wood products date from 1997. SIT also has a narrower scope for NWL than the National GHG Inventory (for instance, wetlands are not included) and does not report GHG fluxes in NWL according to the IPCC's standardized land use categories. Unlike the National GHG Inventory, which reports confidence intervals around each of its GHG flux estimates to indicate the margin of error, SIT reports no margin of error around its state-level GHG estimates.

Other limitations within SIT are carried over from the National GHG Inventory itself. The National GHG Inventory uses statistical extrapolation from field-based sample measurements to estimate GHG fluxes in NWL, which means the estimates are not spatially explicit (i.e., cannot be mapped). The underlying measurements are also averaged across multiple years, meaning the resulting GHG flux estimates cannot be attributed to a specific year or cause, such as wildfire or cover crop adoption. Furthermore, some GHG fluxes in the National GHG Inventory are double-counted (like some urban trees that are also classified as "forest") or omitted altogether (like trees in agricultural lands or terrestrial wetlands).

Executive Summary: Solutions

Using NWL inventories to effectively measure progress toward a state GHG goal, inform state policymaking, or track project performance requires more sophisticated inventory methods than what SIT currently offers. Inventory improvements could entail developing state-specific datasets or methods, adapting federal datasets or methods to a state-level context, or requesting action by federal agencies or Congress to improve national inventory methods. When prioritizing improvement efforts within the NWL inventory, states may start by considering the following criteria:

- **Impact:** Which land use categories (e.g., forests, urban trees or cropland soils) have a significant influence on current or potential future GHG emissions and removals in the state?
- **Policy relevance:** Which sections of the NWL inventory map onto other state policy priorities?
- **Need:** What inventory improvements would fill a true gap in available datasets, accounting for expected near-term releases of federal data?
- **Technical feasibility:** What improvements can be implemented using scientifically established data sources and methods?

The improvement options in this Guide address different land use categories and satisfy different objectives. The objectives that states prioritize for inventory improvement depend on how they plan to use the inventory—for example, an inventory designed primarily to track progress toward a sectoral GHG goal may have different specifications than one designed to inform land use planning or policy decisions. Common inventory objectives that states may pursue include:

- **Reducing uncertainty** around GHG flux estimates in specific land use categories or carbon pools
- **Improving timeliness** of the data underlying GHG flux estimates
- **Enhancing data resolution** to allow for more granular estimation over space and/or time
- **Expanding inventory scope** to include more land use categories, carbon pools, or inventory functionality than default methods
- **Attributing GHG fluxes** to specific causes relating to land management or disturbance

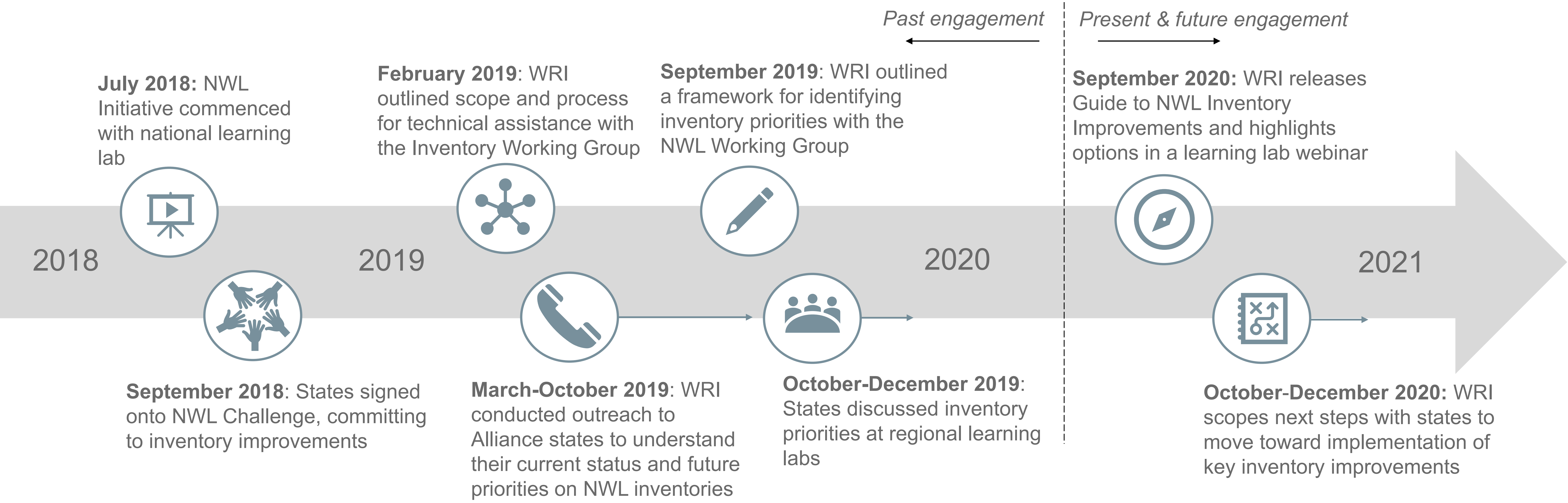
Different improvement options can also bring tradeoffs for states that implement them. Collecting field data can translate to more accurate GHG flux estimates using established scientific methods, but comes at a significant annual cost; on the other hand, focusing on remote sensing-based data and methods may be more cost-effective in the long term, but entails a significant upfront investment to develop the models and methods, and requires advanced technical capacity to process and interpret the data. The inventory improvement options that meet state needs and capacities will vary state by state. Further collaboration among US Climate Alliance states, US Climate Alliance Impact Partners, and other experts can help states assess the costs and benefits of specific inventory improvement plans in more detail.

About the Guide to NWL Inventory Improvements

WRI has prepared this Guide to support states' implementation of the NWL Challenge, which included a commitment to "improve inventory methods for land-based carbon flux." This 7-part Guide aims to:

- Evaluate the capabilities and limitations of current "default" inventory methods among US Climate Alliance states
- Identify "basic improvements" using existing data sources that would better align state inventory methods with the National GHG Inventory
- Provide information and resources for additional inventory improvement options across land uses, including options for baseline development, which can enhance the accuracy and functionality of state inventories beyond what is possible with National GHG Inventory data sources

The release of this Guide builds on 2 years of engagement with US Climate Alliance states on NWL inventories, and sets up future targeted workstreams in support of specific inventory improvements:



July 2018: NWL Initiative commenced with national learning lab

September 2018: States signed onto NWL Challenge, committing to inventory improvements

February 2019: WRI outlined scope and process for technical assistance with the Inventory Working Group

March-October 2019: WRI conducted outreach to Alliance states to understand their current status and future priorities on NWL inventories

September 2019: WRI outlined a framework for identifying inventory priorities with the NWL Working Group

October-December 2019: States discussed inventory priorities at regional learning labs

September 2020: WRI releases Guide to NWL Inventory Improvements and highlights options in a learning lab webinar

October-December 2020: WRI scopes next steps with states to move toward implementation of key inventory improvements

Identifying Inventory Improvements: WRI's process

WRI has identified a range of improvement options for state NWL inventories through three modes of inquiry:

Listening to states. Many improvements to default inventory methods have already been implemented, or are in progress, in one or more US Climate Alliance states. WRI conducted 15+ interviews with NWL working group members and state inventory managers and followed up with agency experts in states that had implemented inventory improvements. Case studies highlight relevant experiences from many of these states.

Soliciting expert ideas. WRI brought together staff from federal agencies, academic researchers, and other experts in multiple workshops to discuss needs for carbon monitoring in NWL and state inventory methods specifically. Through these workshops, WRI collected ideas for how data in the National GHG Inventory could be better translated to the state level—and how the National GHG Inventory itself could improve.

Reviewing research. Published research has evaluated the benefits of some inventory improvements, while others are the subject of ongoing research. WRI compiled information on new tools and technologies that may have applications for state inventories by reviewing research and interviewing the authors of leading papers.

Update: State and Federal Activity

Since this Guide was first released in 2020, many Alliance states have worked to develop or improve their NWL inventories. The federal government has also taken steps to improve the SIT tool and has released a draft of a new 1990-2020 National Greenhouse Gas Inventory, which incorporates updated data and calculations. These state-level and federal improvements support NWL inventories by giving states access to better data and increasing opportunities for states to learn from one another's approaches.

The following 'update' slides are intended to help states understand how federal inventory improvements align with recommendations in this Guide. As of July 2022, the body of the Guide has not been updated, but there may be future updates to the Guide as needed.

Resources: EPA National Greenhouse Gas Inventory: 1990-2020, EPA State GHG Emissions and Removals homepage, Download .xlsx versions of state-level GHG data (zip), Methods used to develop state GHG data (zip)

Key Update: Disaggregation of National GHG Inventory Data

What is it?

- EPA has disaggregated data from the National GHG Inventory (1990-2019) and has published state-level estimates for all 50 states across all gases and sectors using the same methodology as the NGHGI.
- Disaggregated data will be incorporated into the SIT tool by summer 2022 and updates will be completed annually.
- SIT is in the process of adding uncertainty estimates to state-level data in line with NGHGI data.

What is the impact of this update?

- The updated SIT tool use new downscaled inventory data as default values. This will generally align state data with this Guide's **'Basic Improvements'** and will allow states to allocate resources to pursuing actions under **'Additional Improvements'.**

What problems does it solve?

- Includes better data coverage for Alaska and Hawai'i
- Includes vegetated coastal wetlands, which were not previously covered in the SIT tool
- Disaggregated state-level data is accompanied by methodology for each sector, making it easier for states to understand the data underlying SIT.

Limitations of this update

- Disaggregated NGHGI data may differ from official state inventories due to differing methodologies and different data sources
- Perpetuates limitations of the National GHG Inventory (e.g. estimates are not temporally or spatially explicit)
- Still does not cover some key categories such as trees in agroforestry systems and coastal seagrass beds
- State data in the SIT tool lag one year behind NGHGI data

Key Update: Timeline for EPA inventory improvements

September 2020: WRI releases Guide to NWL Inventory Improvements

September 2021: EPA releases draft disaggregated NGHGI state-level NWL data (1990-2019)

November 2022: USCA submits comments to EPA on disaggregated data informed by state feedback

February 2022: EPA releases final disaggregated NGHGI state-level NWL data (1990-2019)

April 2022: EPA releases Inventory of US Greenhouse Gas Emissions and Sinks: 1990-2020

Summer 2022: EPA plans to incorporate disaggregated NGHGI data (1990-2019) into SIT tool

Ongoing: EPA plans to conduct yearly updates to the SIT tool using disaggregated NGHGI data

Key Update: Prioritizing inventory improvements to support climate ambition

As federal inventory data and tools are improved, states can increasingly devote resources to actions that build upon the basic-level functionality of the SIT tool. These actions fall under the '**Additional Improvements**' category of this Guide. As states increase the ambition of their climate plans and move towards economy-wide emissions-reductions or net-zero target setting, these inventory improvements can inform policy-making and assist in tracking program performance towards goals.

A state emissions reductions or net-zero target should...	Include an economy-wide gross GHG emissions target in addition to an NWL-specific goal or target	Have a comprehensive and credible plan for achieving the target, including a plan to increase and protect the natural carbon sink	Accurately quantify the role that the NWL carbon sink plays in counter-balancing emissions from other sectors
To achieve this, an NWL inventory should...	Establish a robust and detailed historical baseline for net and gross emissions that can be used to track progress towards a target	Have the capacity to track the impact of management interventions and disturbances (overlay activity data, be spatially explicit) and inform projection of future trends	Have the capacity to quantify year-to-year changes in greenhouse gas sources and sinks as well as multi-year averages

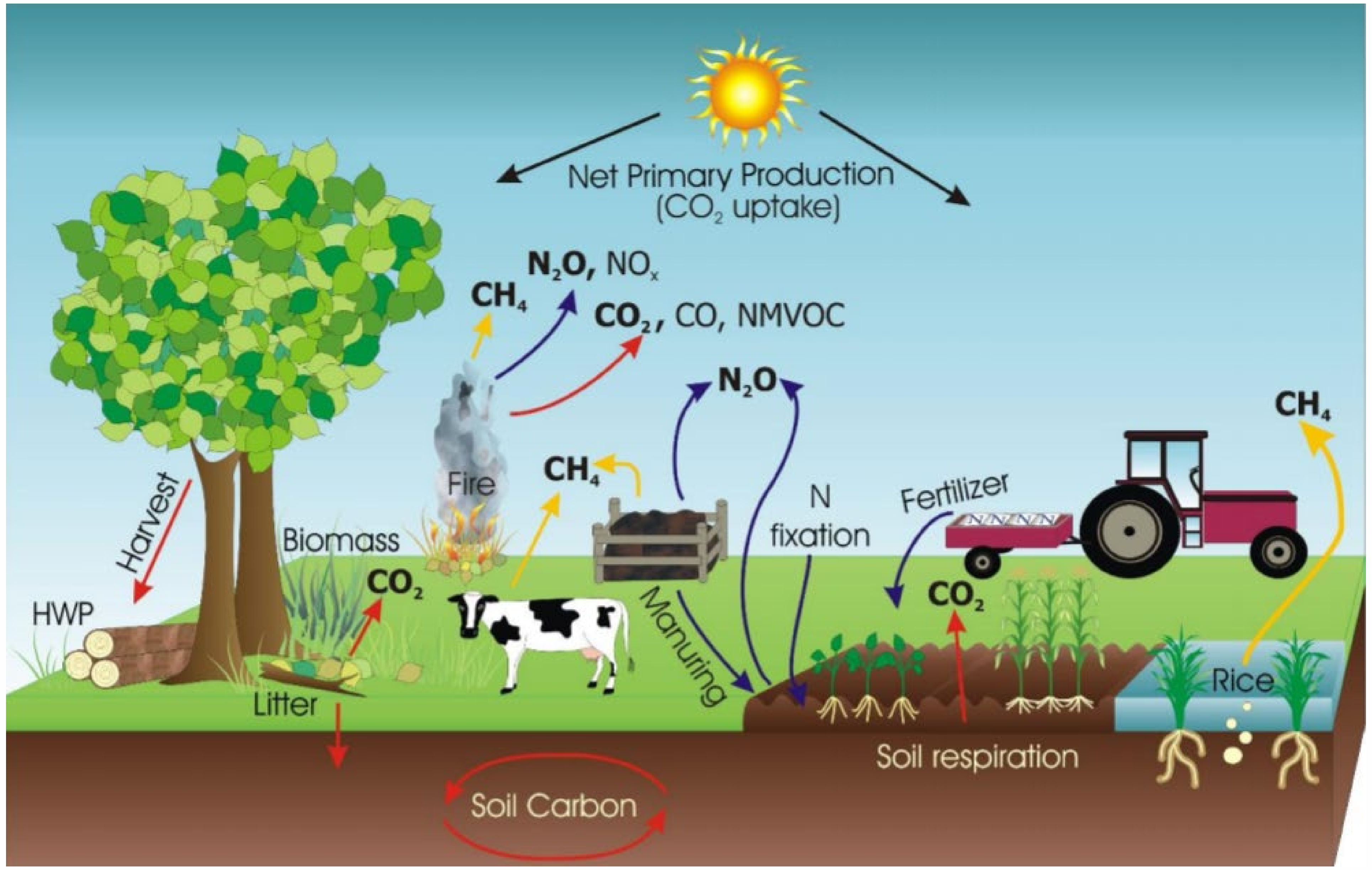
OVERVIEW PART I:

About Natural and Working Lands

What are Natural and Working Lands?

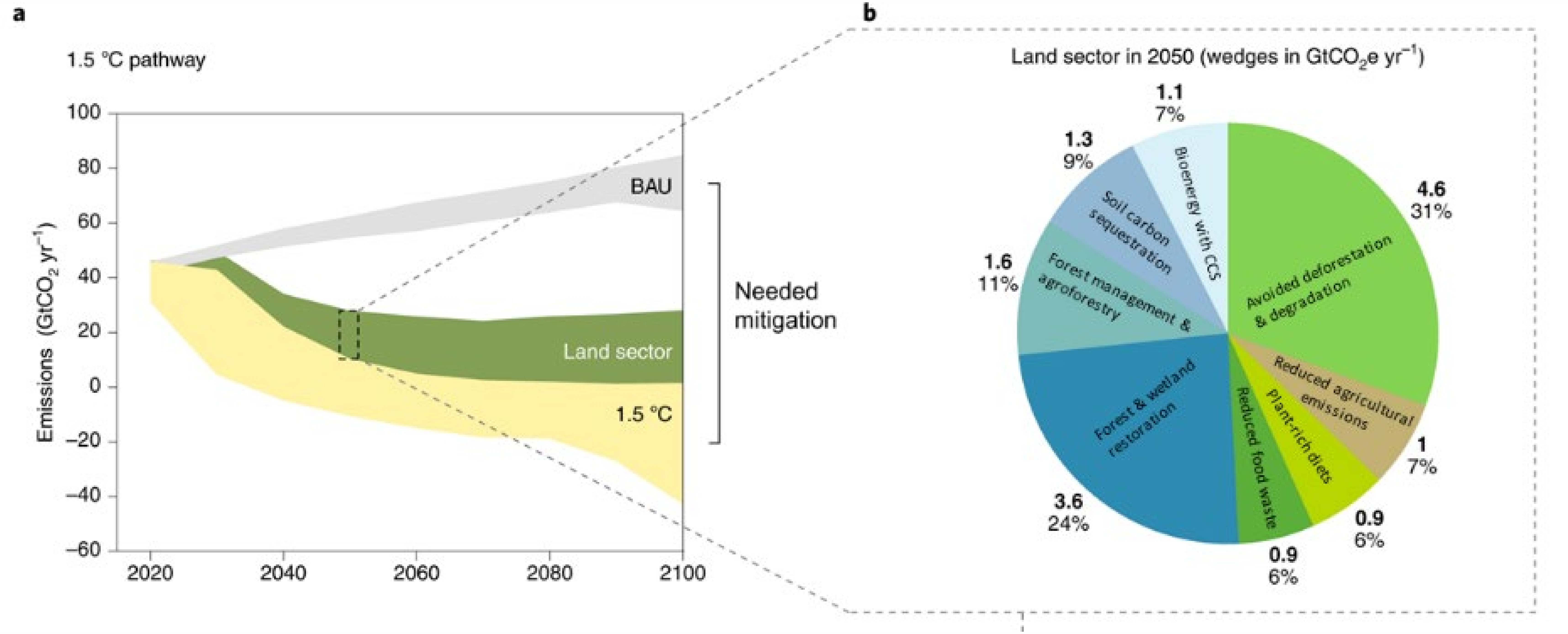
> *The natural systems upon which we depend are essential to life and critical for reducing the impacts of climate change on our communities... including* ***forests, farms, rangelands, and wetlands****…*
>
> **- US Climate Alliance NWL Challenge**

Natural and working lands (NWL) refer to the variety of land uses that make up our natural environment: forests and woodlands, grassland and shrubland, cropland and rangeland, wetlands and urban green spaces. NWL provide us with the food and fiber we use every day. NWL also play a key role in the global carbon cycle, contributing both GHG emissions and removals.



Source: IPCC

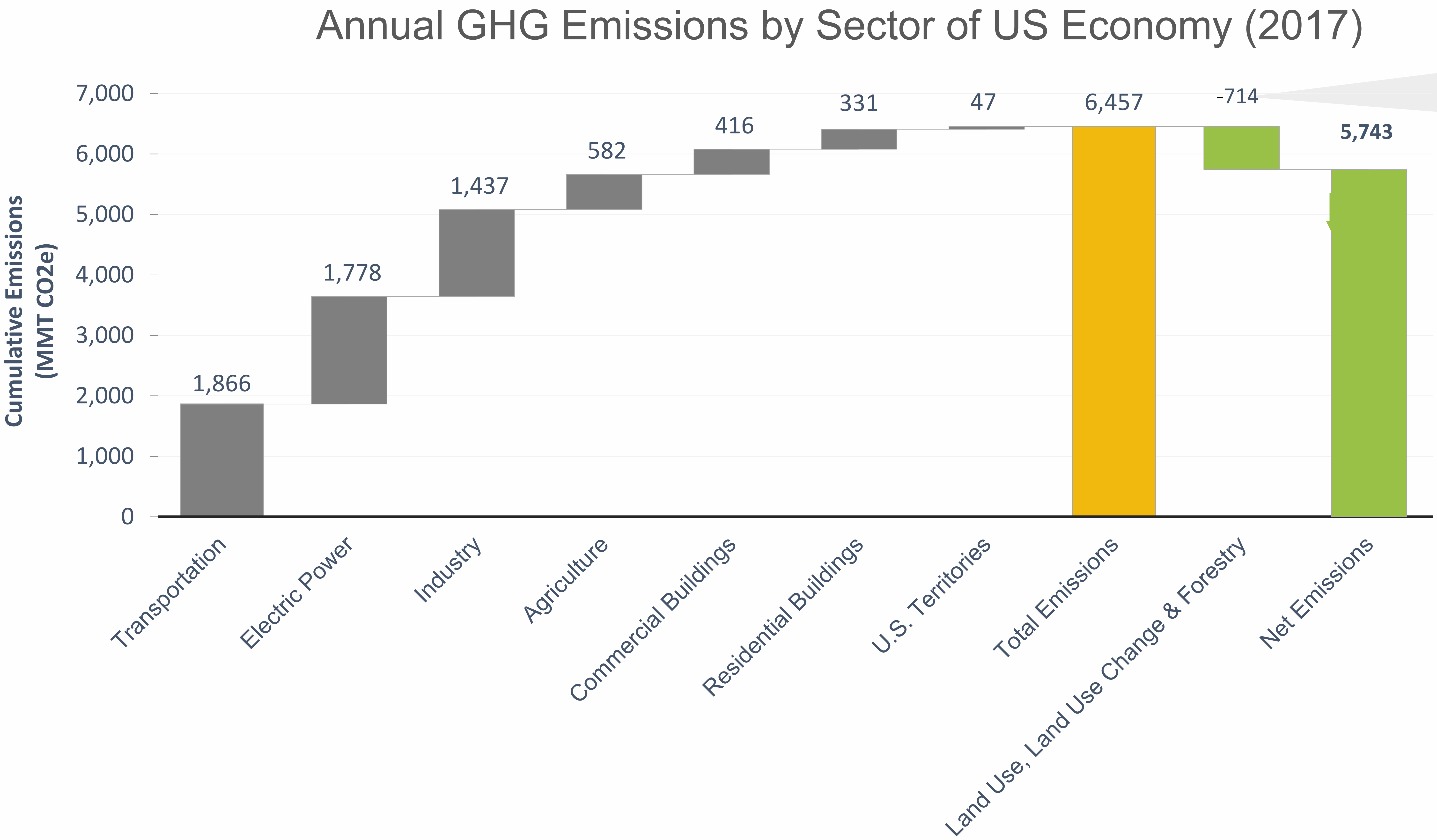
NWL are critical globally for a 1.5ºC pathway



Source: Roe et al. 2019

NWL can remove carbon from the atmosphere and sequester it in vegetation (through photosynthesis) or soil organic matter. Sustainable management of NWL can increase their net carbon removal, delivering up to **30% of the global carbon reduction** needed to limit warming to 1.5ºC.

NWL are already a large carbon sink in the US

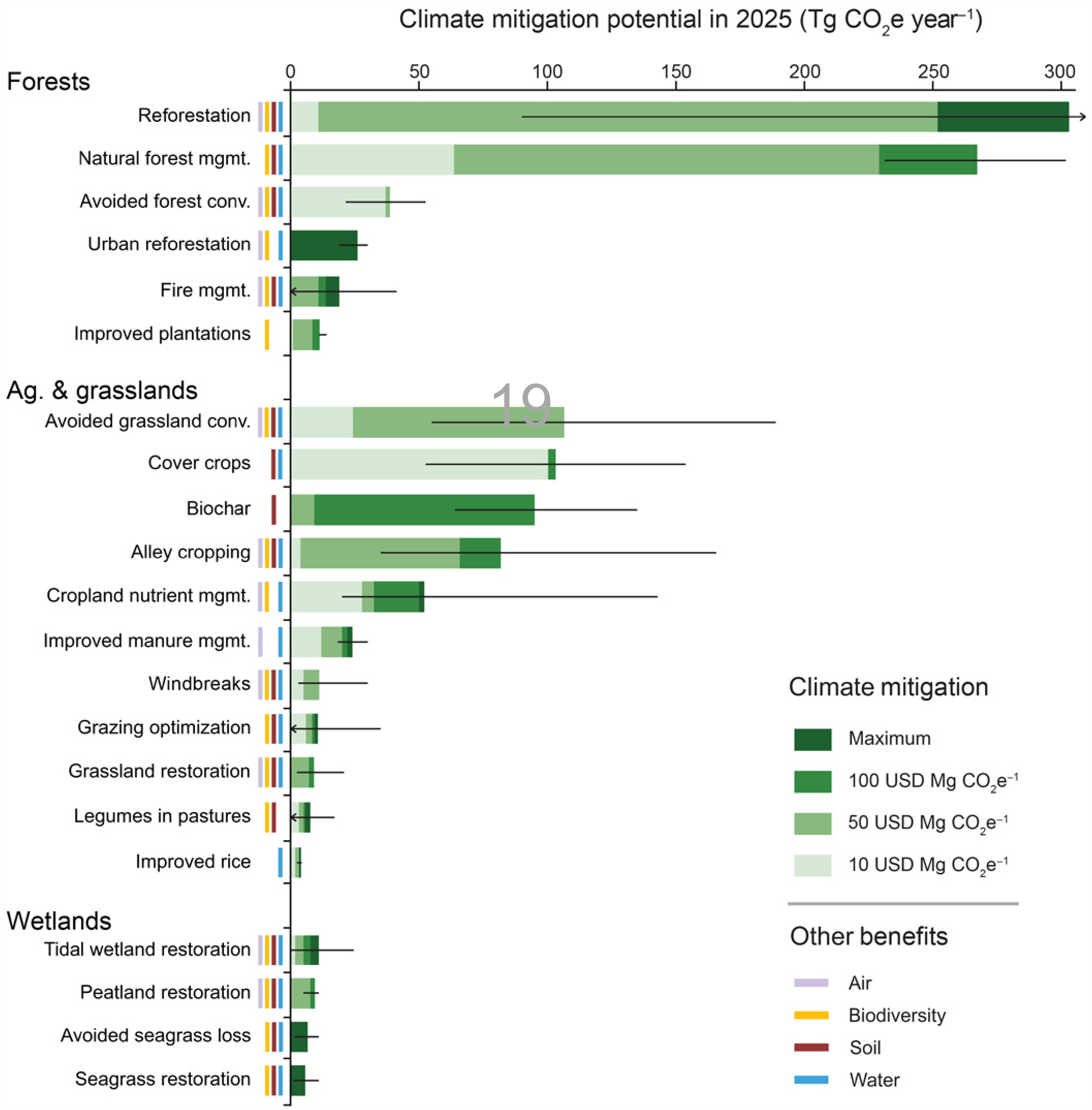


Natural & working lands collectively remove **11%** of annual GHG emissions

When NWL remove more CO_2 than they emit into the atmosphere, they are known as a carbon “sink.” In the US, NWL are a reliable carbon sink that reduces our net GHG emissions.

Data from EPA 2019b

Sustainably managing NWL can contribute to additional climate change mitigation in the US



NWL could reduce US emissions and increase removals by approximately **1 billion tons** of CO_2 per year by 2025

- ➢ Equivalent to **over 20%** of US economy-wide GHG emissions

Go Deeper

KEY CONCEPT:
NWL climate change mitigation pathways

Source: Fargione et al. 2018

OVERVIEW PART II:

Greenhouse Gas Inventory

The role(s) of GHG inventories

- Measure progress toward economy-wide or sectoral GHG reduction goals
- Inform policymaking and adaptive program management
- Track performance of existing programs and projects
- Fulfill regulatory or legislative reporting requirements
- Demonstrate importance of land carbon sink to legislature and governor’s office

What is a GHG inventory for NWL?

> *The NWL Inventory tracks how much carbon exists in…ecosystems, where that carbon is located, and estimates how much carbon is moving in and out of the various land types and carbon pools.*
>
> —California Air Resources Board

NWL inventories, often categorized as “land use, land use change and forestry (LULUCF),” estimate carbon stocks and fluxes across different land use categories. They also quantify the uncertainty around these estimates.

Guidelines from the Intergovernmental Panel on Climate Change (IPCC) provide a standardized approach to developing these inventories.

The United States Environmental Protection Agency (EPA) produces an annual National GHG Inventory that includes NWL. EPA also downscales national GHG flux estimates to the state level in its State Inventory Tool (SIT).

Go deeper

KEY CONCEPT:
Measuring carbon stocks vs. carbon flux

KEY CONCEPT:
Land use categories

KEY CONCEPT:
Global warming potentials of GHGs

KEY CONCEPT:
Uncertainty

KEY TOOL:
IPCC guidelines

About the National GHG Inventory

What is it? A report prepared and updated annually by the EPA in accordance with IPCC guidelines to comply with the United States' commitments under the UNFCCC.

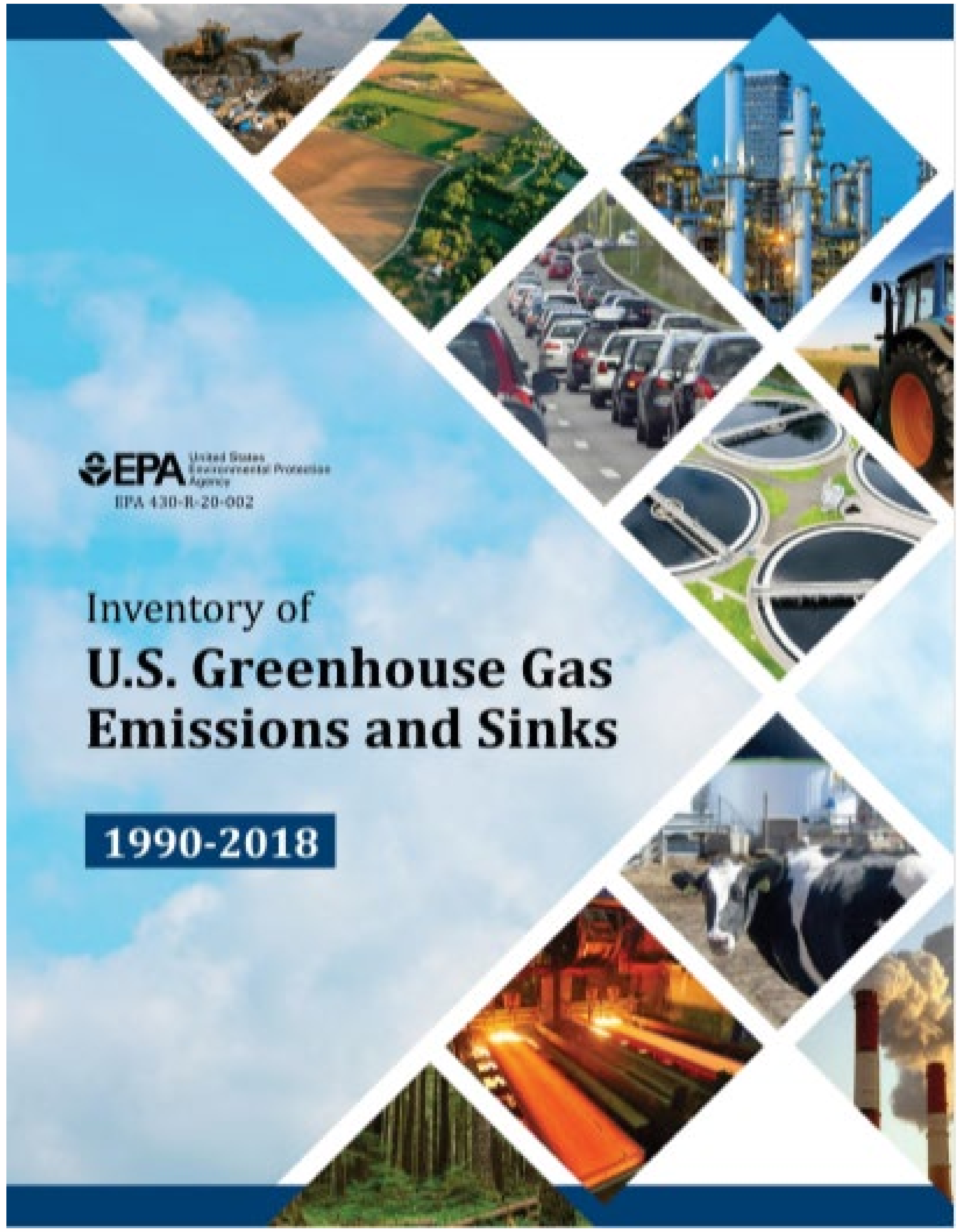
What does it do? Reports GHG emissions and removals (collectively, carbon fluxes) from each sector, starting in 1990.

Relevance for NWL inventories: The National GHG Inventory is the data source of record for GHG fluxes in NWL in the United States. It includes most carbon fluxes in NWL according to IPCC land use categories (e.g., "Forest Land Remaining Forest Land" or "Land Converted to Cropland") and quantifies the uncertainty in these carbon flux estimates with 95% confidence intervals. Many (though not all) of the estimates are based on state-level data, which can be found in annexes or other publications.

Limitations:

- Does not include GHG flux estimates for some minor NWL carbon pools, such as trees in agroforestry systems, some terrestrial wetlands, flooded lands, and coastal seagrass beds. Some of these pools are covered by IPCC guidelines, while others are not.
- Not all data are timely or temporally explicit (i.e., specific to the year in which they are reported) due to limitations in underlying data sources.
- Not spatially explicit, and not all data are available at the state level.

Resources: National GHG Inventory 1990-2018; Annex 3: Methodological Descriptions for Additional Source or Sink Categories; GHG Emissions and Removals from Forest Land, Woodlands, and Urban Trees in the US, 1990-2018

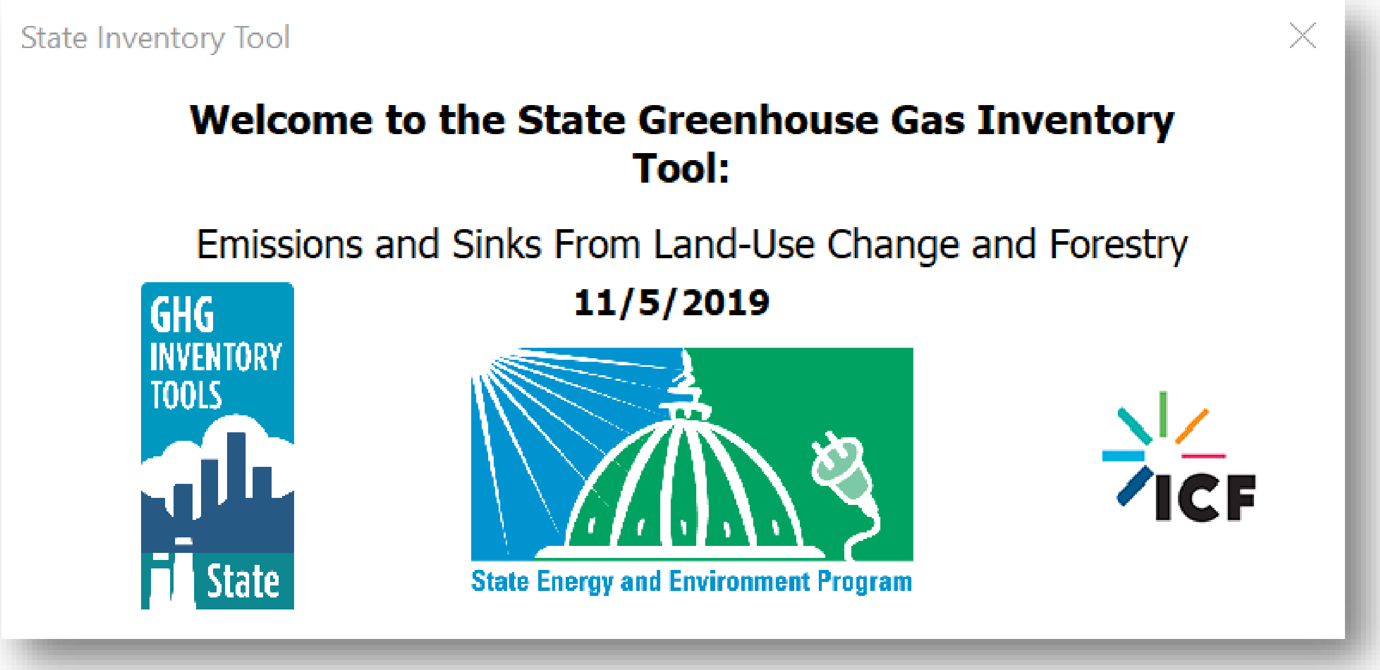


EPA United States Environmental Protection Agency
EPA 430-R-20-002

Inventory of
U.S. Greenhouse Gas
Emissions and Sinks

1990-2018

About the EPA State Inventory Tool (SIT)



Welcome to the State Greenhouse Gas Inventory Tool:

Emissions and Sinks From Land-Use Change and Forestry

11/5/2019

What is it? An interactive spreadsheet model with sector-specific modules updated annually by EPA to help states develop or update a GHG inventory, with similar methods and sectoral coverage to the National GHG Inventory.

What does it do? Estimates GHG fluxes at the state level based on pre-loaded default federal data and/or custom data entered by state users. Data relevant to the NWL inventory is reported within the Land Use, Land Use Change and Forestry (LULUCF) module.

Relevance for NWL inventories: Because SIT is free and easy to use-off-the-shelf, it is considered the default method for states compiling GHG inventories. SIT provides default NWL data for any state in the lower 48 and is customizable with state-specific data.

Limitations:

- Default data are not timely, and many NWL data inputs are not refreshed year-to-year
- Some NWL data sources and estimation methods are less sophisticated than those used in the National GHG Inventory
- Does not report estimates according to IPCC land use categories, making comparisons with the National GHG Inventory difficult
- Excludes wetlands (both tidal and terrestrial)
- Does not quantify uncertainty around GHG flux estimates
- Limited default data available for Alaska and Hawai'i
- Perpetuates other limitations of the National GHG Inventory (e.g., estimates are not temporally or spatially explicit)

Resources: EPA State Inventory and Projection Tool

National GHG Inventory vs. SIT: How do they compare?

	National GHG Inventory	SIT
Timeliness: How recently were data collected?	Most data 1-5 years old	Most data 5-20+ years old
Temporal resolution: What is the minimum length of time over which GHG fluxes are estimated?	Forest Inventory and Analysis (FIA) data averaged across 5-10 years, obscuring annual changes	FIA data averaged across 5-10 years, obscuring annual changes
Spatial resolution: What is the minimum area size over which GHG fluxes are estimated?	National, with some state-level estimates	State-level
Scope: What NWL land use classes are included and reported?	Includes all IPCC categories for land use and land use change	Excludes both tidal and terrestrial wetlands; does not separately report land use change according to IPCC categories
Transparency: How much detail is reported on inventory methodologies and estimate precision?	Cites data sources, describes methods in detail, and reports uncertainty associated with all GHG estimates	Cites data sources, but does not describe methods in detail or report uncertainty

Go deeper

KEY DATA SOURCE:

National GHG Inventory vs. SIT

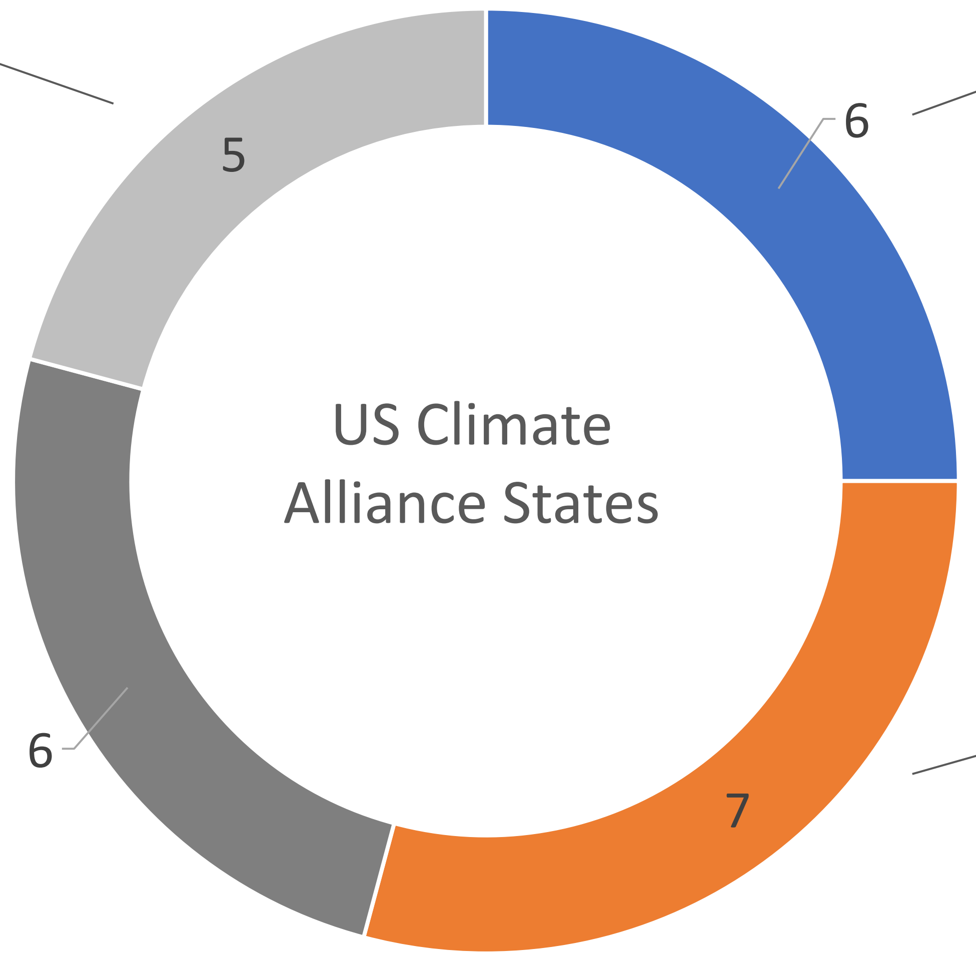
OVERVIEW PART III:

State-Level Inventory Improvements

How are US Climate Alliance states conducting NWL inventories?

States that have not yet published a GHG inventory for any sector:
IL, MI, MT, VA, WI

States that rely mainly on SIT for tracking GHG fluxes in NWL:
CO, DE, MD, NV, NC, PA

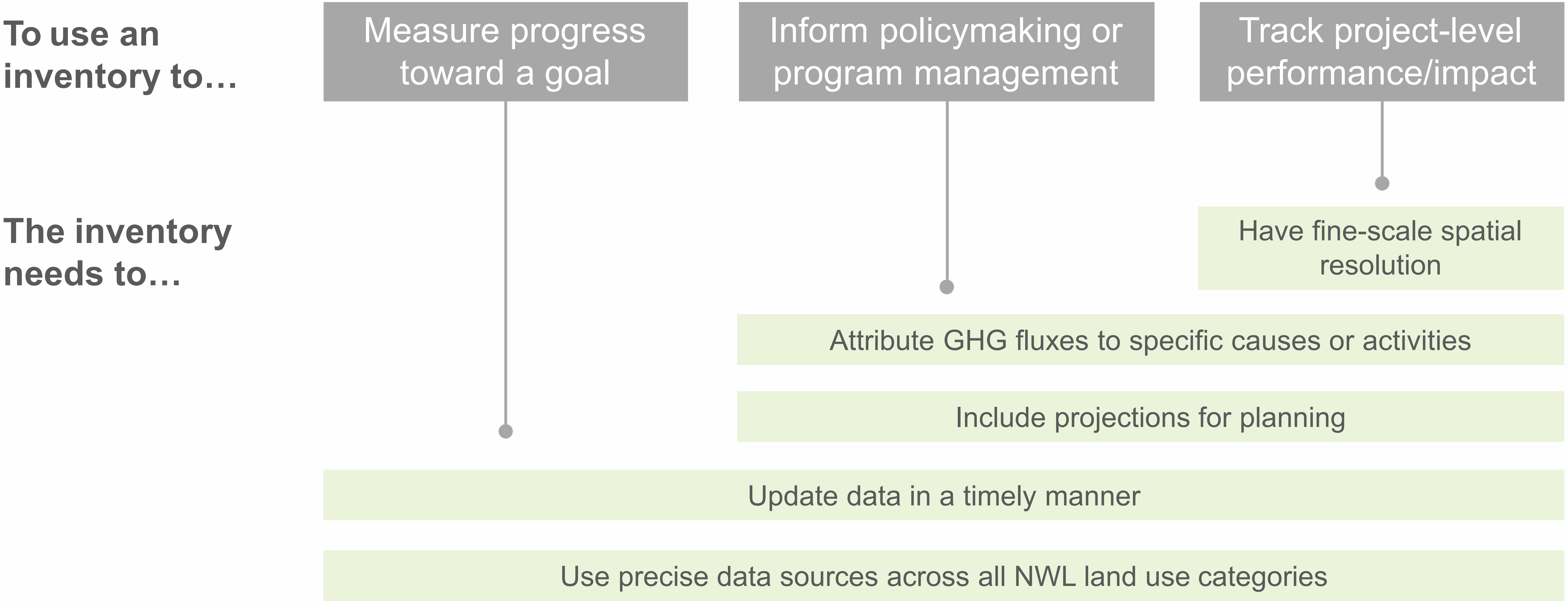


States that use state-specific datasets or other federal data and tools to track GHG fluxes in NWL:
CA, HI, MA, MN, NJ, NY, VT

States that omit LULUCF in their GHG inventory due to a lack of confidence in available datasets:
CT, ME, NM, OR, RI, WA

Why improve on SIT for state inventories?

A state inventory based on default data from SIT is better than no inventory, but many of the inventory functions that states may wish to have require more sophisticated methods than what SIT currently offers. States can use their desired inventory function(s) to determine key **objectives for inventory improvement**.



To use an inventory to…

Measure progress toward a goal

Inform policymaking or program management

Track project-level performance/impact

The inventory needs to…

Have fine-scale spatial resolution

Attribute GHG fluxes to specific causes or activities

Include projections for planning

Update data in a timely manner

Use precise data sources across all NWL land use categories

How sophisticated should an inventory be?

Different improvements to NWL inventories can make them more suitable for different applications. This Guide details two levels of possible improvements: **basic improvements** that would bring a state inventory into closer methodological alignment with the National GHG Inventory, and **additional improvements** that go beyond current National GHG Inventory methods. States should consider both their desired inventory functionality and capacity to implement inventory improvements in choosing how sophisticated their NWL inventory should be.

DEFAULT METHOD:
SIT Default Data

- Appropriate for informational purposes only due to data limitations and inconsistencies
- Future annual updates may improve quality of default data

→

BASIC IMPROVEMENTS:
Alignment with National GHG Inventory

- Appropriate for tracking progress toward a GHG goal or informing NWL policymaking
- Possible with existing federal data and tools, but may require limited new analysis for some categories

→

ADDITIONAL IMPROVEMENTS:
Enhanced Inventory Functionality

- Appropriate for a broader range of applications, such as land management decisions and project evaluation (depending on objectives met by specific improvements)
- Most require new data collection and/or intensive processing and analysis of existing data

Less sophisticated ⟷ More sophisticated

Mapping Potential Inventory Improvements

States that choose to go beyond basic inventory improvements may consider a range of additional improvement options, detailed in subsequent chapters of this Guide. These improvements address different limitations of the default inventory methods, listed here as objectives for inventory improvement. States may pursue one or more improvements depending on which inventory categories they prioritize and which objectives they hope to meet. *Improvements in italics require federal action.*

LEGEND

Improvement Objectives Met:

🟡 Reduce uncertainty in GHG flux estimates
🟣 Improve timeliness of data sources
🟠 Enhance spatial and/or temporal data resolution
🔵 Expand inventory scope to additional land uses, carbon pools or functionalities
🟢 Attribute GHG fluxes to specific causes or activities

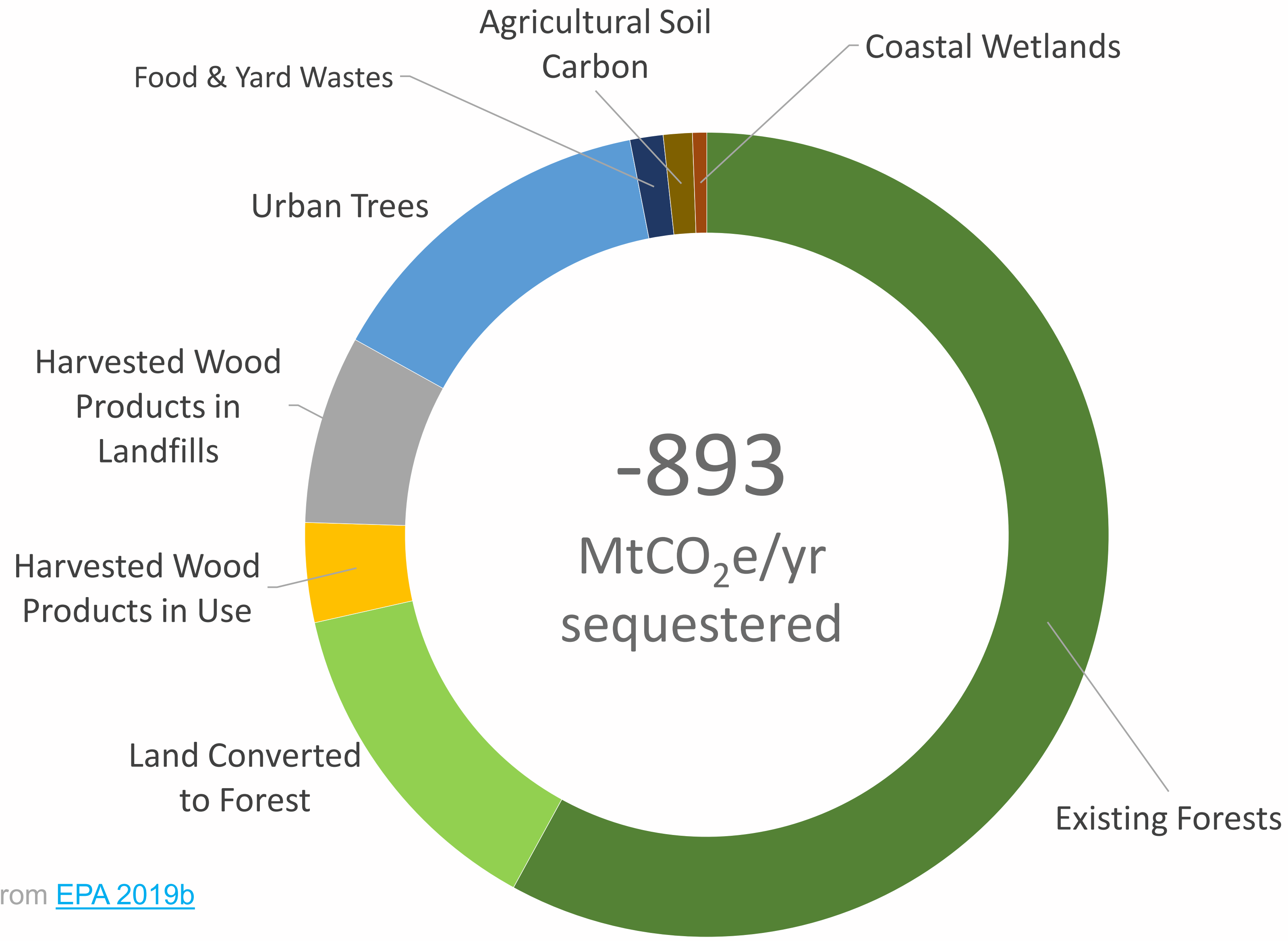
NWL Inventory Category	Inventory Improvement Option	Objectives Met
Trees & Forests	Integrate optical imagery with FIA	🟡🟣🟠🟢
	Integrate LIDAR/ phodar with FIA data	🟡🟠🔵
	Increase statistical power of FIA plot network	🟡🟠
	Create field-based inventory for urban trees	🟡🟠🔵
	Refine accounting for wood products	🟡🟣
	Develop a national remote sensing-based inventory	🟡🟣🟠🔵🟢

NWL Inventory Category	Inventory Improvement Option	Objectives Met
Croplands & Grasslands	Integrate remote sensing for croplands	🟡🟣🟠
	Expand transect surveys	🟡🟣
	Institute farm-level reporting	🟡🟣
	Create a plot network for soil carbon monitoring	🟡🟢
	Monitor soil carbon through national field networks	🟡🟢
Land Use Change	Incorporate info from available federal/ state databases, e.g. NLCD	🟡🟣🟠🟢
	Implement LIDAR/phodar-based monitoring system	🟡🟣🟠
Wetlands	Integrate updated remote sensing data with federal spatial data	🟠🟣🔵
	Refine state-specific stock and flux estimates	🟡🔵
	Develop national spatial inventory of GHG fluxes	🟡🟣🟠🔵
Baselines	Create a custom projected baseline	🟣🟠🔵
	Back-cast updated historical baseline	🟡🟠

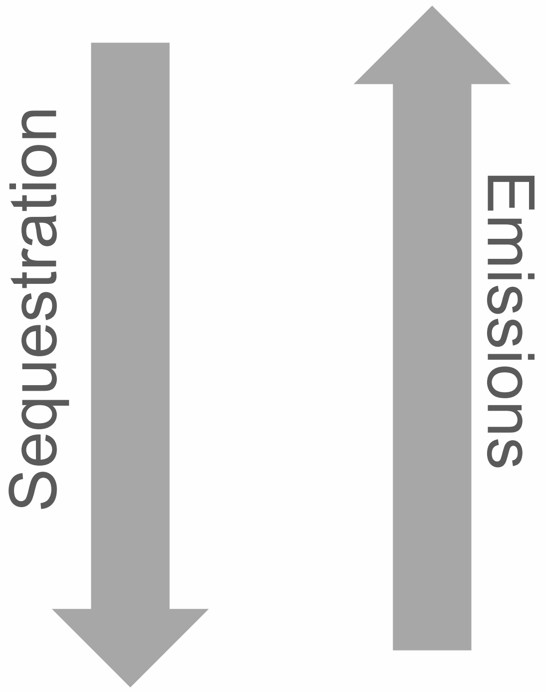
Comparing NWL Inventory Categories

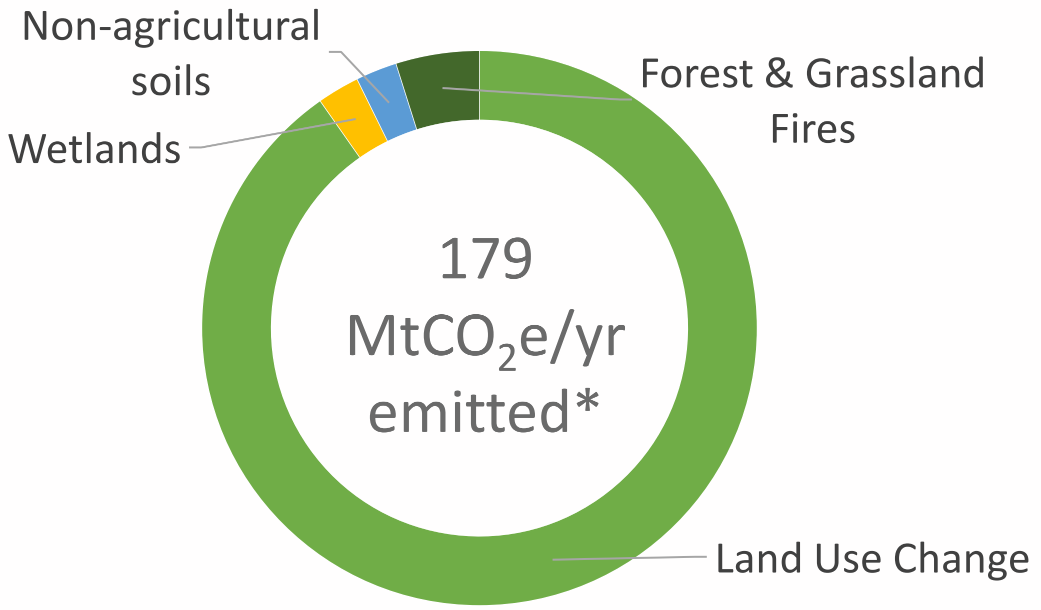
IPCC guidance identifies priorities for inventory improvement as source or sink categories that have a “significant influence” on the level, trend, or uncertainty of GHG emissions and removals.

This analysis shows the relative size (level) of emission sources and sinks in NWL nationally. Existing forests provide the largest carbon sink, while land use change represents the largest source of emissions. A similar analysis at the state level could identify key categories for inventory improvement.



Data from EPA 2019b





Land use change produces **2.5%** of US GHG emissions annually

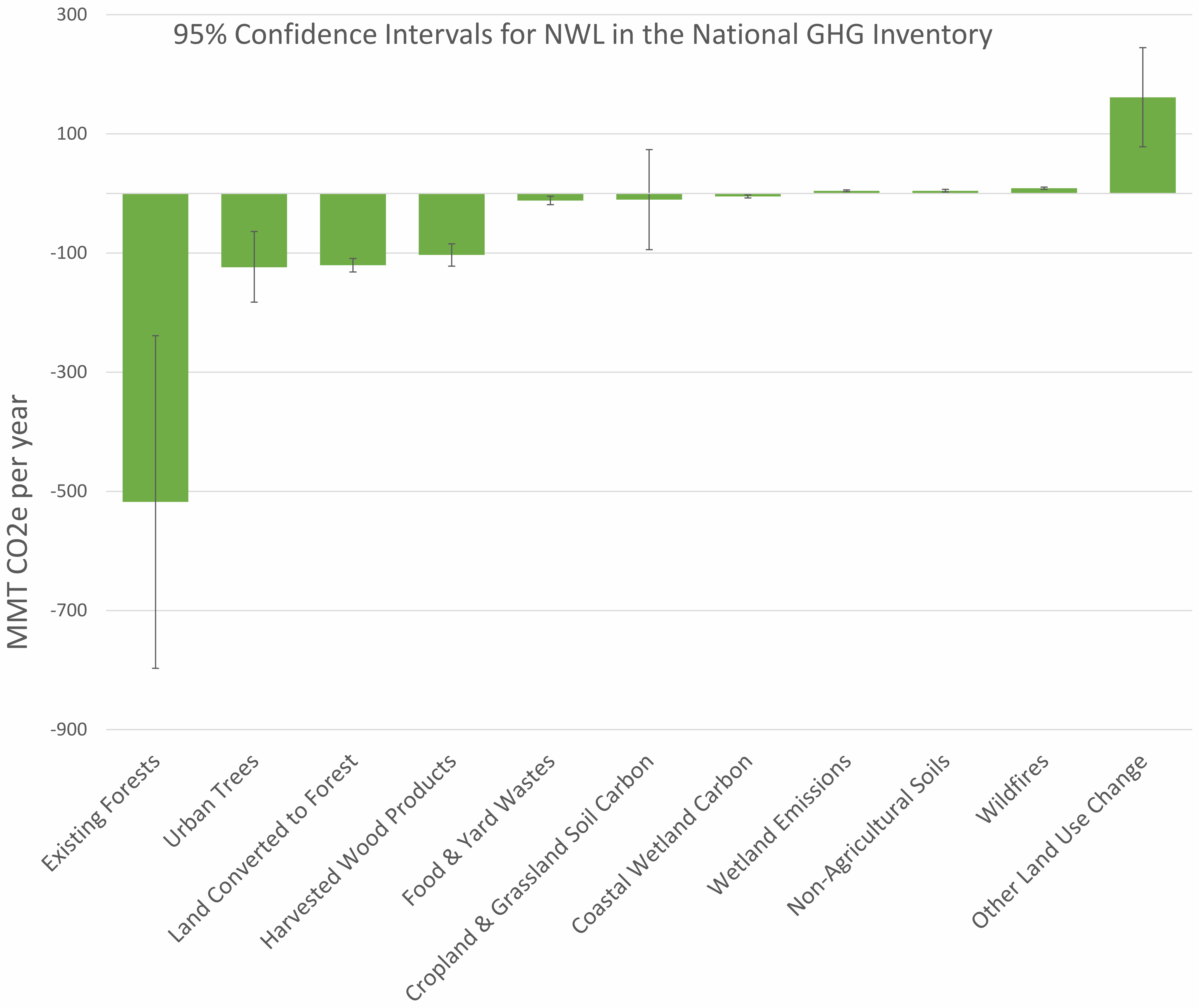
Trees and forests sequester **13%** of US GHG emissions annually

*Agricultural emissions like N_2O from soil management are not included here because they are typically reported outside the NWL inventory, but total 266 $MtCO_2e/yr$ and may benefit from similar inventory improvements

Reducing Uncertainty Across Categories

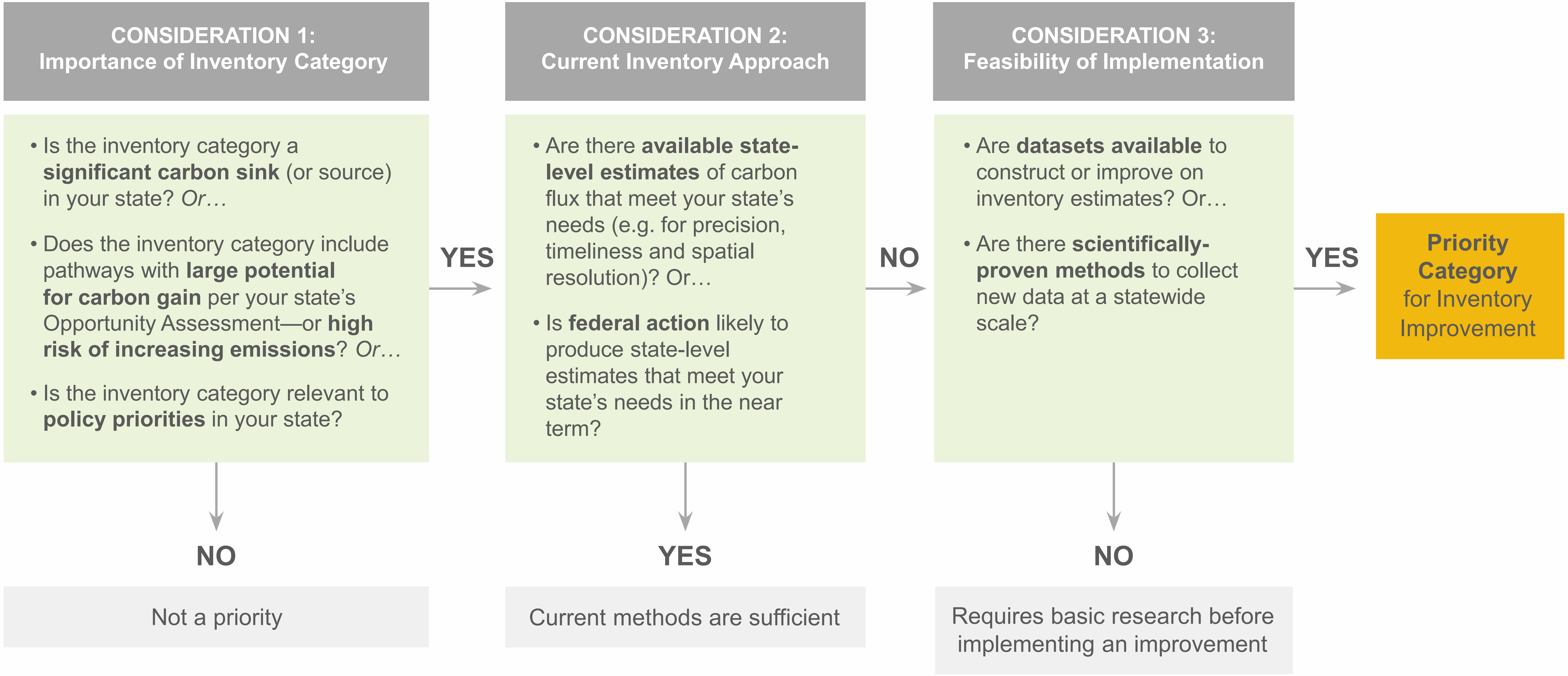
The uncertainty in estimating GHG flux for many NWL categories—including forests, cropland and grassland soils, and land use change—is **disproportionately large** compared to other sectors covered in the National GHG Inventory. This uncertainty can be magnified in state inventories due to **smaller pools of sample data** and **less state-specific calibration of models**.

Improvements in inventory methods for key NWL categories can help reduce this uncertainty.



Data from EPA 2019b

Where to prioritize inventory improvements?



CONSIDERATION 1:
Importance of Inventory Category

- Is the inventory category a **significant carbon sink** (or source) in your state? *Or…*
- Does the inventory category include pathways with **large potential for carbon gain** per your state's Opportunity Assessment—or **high risk of increasing emissions**? *Or…*
- Is the inventory category relevant to **policy priorities** in your state?

NO

Not a priority

YES

CONSIDERATION 2:
Current Inventory Approach

- Are there **available state-level estimates** of carbon flux that meet your state's needs (e.g. for precision, timeliness and spatial resolution)? Or…
- Is **federal action** likely to produce state-level estimates that meet your state's needs in the near term?

YES

Current methods are sufficient

NO

CONSIDERATION 3:
Feasibility of Implementation

- Are **datasets available** to construct or improve on inventory estimates? Or…
- Are there **scientifically-proven methods** to collect new data at a statewide scale?

NO

Requires basic research before implementing an improvement

YES

Priority Category for Inventory Improvement

Investment strategies for priority improvements

After selecting priority NWL categories, states may choose from different strategies for implementing inventory improvements. All of the improvements detailed in this Guide could be implemented using one or more of these strategies, which offer trade-offs between building in-house capacity and leveraging outside expertise. States may elect to pursue multiple strategies, depending on budget and other considerations.

Priority Category for Inventory Improvement

Strategy 1: Invest in field-based monitoring

Requires: Dedicated staff trained in plot sampling techniques; statistical analysis expertise.

Advantages: Low-tech and widely-accepted approach.

Disadvantages: Significant staff time and annual funding.

Strategy 2: Invest in remote sensing data and modeling

Requires: Upfront investment in modeling and analysis; technical capacity; sample data for calibration and validation.

Advantages: Can be cost-effective for monitoring, especially where federal or existing state data can be leveraged.

Disadvantages: Initial investment may be substantial for agencies lacking suitable existing data or relevant technical capacity.

Strategy 3: Leverage partnerships or private contractors

Requires: Ability to partner with a private firm or university with the necessary technical expertise.

Advantages: Flexibility in approaches; ability to bring in capacity only when needed for inventory.

Disadvantages: High cost for private contractors; state agencies accumulate less institutional knowledge.

Go Deeper

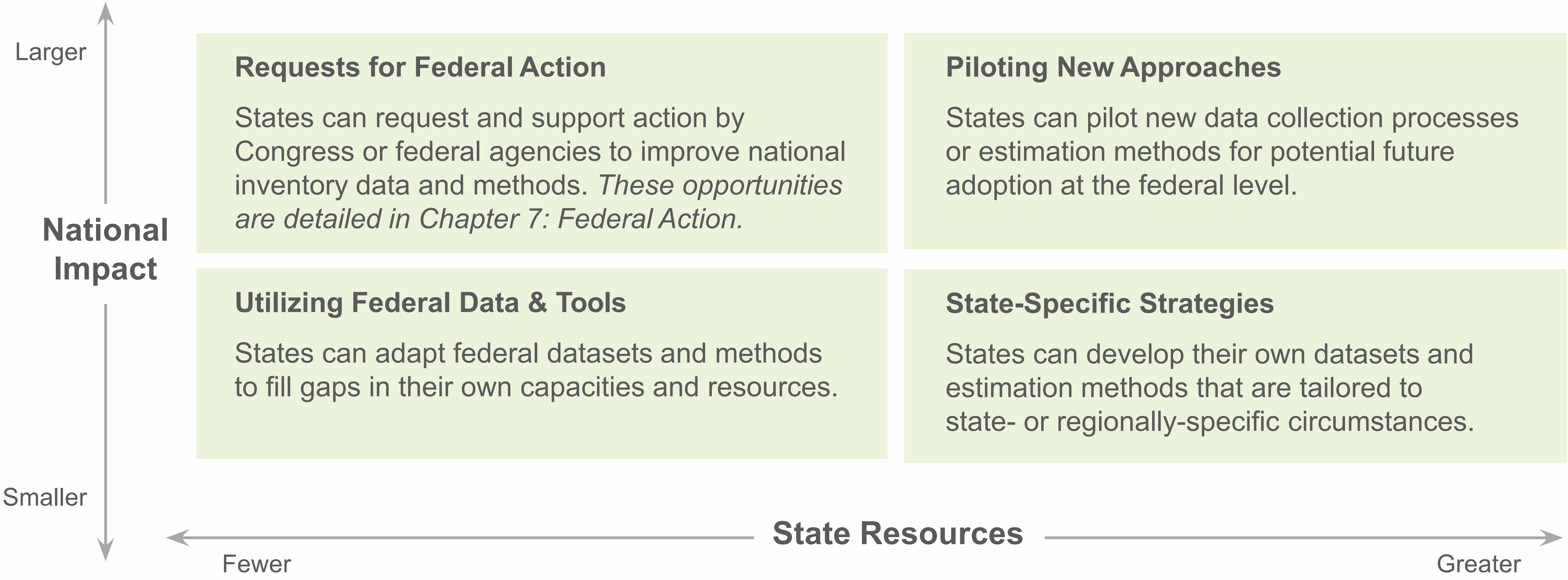
KEY TOOL

Field-based monitoring and remote sensing

Note: These strategies apply only to state-led improvements, not requests for federal action.

Leveraging resources for inventory improvement

States can leverage both federal and state resources to make inventory improvements, which in some cases could have impacts well beyond the state's borders. Inventory improvement strategies include:



Requests for Federal Action

States can request and support action by Congress or federal agencies to improve national inventory data and methods. *These opportunities are detailed in Chapter 7: Federal Action.*

Piloting New Approaches

States can pilot new data collection processes or estimation methods for potential future adoption at the federal level.

Utilizing Federal Data & Tools

States can adapt federal datasets and methods to fill gaps in their own capacities and resources.

State-Specific Strategies

States can develop their own datasets and estimation methods that are tailored to state- or regionally-specific circumstances.

Key takeaways

- NWL are an important carbon sink in the United States and can contribute significantly to future climate change mitigation.
- Estimating carbon fluxes from NWL involves more uncertainty than for other sectors, but improvements to GHG inventory tools and methods can reduce this uncertainty.
- Robust NWL inventories can help states measure progress toward GHG goals, set policies, manage land, and communicate with stakeholders.
- SIT provides a starting point for developing a NWL inventory for states with limited data resources or technical capacity.
- GHG mitigation potential from NWL, quality of existing data, and policy priorities can all guide decisions on what improvements a state could make in its NWL inventory.
- Some NWL inventory improvements can be accomplished with existing data and tools, while others will require new investment from states or action by the federal government.

GOING DEEPER:

Key Concepts, Data Sources and Tools

Going Deeper: Definitions

KEY CONCEPTS
Concepts that are important for understanding the material in this chapter

KEY DATA SOURCES
Documents, datasets, or technologies that can contribute valuable information for state inventories

KEY TOOLS
Guidelines, methodologies, or models that may be valuable for processing data in an inventory

KEY CONCEPT

NWL Climate Change Mitigation Pathways

Sustainably managing NWL can contribute to additional climate change mitigation in the US

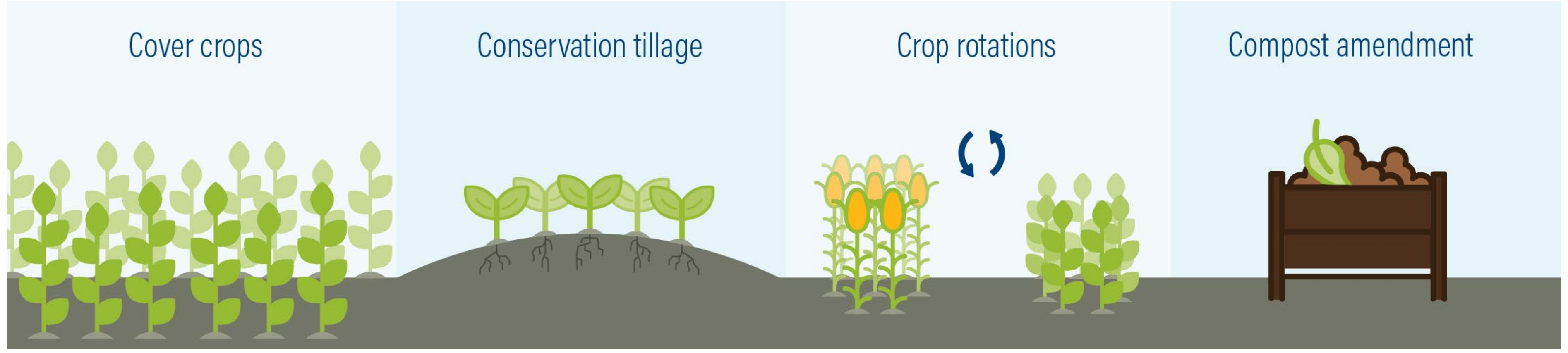
A variety of NWL management practices, or pathways, can help mitigate climate change by removing carbon from the atmosphere. These practices include:

Pathways for carbon removal in trees

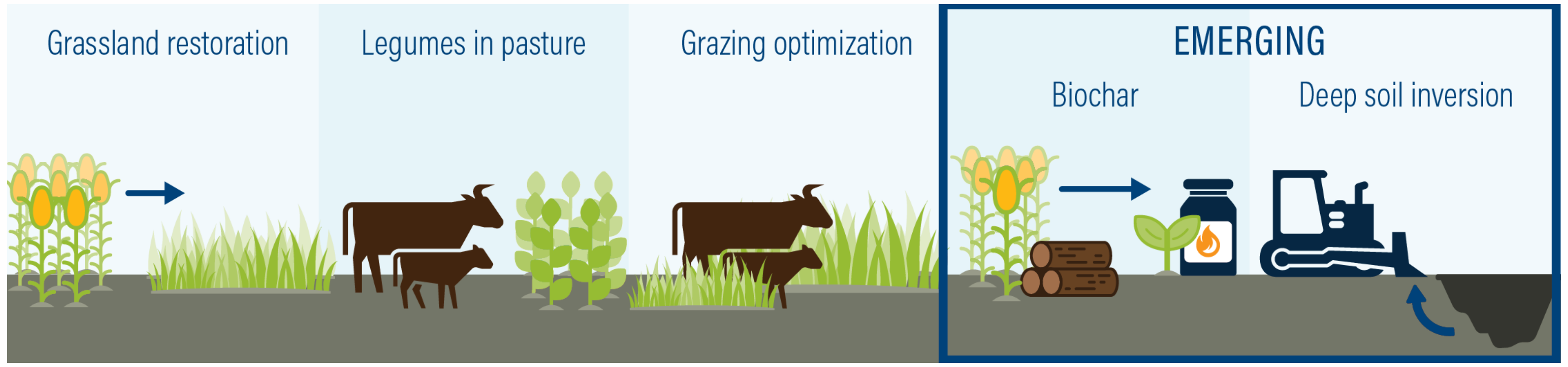
Reforestation	Restocking	Silvopasture	Cropland agroforestry	Urban reforestation
Establishing forest cover on historically forested land	Increasing tree density in existing forests	Integrating trees into pasture	Integrating trees into croplands	Expanding tree cover in urban areas

Additional pathways such as avoided forest and grassland conversion, fire management and cropland nutrient management can also mitigate climate change by reducing GHG emissions from NWL.
Pathways presented here are not intended to be comprehensive.

Pathways for carbon removal in cropland and grassland soils



Cover crops	Conservation tillage	Crop rotations	Compost amendment
Planting crops to restore soil health when fields would otherwise be fallow	Reducing or eliminating tillage of cropland	Alternating conventional crops with legumes or perennial forages	Applying composted organic wastes to cropland or pasture



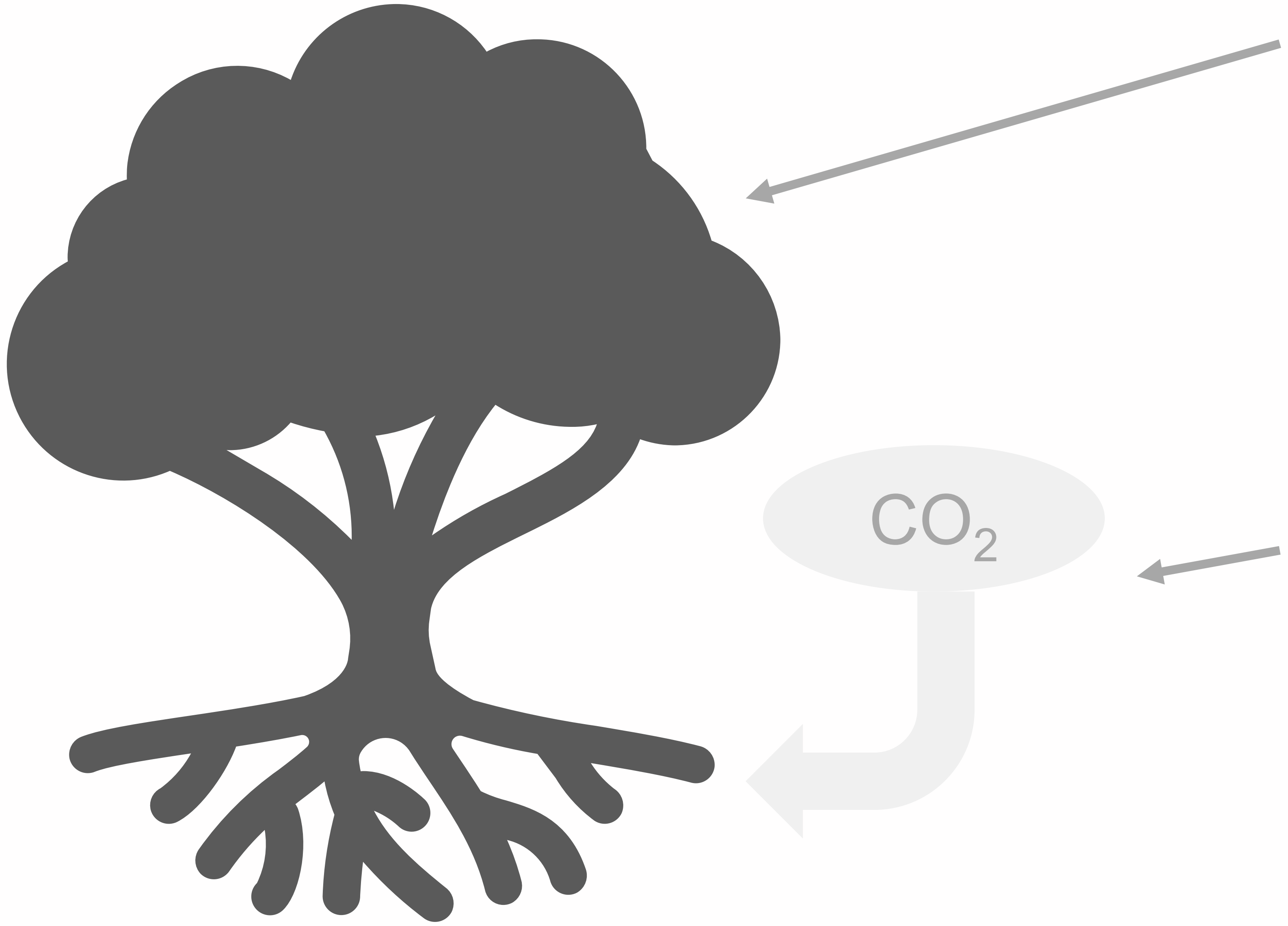
			EMERGING	
Grassland restoration	Legumes in pasture	Grazing optimization	Biochar	Deep soil inversion
Converting idle or unproductive cropland to native grasses	Planting leguminous forages in pastures	Implementing rotational grazing practices	Applying biochar to cropland or pasture soils	Burying carbon-rich topsoil and exposing deeper soil the surface

Source: Mulligan et al. 2020

What is a GHG inventory for NWL?

KEY CONCEPT

Measuring carbon stocks vs. carbon flux



A NWL inventory may report both **carbon stocks** and **carbon fluxes**, but **carbon fluxes** are most relevant to goal-setting and policymaking for NWL.

Carbon stock = the total amount of carbon stored in biomass and soil

- Carbon stocks are relatively stable over time, barring significant disturbances like wildfire or land use change
- Estimated as a function of tree diameter and height (equal to ~½ of tree biomass) or soil bulk density
- Usually a large value for a state NWL inventory with a proportionally small margin of error

Carbon flux = the *change* in carbon storage from one year to the next

- Carbon fluxes are highly variable across space and time as a function of biomass growth, soil management, disturbances, etc.
- Can be estimated using the stock-change method (the difference in carbon stock measured from year to year) or the gain-loss method (estimated carbon gain minus estimated carbon loss, as calculated from proxy measurements like land use change or soil management)
- *GHG flux* also includes emissions of non-CO2 gases like methane and nitrous oxide
- Usually a small number for a state NWL inventory with a proportionally large margin of error

[What is a GHG inventory for NWL?](#)

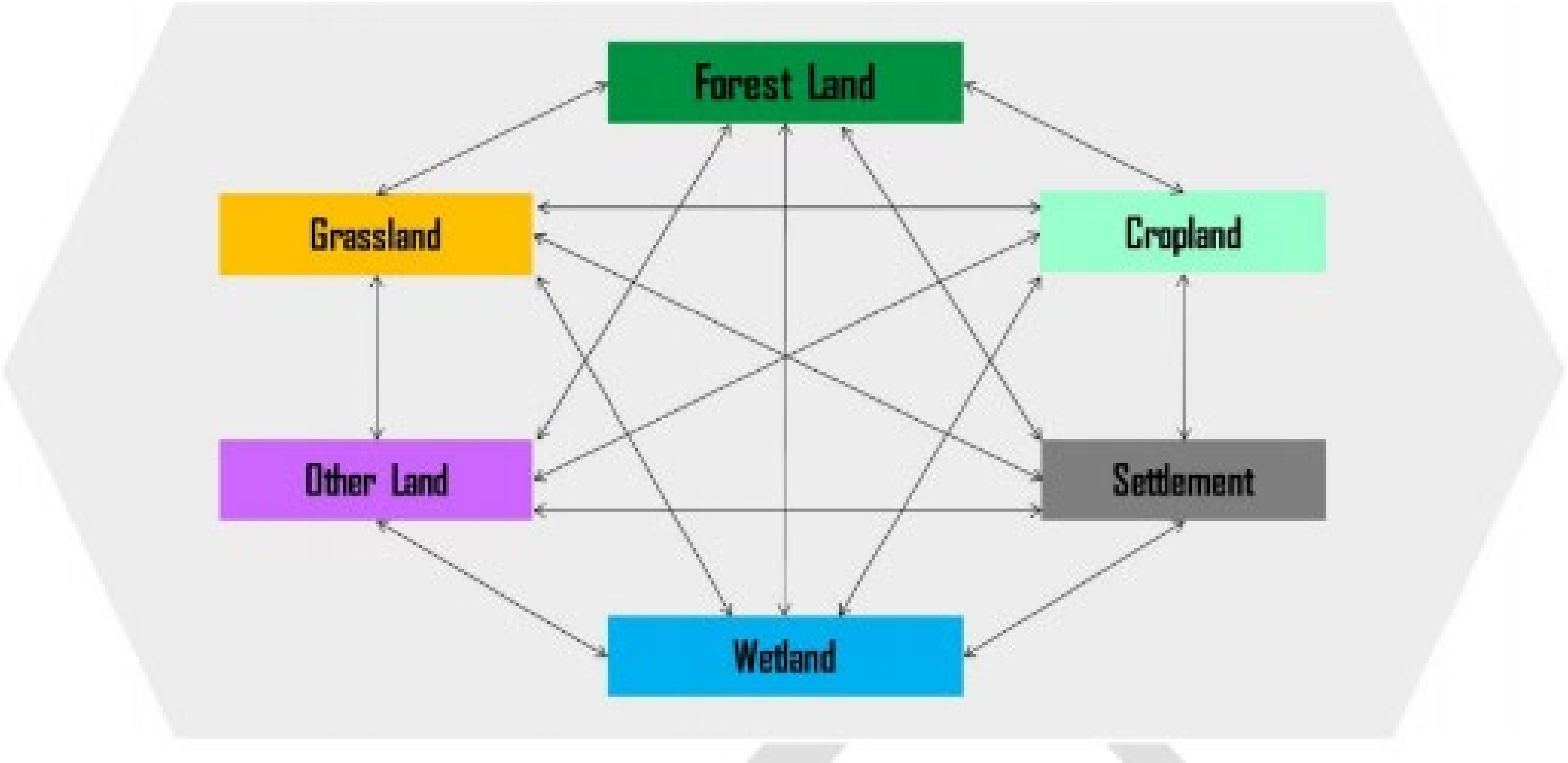
KEY CONCEPT

Land Use Categories

Forest Land	Land with at least 10% live tree cover over 1 contiguous acre, outside of urban areas
Cropland	Land used for the production of crops for harvest, even if temporarily fallow
Grassland	Land primarily supporting grasses, forbs, or shrubs, incl. range, savanna, & desert
Wetland	Land covered or saturated by water for part or all of the year, incl. reservoirs & rivers
Settlements	Developed areas of at least ¼ acre, or tracts of up to 10 acres surrounded by urban areas
Other Land	Bare soil, ice, rock, & other unclassified land—largely devoid of biomass or soil C

NWL inventories typically include GHG fluxes for each of the six land use categories on the left. The IPCC provides standardized definitions for what each category includes in GHG inventories. An inventory also includes GHG fluxes derived from year-to-year changes in land use, reported separately for each of the axes in the figure below (e.g., Forest Land converted to Cropland).

Categories of land use change



Source: California Air Resources Board

KEY CONCEPT

Global Warming Potentials of non-CO2 GHGs

What is a GHG inventory for NWL?

The relative impact of non-CO_2 GHGs on the climate depends on the time horizon considered, since these gases are more potent but generally shorter-lived than CO_2. The Global Warming Potential (GWP) of different GHGs, published by the IPCC, measures their relative impact on the climate over a standardized timeframe. GHG flux estimates are highly sensitive to which GWP is used to estimate the CO_2 equivalence of non-CO_2 emissions.

The 100-year GWP is the standard approach used in the National GHG Inventory and international reporting.

			Global Warming Potential over…			
Greenhouse Gas	**Formula**	**Lifetime (yrs)**	**20 years**	**100 years**	**500 years**	**Sources (or Sinks) Included in NWL Inventory**
Carbon dioxide	CO_2	5 – 200+ (varies by removal process)	1	1	1	Changes in ecosystem carbon stocks, land use change
Methane	CH_4	12	72	25	7.6	Wildfires, wetlands
Nitrous oxide	N_2O	114	289	298	153	Urban soils, wildfires, wetlands, drained peat soils*

*Agricultural soils also produce N_2O, but these emissions are typically classified as part of the agricultural GHG inventory, rather than as part of NWL.
GWP Source: IPCC Fourth Assessment Report, Changes in Atmospheric Constituents and in Radiative Forcing

KEY CONCEPT

Uncertainty

[What is a GHG inventory for NWL?]

> *Uncertainty estimates are an essential element of a complete inventory of GHG emissions and removals, because they **help prioritize future work** and **improve overall inventory quality**.*
>
> - National GHG Inventory

Uncertainty or systematic error can propagate in an estimate of GHG emissions or removals due to **sampling**, **modeling**, and **estimating model parameters**.

IPCC guidelines require the quantitative estimation of uncertainty as a 95% confidence interval, using one or more of these techniques for each type of uncertainty:

Type of Uncertainty	**Sampling Uncertainty**	**Model Uncertainty**	**Model Parameter Uncertainty**	**Combining Multiple Sources of Uncertainty**
Techniques for quantifying uncertainty	Statistical analysis of empirical data	Verification of model results with independent data	Statistical analysis of empirical data	Propagation of errors
		Comparison of alternative model results	Expert judgment	Monte Carlo analysis
		Expert judgment		

KEY TOOL

IPCC guidelines for GHG inventories

What is a GHG inventory for NWL?

What is it? The 2019 Refinement to the 2006 Intergovernmental Panel on Climate Change (IPCC) Guidelines for National GHG Inventories provides the most up-to-date internationally agreed-upon methodologies for countries to estimate their GHG emissions and removals.

What does it do? The IPCC guidelines outline methodologies for:

- Collecting data
- Characterizing and quantifying uncertainty
- Identifying key categories for inventory
- Maintaining time series consistency
- Verifying inventory quality
- Including emissions of non-CO_2 gases
- Reporting GHG emissions and removals

Relevance for NWL inventories: All countries use these guidelines to standardize their GHG emission reports to the UN Framework Convention on Climate Change (UNFCCC). The IPCC guidelines include both broad and sector-specific guidelines (including NWL) for developing GHG inventories. These guidelines are applied in the National GHG inventory and increasingly to state inventories.

Limitations: The IPCC guidelines are designed for national inventories, and therefore do not cover some unique considerations for state inventories such as inventory boundaries, attribution of GHG fluxes, and emission leakage.

Resources: 2019 Refinement to the 2006 IPCC Guidelines for Agriculture, Forestry and Other Land Use; 2006 IPCC Guidelines for Agriculture, Forestry and Other Land Use; Application of 2006 IPCC Guidelines to Other Areas

KEY DATA SOURCE

Key Data Sources: National GHG Inventory vs. SIT

National GHG Inventory vs. SIT

NWL Category	Underlying Data for the National GHG Inventory (1990-2018, released in 2020)	Underlying Data for SIT (2019 version)
Forests (and land converted to/from forest)	Forest Inventory & Analysis (FIA) 2018	FIA 2014 via Carbon Calculation Tool (CCT)
Urban Trees	Urban area: National Resources Inventory (NRI) 2015 Tree cover: National Land Cover Database (NLCD) 2015 Carbon estimation: Nowak et al. 2013 and others; i-Tree database; Urban FIA	Urban area: US Census 2010 Tree cover: Nowak et al. 2012 Carbon estimation: Nowak et al. 2013
Wood Products	Timber production: USDA Forest Service data (Howard & Liang 2019) Carbon estimation: WOODCARB II model	Smith et al. 2001
Forest Fire Emissions	Forest area: Monitoring Trends in Burn Severity (MTBS) 2015; National Land Cover Database (NLCD) 2015 Fuel estimates: FIA	EPA 2003; Smith et al. 2001
Croplands and Grasslands	Land use: National Resources Inventory (NRI) 2015; Conservation Effects and Assessment Project (CEAP) 2006 Carbon estimation: DayCent model	National GHG Inventory 2017
Land Use Change (non-forest)	NLCD 2015	*Not reported separately*
Wetlands	Wetland area: NOAA Coastal Change Analysis Program (C-CAP) Emission factor: Holmquist et al. 2018	*Not included*

KEY TOOL

Field-based monitoring and remote sensing

Investment Strategies for Priority Improvements

Field-based monitoring

What is it? Inventory method using data primarily from on-the-ground field plots

How does it work? A team physically measures tree or soil attributes within designated sample plots and uses statistical extrapolation to estimate carbon stocks over a larger area

Relevance to NWL inventories: All estimates of GHG flux must be based on field measurements, either directly based on sampling protocols or indirectly through model calibration and validation.

Limitations:

- Plot surveys can be costly and time-consuming to implement
- Subject to human error in sampling and measurement
- Sample-based approach does not allow for fine-scale spatially explicit estimates

Remote sensing

What is it? Inventory method using primarily remotely sensed data, e.g. satellite imagery or lidar

How does it work? A sensor attached to an aircraft or satellite records the intensity of reflected light or energy. These data can create images or maps of land cover or estimate carbon stocks if calibrated with field data.

Relevance to NWL inventories: Remote sensing data are used in the National GHG Inventory to track land uses and land use change. Greater integration of remote sensing tools into GHG inventories can produce carbon estimates that are explicit in space and time.

Limitations:

- Requires field data for calibration and validation in order to produce carbon estimates
- Requires technical expertise in data processing and modeling to translate data for GHG inventory
- Some data, like aerial lidar, can be expensive to collect

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CHAPTER 2: TREES & FORESTS

Guide at a Glance

Chapter	Topic	Purpose
1	Overview	Understand basic concepts and identify inventory priorities for your state *(designed for state policymakers and agency staff)*
2	Trees & Forests	Deep dive into inventory improvement options across land use classes *(designed for agency staff)*
3	Croplands & Grasslands	Deep dive into inventory improvement options across land use classes *(designed for agency staff)*
4	Land Use Change	Deep dive into inventory improvement options across land use classes *(designed for agency staff)*
5	Wetlands	Deep dive into inventory improvement options across land use classes *(designed for agency staff)*
6	Baselines	Deep dive into options for creating a historical or projected inventory baseline *(designed for agency staff)*
7	Federal Action	Overview of inventory improvement options that require action by Congress or federal agencies *(designed for state policymakers)*

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Executive Summary: The Issue

Trees and forests make up the primary carbon sink across the United States. Including accurate estimates of annual carbon flux in trees and forests in state-level greenhouse gas (GHG) inventories is important to reflect the role these natural systems play in regulating carbon emissions. More sophisticated inventories for trees and forests can also help inform state policies to steward forests and increase tree cover in urban areas. However, several limitations in nationally available datasets make it challenging to develop a sophisticated inventory for trees and forests:

- **Margins of error are large.** The 95% confidence interval reported in the 2017 National GHG Inventory for “Forestland Remaining Forestland” spans nearly 600 million metric tons of CO_2. That’s a difference between forests offsetting 5% or 14% of gross US emissions. While the EPA State Inventory Tool (SIT) does not measure uncertainty at the state level, uncertainty tends to increase for smaller-area estimates, which have fewer measurements to average. States may therefore experience challenges in using downscaled national data for applications that require precise estimates, such as targeted policymaking or goal-setting.
- **Estimates are not specific in time or space.** SIT and the National GHG Inventory both rely on the Forest Inventory & Analysis (FIA) program, which estimates forest carbon based on a rolling average of 7-10 years of sample measurements across many different plot sites. These carbon flux estimates are not associated with a specific year or location, so they cannot be used to track carbon fluxes on specific parcels/land ownerships or forest types. The rolling average approach employed by FIA also makes it challenging to attribute carbon fluxes to specific causes (e.g., wildfire or timber harvest).
- **Trees outside forests are treated differently.** FIA only collects nationwide data for areas of forest at least 1 acre in size, which omits trees outside forests—including in agricultural lands, cities, and natural non-forest ecosystems. SIT and the National GHG Inventory estimate carbon fluxes in urban trees separately using other federal datasets and literature, but this estimation method is not consistent with the FIA approach for forests, leading to some double-counting of carbon and discrepancies in the timeliness of data. The National GHG Inventory estimates carbon fluxes in woodlands that do not meet the FIA definition of forest based on plot data from the Central Plains and Southwest regions, but these plots do not represent a comprehensive assessment of trees in natural savannas or woodlands. Trees on agricultural lands are omitted entirely from both the National GHG Inventory and SIT, making it difficult for states to manage these carbon stocks.
- **Carbon fluxes in wood products are not estimated at the state level.** Carbon sequestered in harvested wood products made up 17% of all forest carbon sequestration in the 2017 National GHG Inventory, but wood product data are not disaggregated down to the state level. SIT relies on state data from the 1990s and does not incorporate any more recent changes in wood product trends into its estimates of carbon flux.

Executive Summary: Solutions

States relying on the land use, land use change and forestry (LULUCF) module of SIT for estimates of carbon flux in trees and forests could improve their inventories immediately by using **new state-level FIA data** on forest carbon flux, forest fire emissions and carbon flux in urban trees. The USDA Forest Service released this dataset in April 2020 to support the National GHG Inventory and plans to update it on an annual schedule. SIT plans to incorporate the new data for “Forest Land Remaining Forest Land” in its 2020 update, replacing the outdated Forest Service calculation tool it currently uses to estimate forest carbon flux (data on forest fires and urban trees will not be updated until a later release). The new Forest Service dataset provides state-level estimates with a consistent methodology to that used in the National GHG Inventory. It would also allow states to report and potentially reduce the margins of error around these estimates, though states would need to contact the Forest Service directly for data on uncertainty. Because the dataset is based on FIA, however, it would not solve the other issues relating to data resolution, the treatment of trees outside forests, or state-level estimation of carbon in wood products.

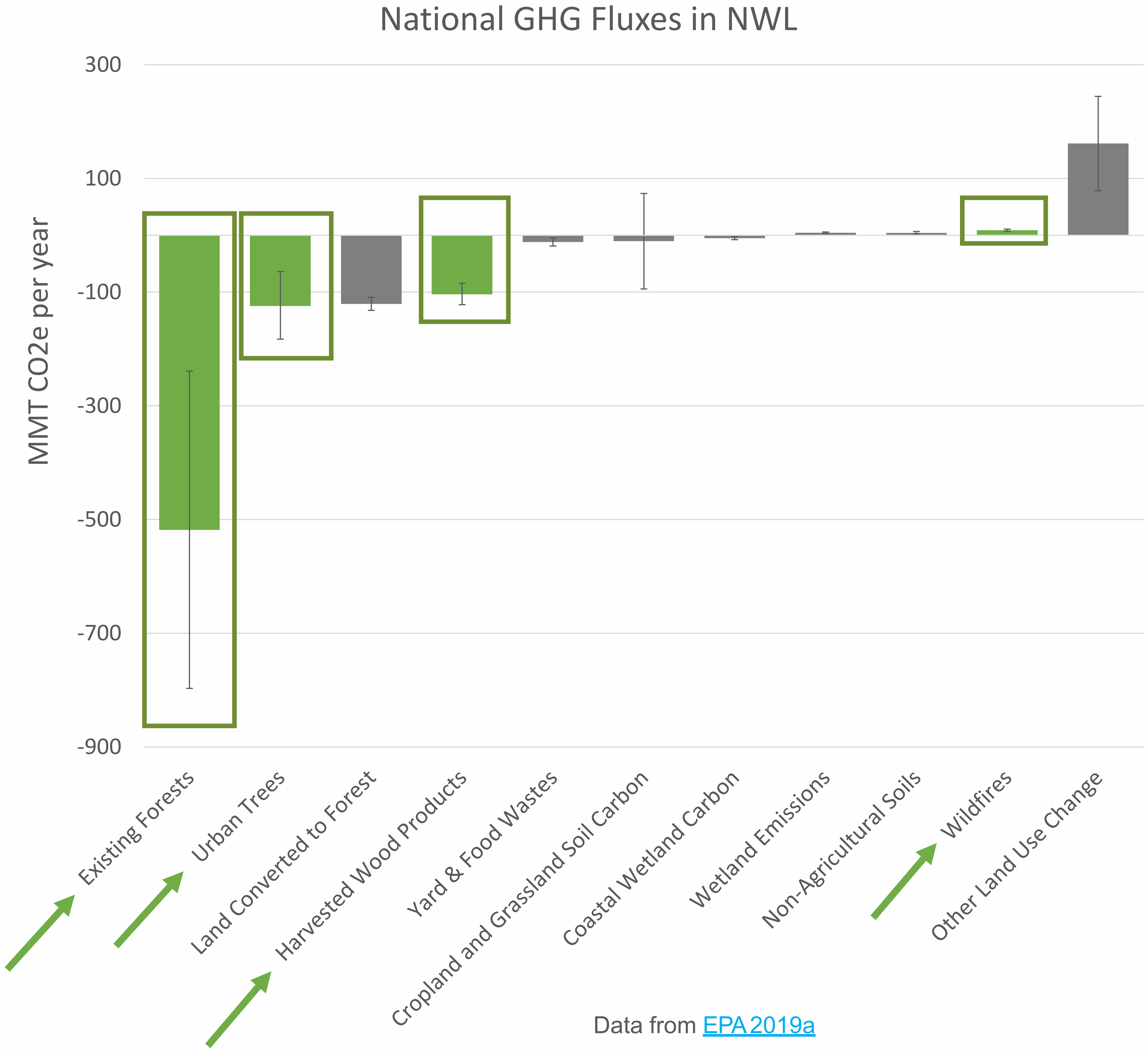
States could more comprehensively address the issues inherent in current FIA data by building more sophisticated inventory systems for trees and forests grounded in **remote sensing datasets**. Either **optical imagery-based** or **LIDAR-based** inventories would allow states to pinpoint carbon fluxes in time and space, monitor forests and trees outside forests using a common methodology (given fine enough resolution), and reduce the uncertainty around their carbon flux estimates. This chapter details these improvement options and highlights the work that **California, Maryland, Delaware,** and **Washington** have done to pursue inventory improvements in this vein. The benefits of a **national remote sensing-based inventory system** for trees and forests are discussed further in *Chapter 7: Federal Policy.*

States may also elect to reduce uncertainty, enhance the resolution, and/or increase the timeliness of their carbon flux estimates for trees and forests by making other inventory improvements, such as **increasing the statistical power of their FIA plot network** (by either adding more plots or measuring plots more frequently), **creating a field-based inventory for urban trees**, or **refining in-state accounting of harvested wood products**. This chapter details these improvement options as well, with examples of how **Wisconsin** and **California** have utilized these respective methods.

Prioritizing inventory improvements for trees & forests

Forests, **urban trees** and **harvested wood products** together provide the greatest amount of carbon sequestration nationally.* States with significant carbon sinks, potential for changes in the strength of the sink, and/or significant uncertainty around the size of sinks provided by trees and forests should consider prioritizing inventory improvements in this chapter.

*NOTE: Land converted to forest is considered separately in the chapter on Land Use Change.



Data from EPA 2019a

DEFAULT APPROACH

EPA State Inventory Tool

Go deeper

KEY DATA SOURCE: Forest Inventory and Analysis

What does it include?

- Annualized estimates of state-level forest carbon flux in 2019 version of SIT are calculated from Forest Inventory & Analysis (FIA) data use a stock-difference approach through the Carbon Calculation Tool (CCT)
- Estimates of carbon flux in urban trees calculated from US Census data on urban areas and literature estimates of % urban tree cover by state
- Carbon flux in wood products estimated from Forest Service publications

Major limitations

- No margin of error provided, but uncertainty around estimates is likely large, especially for small states
    - ➢ The only published uncertainty estimates for CCT come from a 2015 assessment of carbon fluxes in southern National Forest units, which reported uncertainties between 50% and >500%
    - ➢ Margin of error for underlying FIA data is equivalent to 40%+ of land carbon sink nationally

Major limitations (cont.)

- Default data are out-of-date
    - ➢ Most recent FIA data in the 2019 version of SIT are from 2014, while the National GHG Inventory includes data through 2018
    - ➢ Wood products are estimated from 1997 data
- Some data sources and tools are not consistent with National GHG Inventory
    - ➢ CCT does not explicitly account for land use change, so year-to-year changes in carbon flux may result in part from changes in forest land area
    - ➢ Estimates for % urban tree cover differ from those used in National GHG Inventory
- Forest and urban tree estimates may overlap due to differences in calculation methodologies
- Data are non-spatial—cannot be broken out by county, ownership class, or other sub-state classifications
- Spatial and temporal resolution of data are insufficient to allow for attribution of carbon fluxes to specific causes

BASIC IMPROVEMENT

Use current state-level FIA data

What does it entail?

- In April 2020, USDA Forest Service published state-level FIA data on carbon fluxes in forests, urban trees, and land converted to/from forests, as well as non-CO2 emissions from forest fires, that aligns with national data in the 2018 National GHG Inventory
- State-level uncertainty analysis available on request
- EPA plans to integrate data for Forest Land Remaining Forest Land into the next SIT update in late 2020, but data on forest fires and urban trees will not be updated until a later release; states can also use the data off-the-shelf from the Forest Service Resource Update
- Planned annual updates to Forest Service data will be automatically embedded in annual SIT updates, but with some delay

What problem(s) will it solve?

- Makes state-level estimates more timely (using FIA data through 2018, compared to 2014 in SIT)
- Explicitly accounts for carbon flux associated with land use change to/from forest, which SIT does not
- Includes estimates of carbon flux in urban trees that are consistent with the National GHG Inventory methodology
- Reports carbon fluxes according to IPCC land use categories, consistent with National GHG Inventory

Major limitations

These data carry all the limitations of the FIA program, including:

- Double-counting some carbon fluxes between forests and urban trees due to different estimation methodologies
- No sub-state or spatially explicit estimates of carbon flux
- Rolling average approach for annualized estimates obscures the impacts of short-term carbon fluxes in forests
- No attribution for causes of carbon loss in forests
- Does not include carbon flux estimates in harvested wood products
- Does not include data on forest carbon flux for Alaska or Hawai'i (but does include data urban trees)

Beyond FIA: Why pursue additional improvements for Trees & Forests?

- **Reduce uncertainty** around GHG flux estimates—especially at smaller spatial scales
  - *Particularly important for states prioritizing management of forests or trees outside forests*
- Make estimates **more timely** for GHG fluxes in forests and harvested wood products
  - *Particularly important for states experiencing significant changes in forest cover or timber production*
- **Enhance data resolution**—both spatial and temporal
  - *Particularly important for states that want to effectively target policy interventions at the sub-state level*
- **Attribute GHG fluxes** to specific causes
  - *Particularly important for states experiencing unplanned large-scale forest loss, e.g. from wildfire or disease*
- **Refine estimates** for urban trees and capture other trees outside forests in the GHG inventory
  - *Particularly important for states prioritizing policies for urban forests, or states with significant tree cover in croplands or grasslands*

TREES & FORESTS

Additional Improvements

	IMPROVEMENT 1	IMPROVEMENT 2	IMPROVEMENT 3	IMPROVEMENT 4	IMPROVEMENT 5	FEDERAL ACTION
Improvement Objective	Integrate optical imagery with FIA	Integrate LIDAR/ phodar with FIA data	Increase statistical power of FIA plot network	Create field-based inventory for urban trees	Refine accounting for wood products	Develop a national remote sensing-based inventory
Reduce uncertainty	✓	✓	✓	✓	✓	✓
Improve timeliness	✓				✓	✓
Enhance data resolution	✓	✓	✓	✓		✓
Enable attribution of GHG fluxes	✓					✓
Include trees outside forests in inventory scope		✓		✓		✓

IMPROVEMENT 1

Integrate optical imagery with FIA data

What would it entail?

- Acquiring and analyzing optical data from passive remote sensors, such as satellite imagery
- Many optical imagery tools are freely available but require resources and technical capacity for intensive data processing and analysis
- Calibrating optical data with plot measurements from FIA data (or a state's own forest inventory) to model carbon fluxes

What problem(s) would it solve?

- Improves temporal resolution of carbon flux estimates by representing land cover at a series of snapshots in time, rather than the 7-10 year "rolling average" estimate of land cover embedded in FIA data
- Allows more accurate and timely accounting for forest disturbance and conversion, which can feed into an annual GHG inventory

What problem(s) would it solve? (cont.)

- Improves spatial resolution of carbon flux estimates, potentially up to the resolution of optical imagery (though may be lower if used in conjunction with other data sources)
- Enables analysis that links disturbances to site-specific climate, environmental, or land management factors (as long as disturbances cover areas larger than the imagery resolution)

Major limitations

- Precision of estimates derived from optical imagery depends on sample size of FIA or other field data used for calibration
- Requires additional data to identify sources of disturbance such as wildfire and quantify carbon impacts of those disturbances
- Requires additional field data to quantify carbon flux in urban trees (see Improvement 4) or other trees outside forests
- Timeliness is limited by frequency of imagery updates

Go deeper

KEY DATA SOURCES:
Passive Remote Sensors

CASE STUDY:

California NWL Inventory

This improvement option is also suitable for federal action. For more details, see ***Chapter 7: Federal Action****.*

CASE STUDY

California Natural & Working Lands Inventory

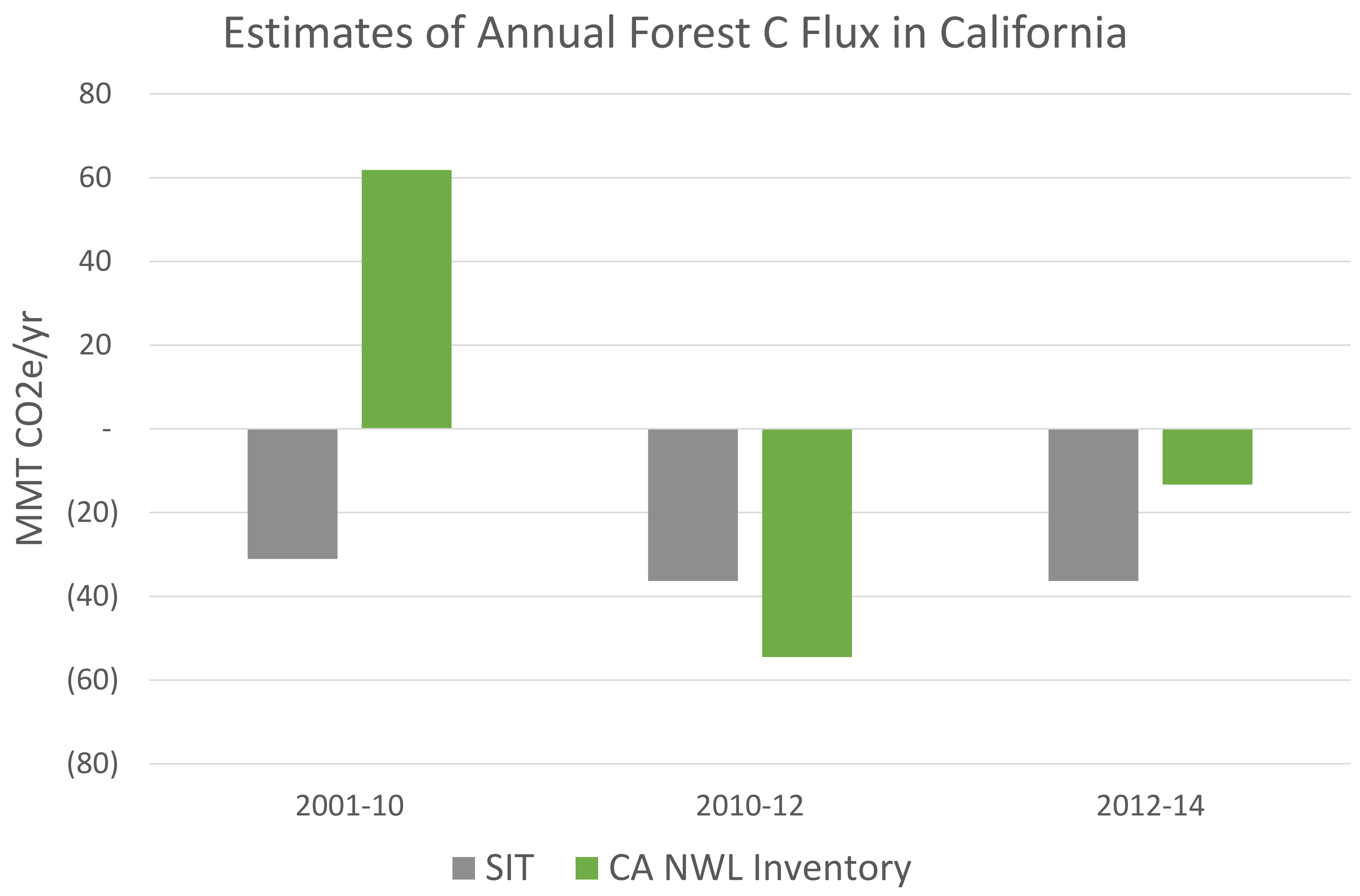
What: California Air Resources Board (CARB) estimated forest carbon flux in the state's 2018 Inventory of Ecosystem Carbon in NWL using geospatial data on land use, vegetation type, tree canopy cover and height, and forest disturbances from the LANDFIRE tool, which is based on Landsat optical imagery, in combination with georeferenced FIA field plot data.

Why: LANDFIRE allowed CARB to use a consistent data source across all land cover types and categorize disturbance impacts on NWL carbon stocks, in order to inform state investments in NWL.

Results: Analysis found that year-to-year variation in forest carbon flux is over 20x greater than shown in SIT, and attributed that variation to disturbances—with 74% coming from wildfire.

Limitations:

- Timeliness – LANDFIRE is updated on a multi-year cycle, with an additional time lag before data are released
- Consistency – The LANDFIRE data classification scheme has become more granular in recent releases, making comparisons to earlier releases more challenging
- Precision – LANDFIRE under-reports tree growth because it relies on multi-meter bins for classifying tree height (this has been addressed in latest update)
- Accuracy of harvest data – California supplemented LANDFIRE with data from the state's Timber Harvest Plan after it found that LANDFIRE under-represented harvest volumes



Resources: Inventory of Ecosystem Carbon in California's NWL, Technical Support Document for NWL Inventory

Go deeper

KEY TOOLS: LANDFIRE

IMPROVEMENT 2

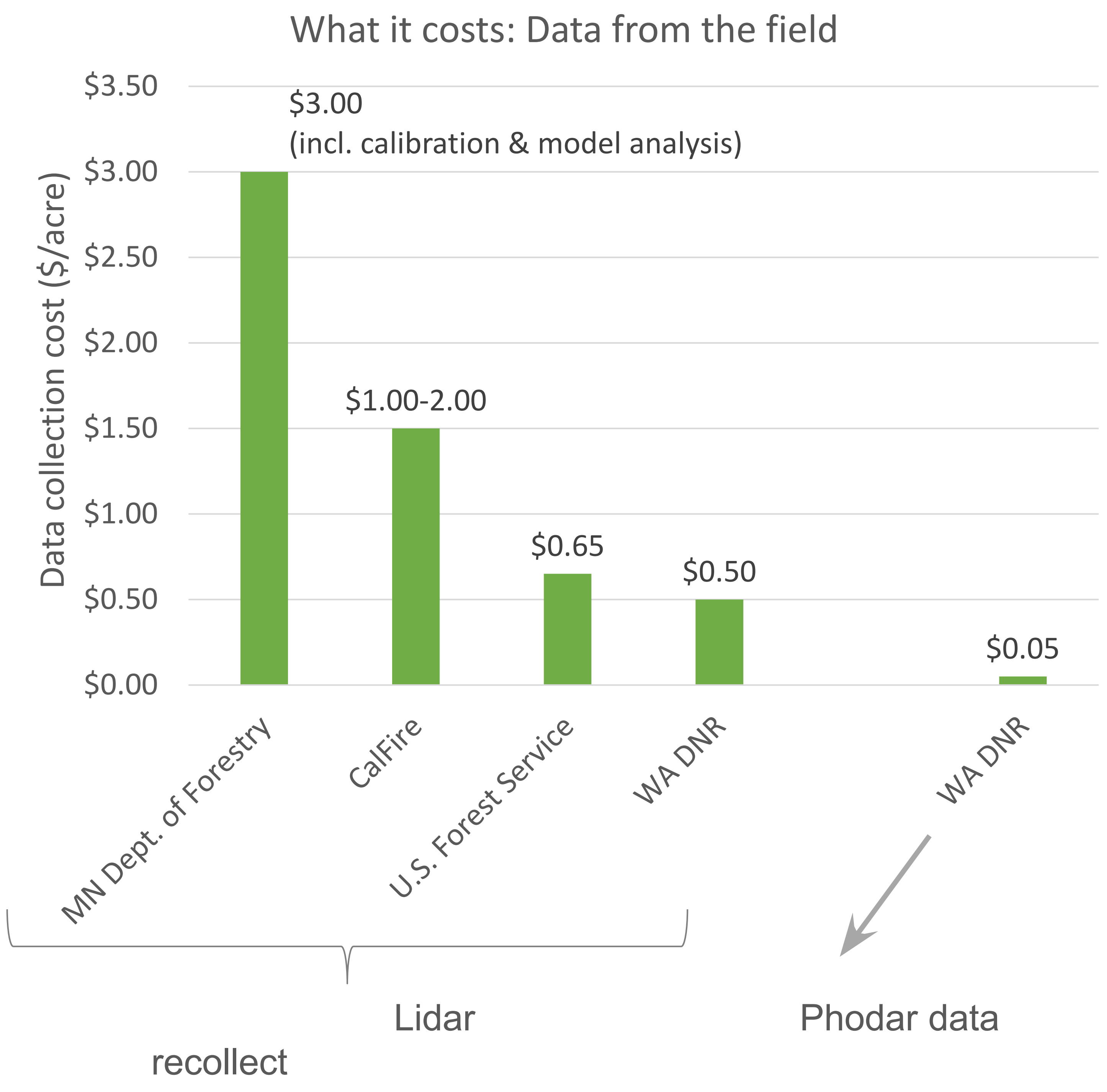
Integrate LIDAR/phodar with FIA data

What would it entail?

- LIDAR data, or phodar data (3D digital imagery) paired with a digital elevation map, can be used to construct a “base map,” documenting initial conditions of tree height and forest structure across the landscape
- Calibration to FIA or other field data on tree heights and basal area is necessary to operationalize LIDAR/phodar data for GHG inventories
    - ➢ Required density of calibration plots is less dense than states typically maintain for other purposes
- LIDAR/phodar-derived base carbon map can be updated periodically to reflect tree growth rates as measured by FIA, disturbances captured by optical imagery, and/or changes to forest height and area captured by LIDAR/phodar
- Some states can use existing LIDAR data collected for other purposes, but collecting new LIDAR data is expensive
    - ➢ Phodar data could be a more affordable option for repeated or new data collection
- Any new or existing LIDAR/phodar data would require resources and technical capacity for data processing and analysis

What problem(s) would it solve?

- Can be applied across all land uses, capturing forests, urban trees, and other trees outside forests within the same inventory product using a consistent methodology
- Produces a spatially explicit map of carbon fluxes in trees and forests



Go deeper

KEY DATA SOURCE:
Active remote sensors

IMPROVEMENT 2

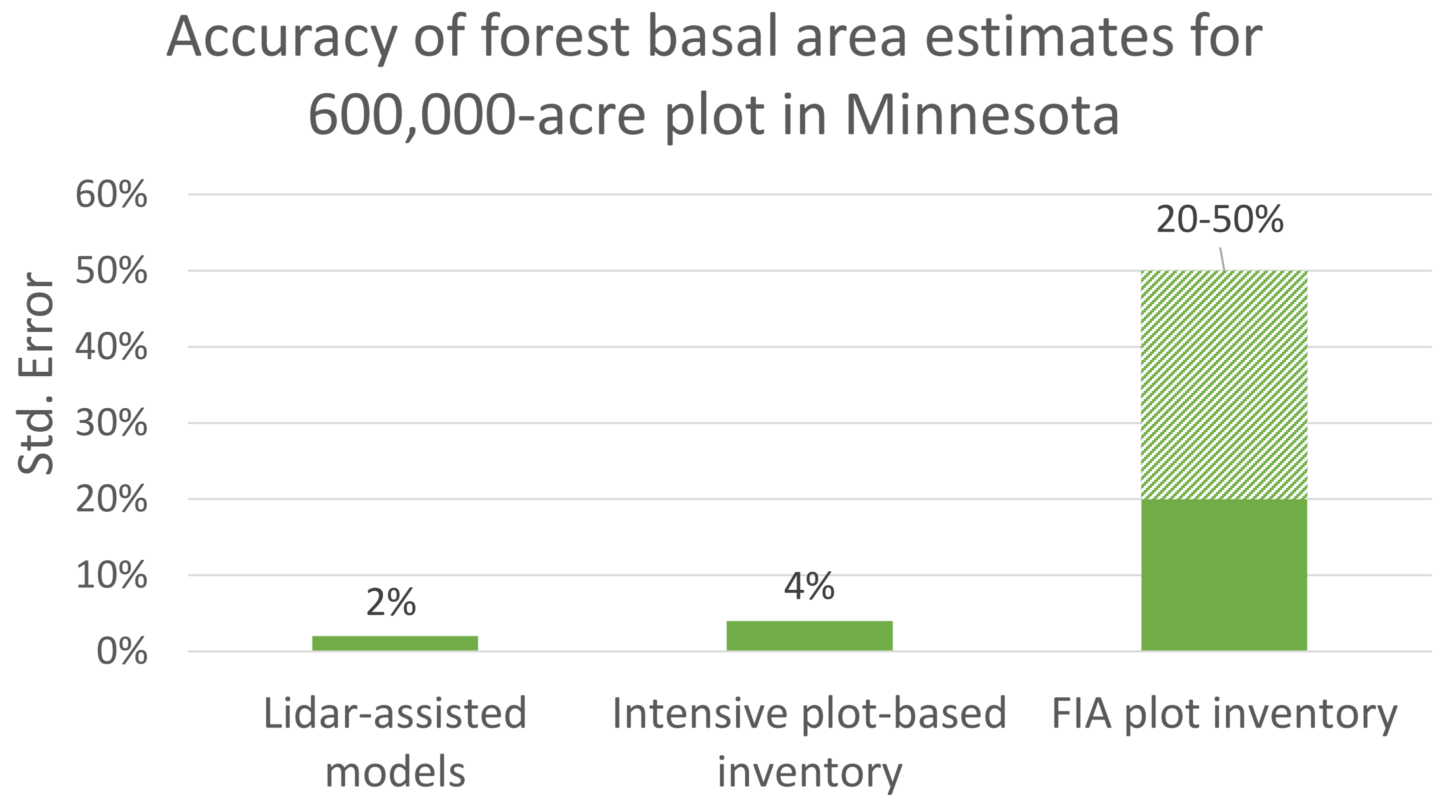
Integrate LIDAR/phodar with FIA data (cont.)

What problem(s) would it solve? (cont.)

- Reduces uncertainty of forest carbon stock estimates--pairing FIA plots with LIDAR results in precision equivalent to a 2-4x intensification of FIA plot density (Hughes et al. 2014)
- May be most attractive where hi-res LIDAR data are already available, or for rugged landscapes where plot intensification is impracticable
- Can be less expensive than intensifying field-based inventory: Washington DNR estimated per-acre cost reduction of 70-80% by using LIDAR/phodar-based forest inventory over field-based inventory (Gould & Strunk 2016)

Major limitations

- Most airborne LIDAR data are project-specific and collected piecemeal within a state, with differences in vintage, spatial resolution, and data format that must be reconciled to create a single LIDAR base map
- Space-borne LIDAR from NASA's Global Ecosystem Dynamics Investigation (GEDI) could be an alternative, but has its own limitations: it is coarser resolution, collects sample-based rather than wall-to-wall imagery, and will only collect data for 2019-21 during its current mission
- Phodar data must be paired with LIDAR to account for the effect of terrain on observed tree height



Source: Scott Hillard, MN Division of Forestry

Go deeper

CASE STUDY:

Maryland & Delaware

CASE STUDY:

Washington

This improvement option is also suitable for federal action. For more details, see ***Chapter 7: Federal Action****.*

CASE STUDY

Maryland & Delaware

What: University of Maryland (UMD) modeled carbon stocks in tree biomass across all land cover types using LIDAR data calibrated to field measurements from FIA and a complementary plot network established by UMD. UMD is now estimating annual forest carbon flux based on modeled gains and detected areas of loss from satellite data under a US Climate Alliance Technical Grant.

Earth Observing System 2019

Why: An annual inventory product based on LIDAR data and modeling will allow Maryland and Delaware to replace default SIT data in their GHG inventories with higher-resolution estimates that are spatially explicit and include trees outside of forests under the same methodology.

Results: Estimated carbon stocks and annual fluxes show good agreement with FIA methods in forest areas. Monitoring methodology expected to be completed in early 2021. Maryland is discussing plans to use the LIDAR-based inventory in place of SIT for its 2020 GHG inventory, to be released in 2021.

Limitations: Airborne LIDAR recollect data (or conversion to regularly-updated space-based LIDAR data source) will be necessary to limit growth in the margin of error for GHG flux estimates in subsequent years. LIDAR data are not available to determine a 1990 baseline for carbon flux in trees and forests without back-casting (see Baselines chapter).

Resources: High-resolution mapping of aboveground biomass for forest carbon monitoring

CASE STUDY

Washington

What: Washington State Department of Natural Resources (DNR) pursued multiple inventory improvements on 2.1 million acres of state-owned forest lands starting in 2014. Their methodology included 1) adding additional sampling plots, 2) acquiring LIDAR data that provided a high-resolution estimate of tree canopy height, and 3) acquiring phodar data to update aboveground biomass estimates at a lower cost than LIDAR.

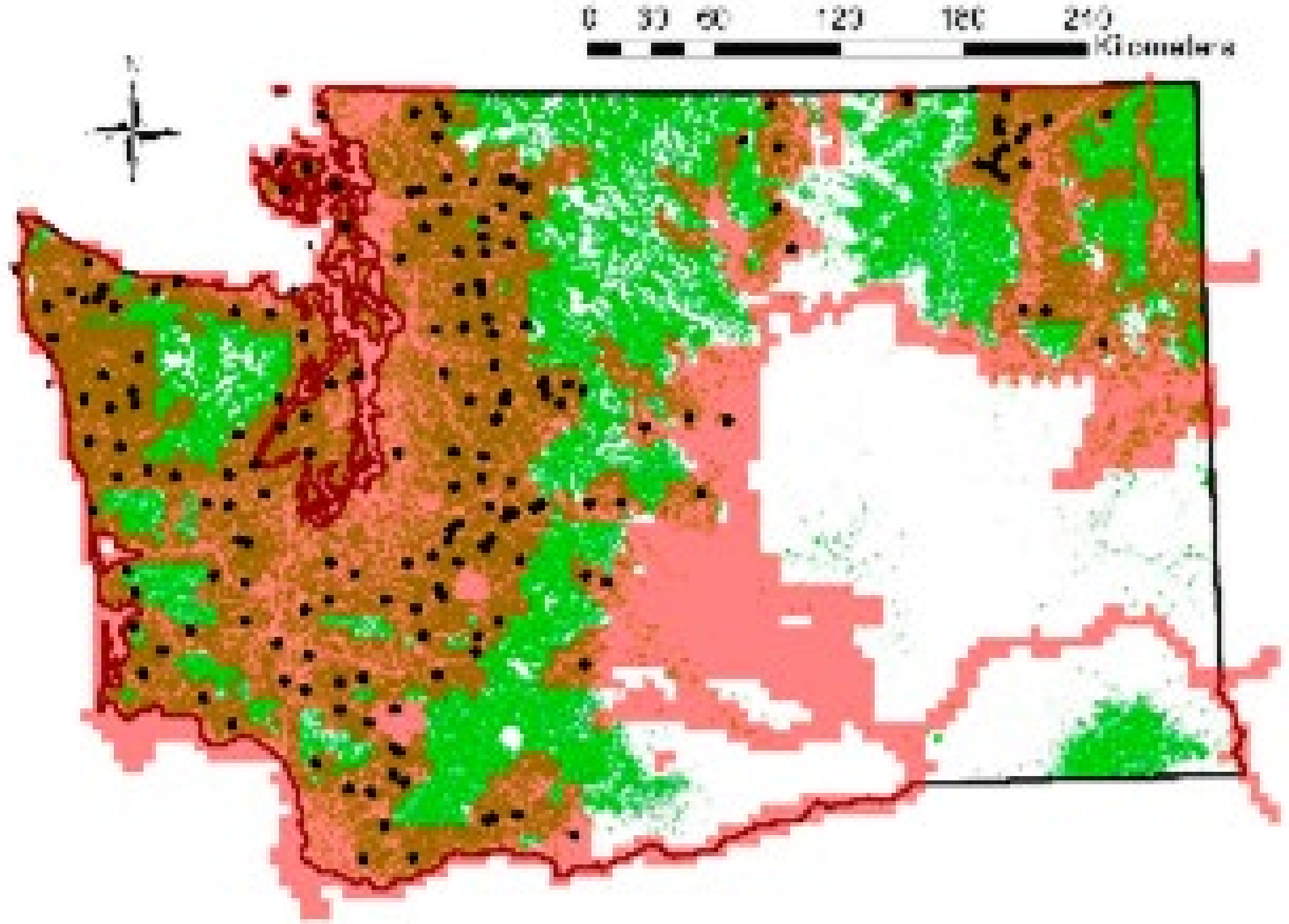
Why: Washington DNR wanted higher-resolution data on tree growth to support management of state-owned forest lands at the stand level (5-10 acres). FIA was both too coarse and remeasured too infrequently to capture effects of their management activities.

Results: Estimates of forest biomass using phodar and LIDAR terrain models were up to 4 times as precise as estimates without remote sensing.

Limitations:

- Methodology does not currently incorporate remeasurements of inventory plots as FIA does, so Washington DNR cannot contribute flux estimates to GHG inventories.
- Data collection does not include forest land under private or non-state public ownership, so additional data would be needed to integrate with a statewide GHG inventory.

Resources: Large area forest yield estimation with pushbroom digital aerial photogrammetry



Map shows overlay of state-owned forest (green), LIDAR-derived terrain model coverage (red), and approximate FIA plot locations (black dots). Image from Strunk et al. 2019

IMPROVEMENT 3

Increase statistical power of FIA plot network

OPTION A: INTENSIFY MEASUREMENT FREQUENCY

What would it entail?

- Sampling existing FIA plots more often
- State funding to supplement federal FIA funding
- Measurement intensification can be more costly in Western states due to longer travel times between plots (travel is largest component of cost)

Examples:

- California plans to spend $1.2M per year to increase FIA measurement frequency from 10 years to 5 years, plus $740K for initial prep work (totaling $2,750 per plot)
- Minnesota spends about $350K total per year to maintain 5-year measurement frequency (compared to 7-year standard for Eastern states) and double FIA plot density

What problem(s) would it solve?

- Reduces uncertainty in carbon flux estimates by measuring more plots each year
- Improves temporal resolution of carbon flux estimates by reducing remeasurement interval of plots
- Allows for more timely and precise estimation of forest carbon loss

Major limitations

- This approach includes all the limitations of the FIA program, including:
    - ➢ No spatially explicit maps of carbon flux because exact plot locations are kept confidential for landowner privacy
    - ➢ No year-to-year identification of disturbance events (FIA would still produce a rolling average of carbon fluxes over a number of years)
- No coverage for trees outside of forests
- Requires sustained state funding for additional FIA plot measurements (not a one-time investment)

IMPROVEMENT 3

Increase statistical power of FIA plot network (cont.)

OPTION B:
INTENSIFY PLOT DENSITY

What would it entail?

- Establishing new state sample plots linked with FIA, re-measured on the same time interval as other FIA plots in the state
- State funding to supplement federal funds for FIA sampling
  - ➢ Cost to establish a new plot is roughly equivalent to doubling the sampling frequency—with travel time between plots being the biggest determinant of cost

Examples:

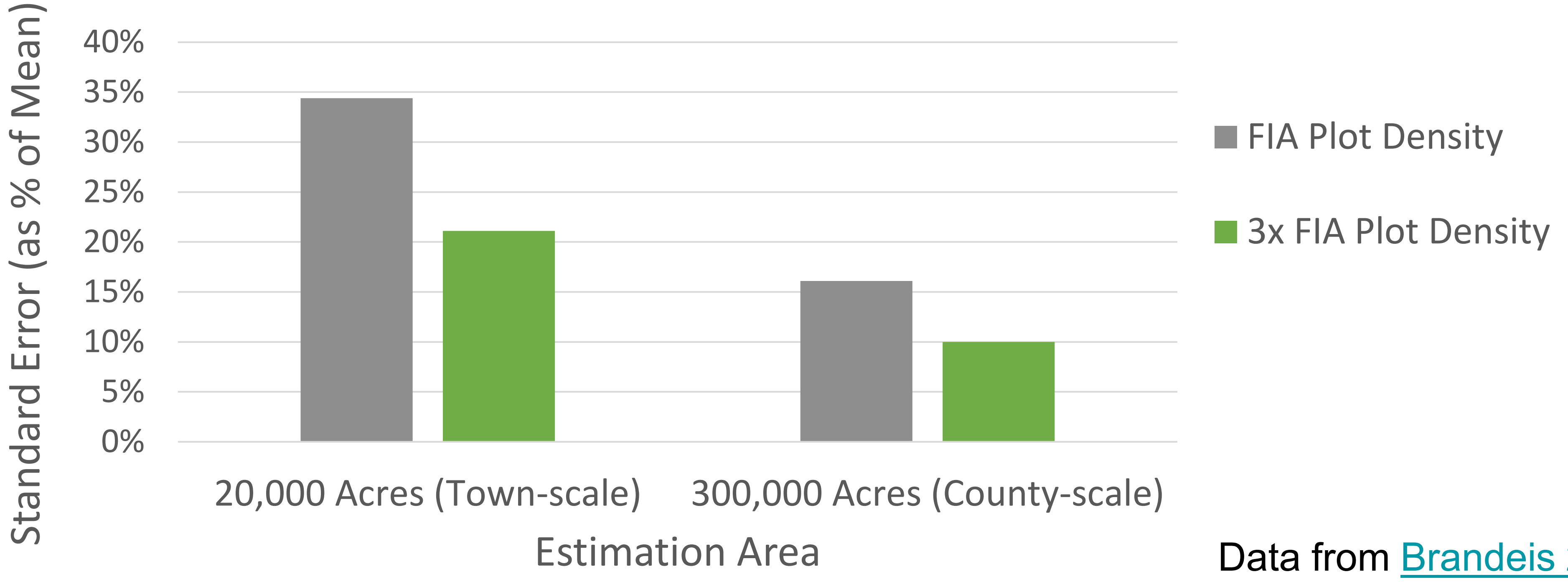
- Wisconsin spent $390,000 per year to double the density of FIA plots, to 7,500 total plots in the state (~$100 per additional plot)
- Washington spent $500 per plot for an inventory of state-owned forest lands (using similar approach but not integrated with FIA)

What problem(s) would it solve?

- Reduces uncertainty in carbon flux estimates
- Doubling plot density reduces uncertainty by 30% (Mark Rosenberg, personal communication)
  - ➢ A study in Hawai'i reduced standard errors for carbon stocks from 20-40% at standard FIA density (9 plots) to 10% at 4x FIA density (40 plots) (Hughes et al. 2014)
- Intensifying density improves spatial resolution of carbon flux estimates, enabling estimates at smaller scales (Brandeis 2003)

Major limitations – same as Option A

Uncertainty in Biomass Estimation at Small Spatial Scales



Data from Brandeis 2003

Go deeper

CASE STUDY:

Wisconsin

CASE STUDY

Wisconsin

What: Wisconsin has doubled the density of FIA plot measurements statewide in every inventory since 1996, at a cost to the state of $390,000 per year for 3,750 additional FIA plots

Why: Wisconsin had a goal to decrease sampling error to under 10% for county-level estimates of timberland in order to inform small-area forest management planning. Meeting that goal required spatial intensification to increase the number of inventory plots in heterogeneous areas (e.g. across different forest types or age classes).

Results: Doubling the FIA intensity increased the precision of FIA estimates for variables like species composition, timber volumes, tree mortality, and carbon stocks—making state-level estimates of carbon flux from FIA data more accurate. Wisconsin is also meeting its sampling error goal.

Limitations: Wisconsin has not published a statewide GHG inventory, limiting the application of the state's FIA intensification to forest carbon management or climate policymaking.

Image from FIA

IMPROVEMENT 4

Create a field-based inventory for urban trees

What would it entail?

- Develop a methodology to estimate statewide carbon flux in urban trees using a field-based ("bottom up") approach:
- Collect sample data on urban trees throughout the state—or compile existing data from state or federal agencies, universities, or municipalities
    - Sampling 200 one-tenth acre plots within a municipality typically allows for estimation of total urban tree stock with a relative standard error of 10-15%; sampling more plots or increasing plot size can reduce uncertainty further (Nowak et al. 2008)
- Analyze sample data and model carbon fluxes in urban areas, using a software tool like i-Tree Eco (freely available) or TreePlotter Inventory (proprietary)
    - Professional consulting services for a typical i-Tree Eco assessment could cost up to $40,000 for a 200-plot sample; using students or volunteers to collect data may lower costs
- Model carbon fluxes statewide, such as by integrating i-Tree Eco results with land use data from optical imagery (see Improvement 1)
- Software like i-Tree Canopy or i-Tree Landscape can assist with interpretation of optical imagery
- American Forests details additional tools in their Urban Forest Assessment Resource Guide

What problem(s) would it solve?

- Reduces uncertainty in carbon flux estimates—currently over 50% for urban trees in the National GHG Inventory
- Enhances accuracy and timeliness of carbon flux estimates for urban trees, which are based on 2015 land use data with no field plot calibration in the 2018 National GHG Inventory (and even older data in SIT)
- Increases spatial resolution of GHG flux estimates—can be downscaled to municipal level for local planning and policymaking

Major limitations:

- Combining different datasets (e.g. from existing municipal tree inventories) may increase methodological complexity to estimate statewide carbon flux in urban trees
- Field-based approach does not address the potential double-counting of FIA plots in urban areas (estimated to include 1.5% of plots) in the National GHG Inventory and SIT
- Regular remeasurement needed to provide accurate data on carbon flux in future GHG inventories
- Field-based inventories are time-intensive and costly to implement, posing challenges in keeping data timely

Go deeper

CASE STUDY:

California's urban forests

KEY TOOL:

i-Tree Eco

CASE STUDY

California’s urban forests

What: Researchers from the University of California-Davis and USDA Forest Service assessed carbon sequestration of urban trees in California using field data from Urban FIA plots and i-Tree Eco sample plots. The study calculated other co-benefits of urban trees using existing municipal street tree inventories and the i-Tree Streets model.

Why: Previous assessments relied on national data for tree attributes, which were not well-calibrated for California’s unique range of climates. This study aimed to identify priority areas for urban tree planting and refine estimates of statewide carbon stock change in urban forests.

Results: The study produced carbon sequestration maps for key urban areas in California. Total annual carbon sequestration was found to be 25% higher than the estimate in SIT. The study also estimated carbon storage in urban trees statewide, which CARB used as the anchor point for estimating annual carbon fluxes in urban forests for California’s 2018 NWL Inventory.

Limitations: The study provided a snapshot of carbon stocks and flux for one year but did not track changes over time. To estimate annual carbon flux, CARB uses geospatial data from Landsat-based canopy cover maps, census tracks, the National Land Cover Database (NLCD) and other sources, rather than updating its field data.

Resources: [Biomass, Carbon Sequestration, and Avoided Emissions: Assessing the Role of Urban Trees in California]

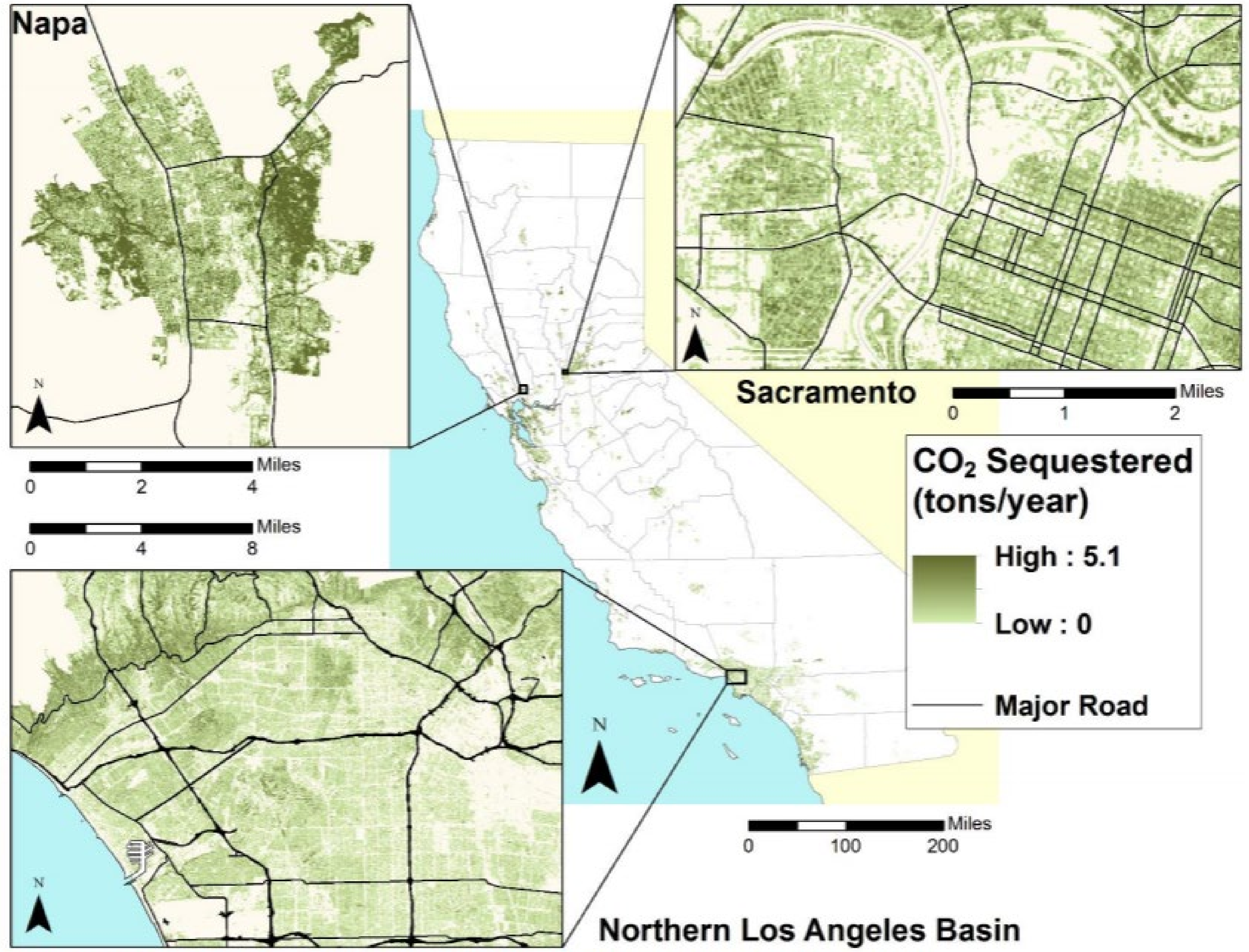


Figure 3-4. Estimated CO2 sequestered (tons/year/grid cell) within California urban areas (map).

Source: Bjorkman et al. 2015

IMPROVEMENT 5

Refine accounting of harvested wood products

What would it entail?

- Accessing timber product output (TPO) data from the USDA Forest Service or state-specific studies
    - ➢ Additional data collection may be required for some states, particularly about imports and exports from the state
- Using a model (e.g., WOODCARB II, as described in Skog 2008) to estimate carbon flux in wood products (both in use and in solid waste disposal sites)
    - ➢ Most models account for wood products made from timber *produced* in the state, whether they are consumed in or out of state (called the “production approach” for wood product accounting)

What problem(s) would it solve?

- Increases accuracy of carbon flux estimates in HWP, which accounts for one-sixth of all carbon removal in forests in the 2019 National GHG Inventory
    - ➢ The national carbon flux estimate for HWP has a margin of error of +/-18%, 3 times lower than the margin of error for other forest carbon pools
- Uses more timely HWP data than SIT

Major Limitations:

- Quantification of HWP carbon pools relies on a model that has not been tailored for use by states
- The production approach for HWP accounting makes assumptions about the fate of HWP exports that may not hold true, especially if exported wood is used to produce bioenergy– leading to possible overestimation of carbon sequestration in HWP

Go deeper

KEY CONCEPT:

Production approach

CASE STUDY:

California’s wood products

CASE STUDY

California's wood products

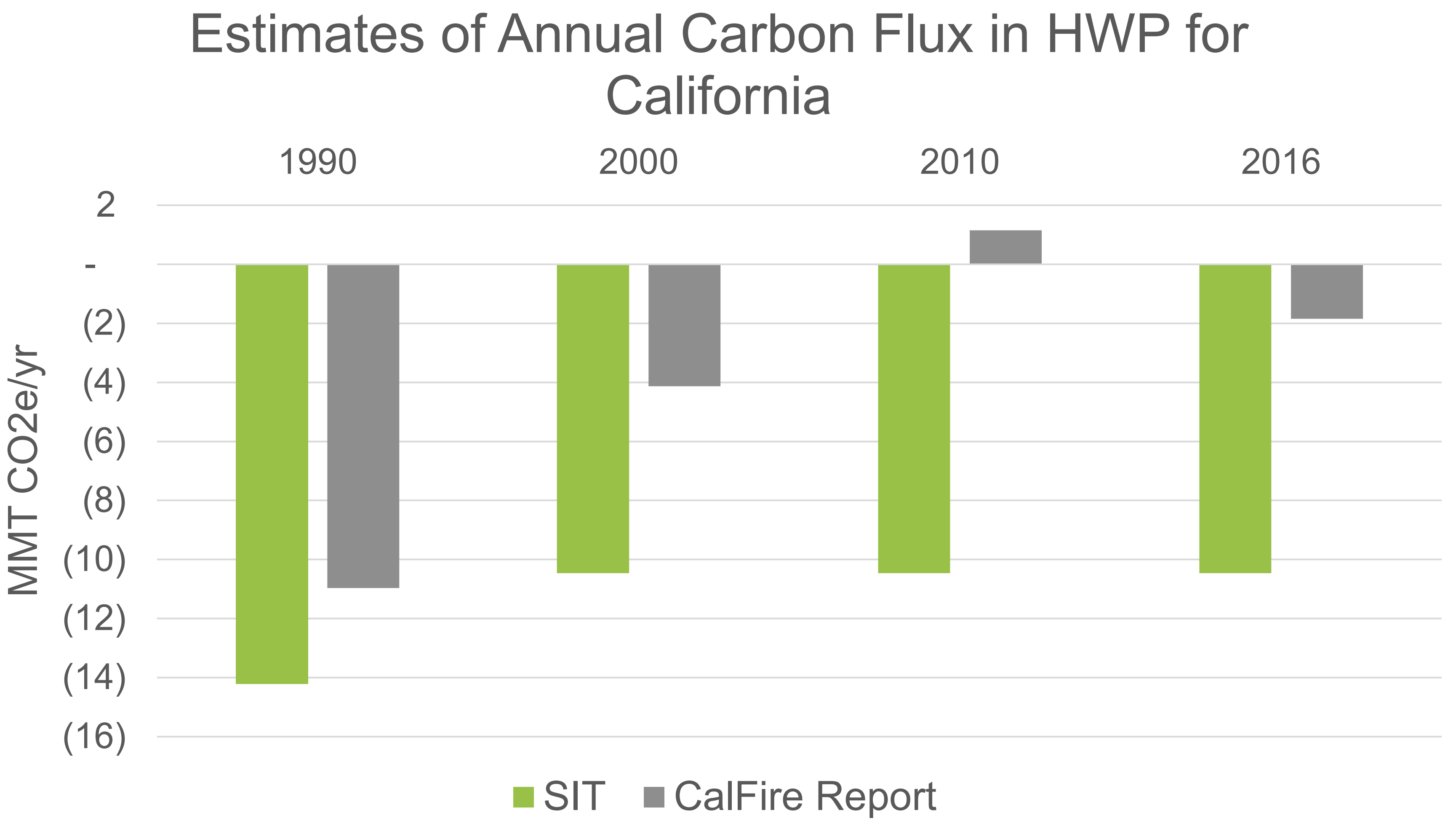
What: California Dept. of Forestry and Fire Protection (CAL FIRE) contracted the University of Montana's Bureau of Business and Economic Research to provide annual cumulative estimates of carbon in HWP from 1952-2017 using state-specific data and IPCC-compliant Production Approach accounting.

Why: Cal. Assembly Bill 1504 mandated that commercial harvesting regulations account for the carbon sequestration value of forest resources.

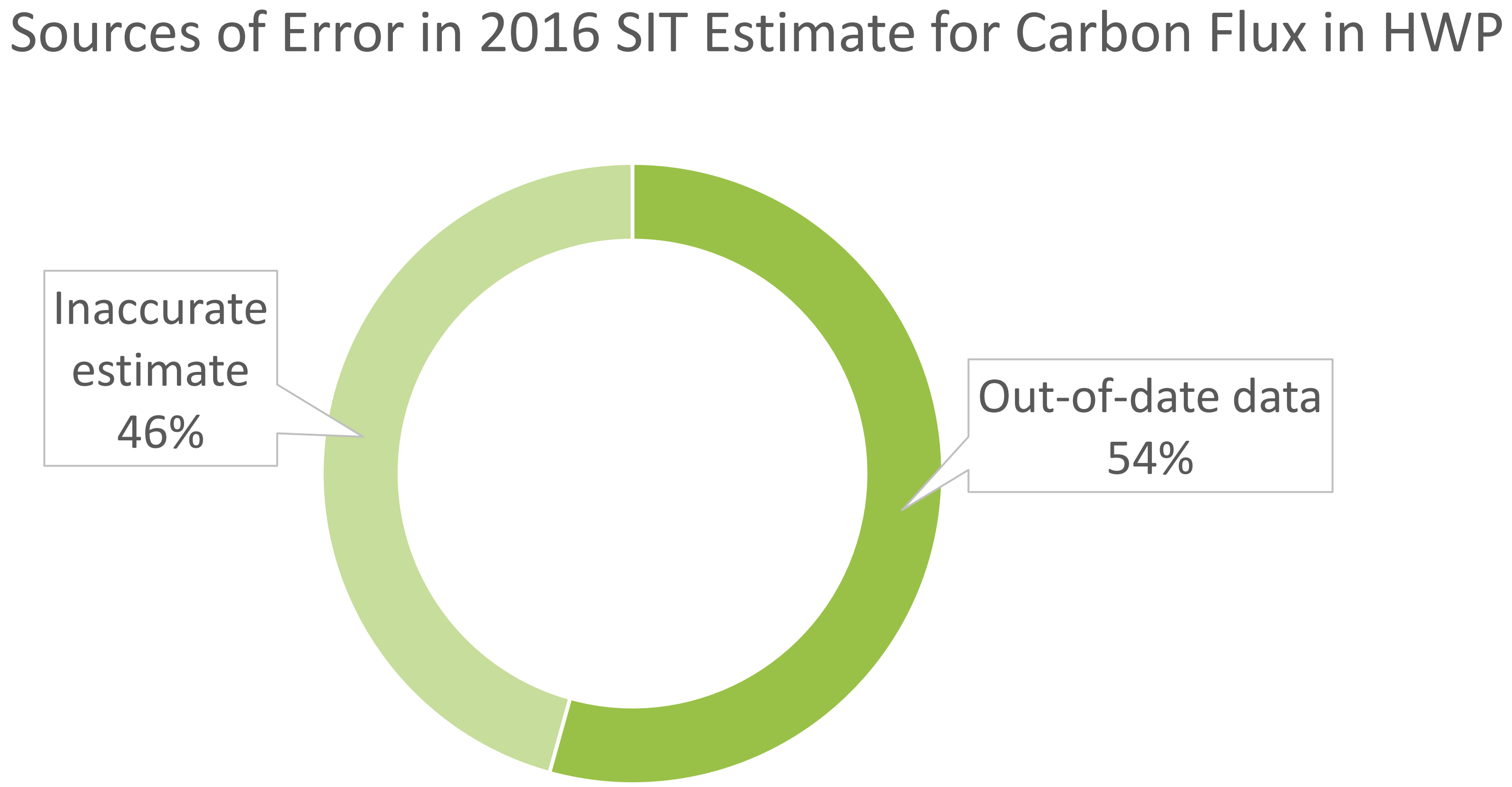
Results: CAL FIRE found that the net carbon sequestration in HWP was one-fifth of the same year's estimate from SIT default data, accounting for 6% of forest carbon flux. Harvesting volumes in the state have declined significantly in recent decades, making the outdated estimates in SIT highly inaccurate. CARB is now working with CAL FIRE to incorporate this HWP study into its NWL inventory.

Limitations: Carbon impacts from utilization of harvest by-products like slash, sub-merchantable biomass and bark are not included, but are likely to have negligible effects on overall carbon flux.

Resources: [AB 1504 California Forest Ecosystem and HWP Carbon Inventory](), [Estimates of carbon stored in HWP from USFS Southwest Region, 1909-2012]()



Estimates of Annual Carbon Flux in HWP for California



Sources of Error in 2016 SIT Estimate for Carbon Flux in HWP

Data from [Christensen et al. 2019,]()
2019 State Inventory Tool

Key takeaways

- SIT may not be adequate for some states' GHG inventory needs for Trees & Forests as of its 2019 update because it relies on outdated data sources, does not provide spatial or sub-state estimates of carbon flux, and does not quantify the uncertainty around its estimates.
- Data published by the USDA Forest Service in April 2020 improves upon current SIT default data by making its estimates more timely and consistent with the National GHG Inventory methodology for forests and urban trees. These data will be incorporated into the upcoming 2020 SIT update.
- States managing significant forest or urban forest resources, experiencing unplanned forest loss, or prioritizing climate policies for trees and forests may wish to make additional improvements to their GHG Inventory for Trees & Forests. These improvements can reduce uncertainty in carbon flux estimates for both standing trees and harvested wood products, improve the timeliness and resolution of data sources, allow attribution of carbon fluxes to specific causes, and enhance estimation techniques for trees outside forests.
- States can improve their GHG inventories for Trees & Forests by incorporating remote sensing data and tools (such as optical imagery or LIDAR), enhancing field-based inventories (through forest inventory intensification and urban tree sampling), and conducting state-specific modeling for harvested wood products. Some states may be able to leverage supplementary data resources that have already been collected for other purposes.

GOING DEEPER:

Key Concepts, Data Sources and Tools

KEY DATA SOURCE

Forest Inventory & Analysis (FIA)

EPA State Inventory Tool

What is it? Plot-based annual forest inventory administered by the USDA Forest Service. Continuous annual data have been collected since 2001 throughout the conterminous United States. Periodic data are collected for Hawai'i and the Pacific Islands (remeasurements of Hawai'ian plots expected to be complete in 2021). Addition of FIA plots in interior Alaska, which accounts for 15% of US forest land, began in 2016 and is expected to take 12-15 years.

What does it do?

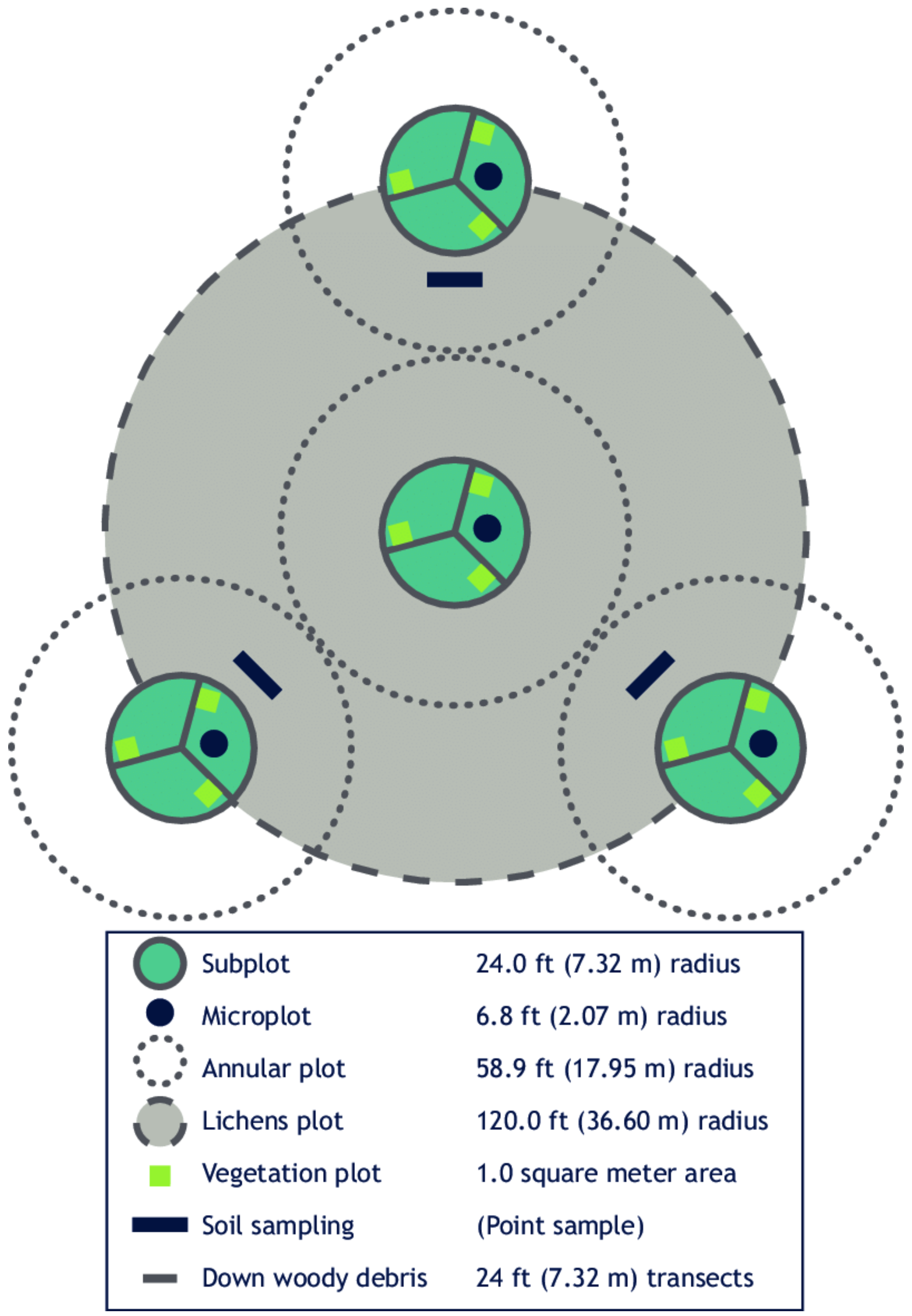
- Systematically re-measures forest stocks and other attributes (including forest type; site attributes; tree species, size, and condition) every 7-10 years on plots spaced every 6,000 acres across the lower 48 states and southern Alaska Statistically extrapolates plot-based measurements to produce biomass estimates over entire forest area
- Calculates annual forest carbon flux from biomass estimates using a stock-change approach

Relevance for NWL inventories: FIA data are used to estimate forest carbon in the National GHG Inventory and SIT.

Limitations:

- FIA “annual” carbon flux estimates are actually rolling averages from measurements over 7-10 years, obscuring the effects of short-term events like wildfire and making it challenging to attribute fluxes to specific causes.
- FIA plot locations are “fuzzed” to protect information on private lands, meaning the data are not spatially explicit
- FIA does not systematically collect data on trees outside forests. (A new Urban FIA program is collecting data in 35 cities, with plans to include the most populous 100 US cities, but this program does not yet have sufficient data available to inform a GHG inventory at the state or national level.)

Resources: FIA Factsheets; The Enhanced FIA Program—National Sampling Design and Estimation Procedures



FIA plot diagram from Janowiak et al. 2017

KEY DATA SOURCE

Passive remote sensors (“optical” imagery)

Integrate optical imagery with FIA data

What is it? Imaging devices attached to a satellite or aircraft that can be used to identify land cover on the ground (see next page for details on different remote sensors).

Satellite Imagery	Aerial Imagery
Typically moderate to coarse spatial resolution (10-250m)	Typically finer resolution (up to ~1m)
Quick return time (1-8 days)	Annual or ad-hoc return times
Global extent	National or subnational extent
Examples: Landsat, Sentinel, MODIS	Example: NAIP

What does it do? Sequences of images over time can be used to monitor land cover change over time and can be paired with field data to extrapolate carbon flux estimates over large areas.

Relevance to NWL inventories: Databases including FIA, the National Resources Inventory (NRI) and the National Land Cover Dataset (NLCD) use optical imagery data to assess land use. All of these datasets contribute to the assessment of the US land base in the National GHG Inventory. States may use optical imagery data to assess land use and land use change or map forest disturbances like wildfire or harvesting.

Limitations: Optical imagery data requires processing in order to support NWL inventories, which can entail significant added costs. States may contract for custom data processing or rely on existing tools, including free tools like LANDFIRE (for land use, vegetation and forest disturbances) or i-Tree Landscape (for urban tree canopy).

KEY DATA SOURCE

Passive remote sensors (cont.)

Dataset name	How it works	Typical resolution	Available extent	Data costs (not including processing)	Limitations
Landsat	Several reflected visible and infrared bands of spectrum are collected, which can be processed to ID land cover	30m	Nearly global; consistent operation since 1970s; 8-day return interval	Freely available for download; often processed info available (e.g. GFW)	Can't penetrate clouds; data gaps over some time periods
MODIS	Collects narrower bands of spectrum; special tools for detecting fires	250m	Nearly global; 1-2 day return interval	Free	Lower resolution; Specialized processing required
Google Earth	Composite of data sources and time intervals	Up to a few meters	Global; up to 6 month return interval	Free	Return interval and consistency
Hyperspectral	Collects hundreds of narrow bands, revealing information about plant health, etc.	1-25m, depending on sensor	Custom	Very high	Can't penetrate clouds
National Agricultural Inventory Program (NAIP)	Aerial imagery collected biannually during crop growing season; as of 2018, 3D imagery was processed for some states	60cm (1.2m for 3D height maps)	Entire US	$0.30-$1.00/sq mi (<$0.01/acre)	Lower frequency of data collection

KEY TOOL

LANDFIRE

California Natural and Working Lands Inventory

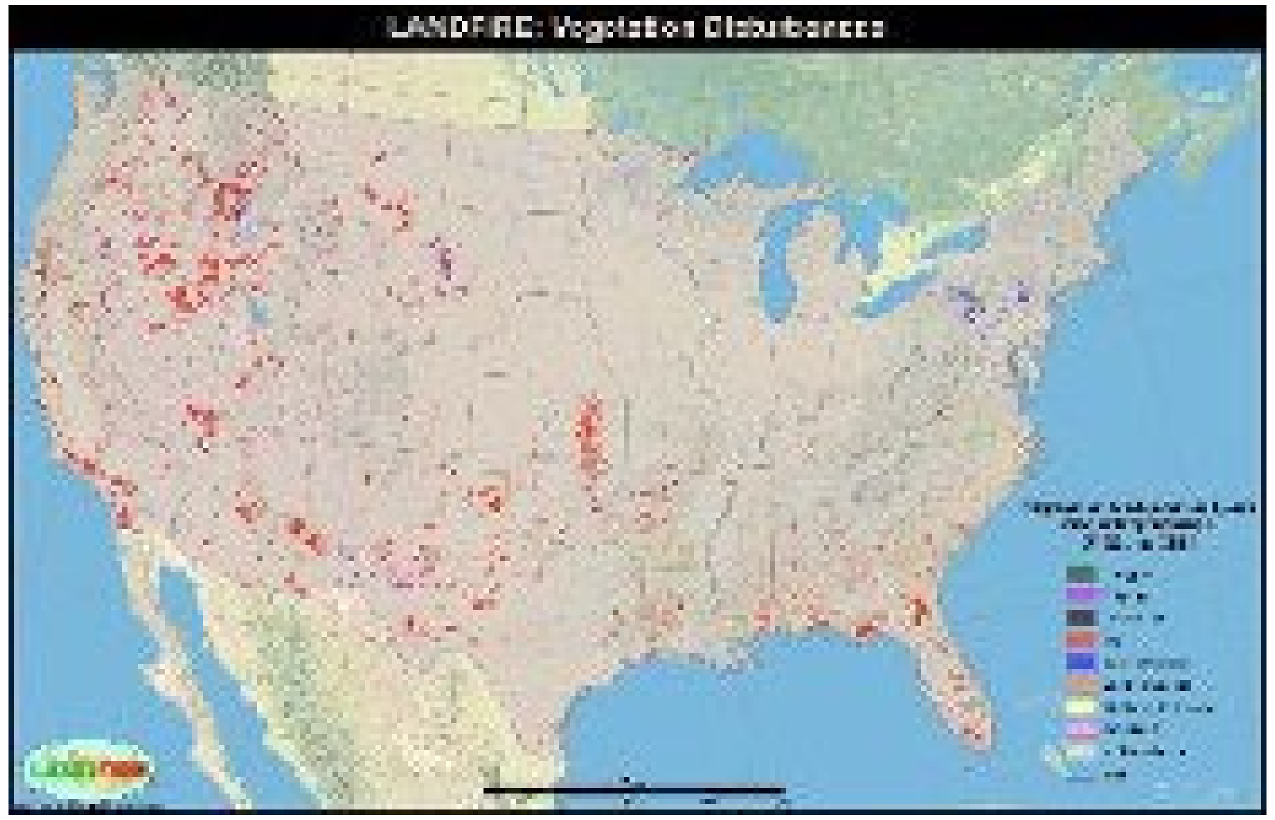
What is it? Free tool produced jointly by Forest Service and Dept. of Interior in partnership with The Nature Conservancy that includes geospatial data layers for land use and land use change, vegetation type, canopy cover and tree height, and disturbance events such as wildfire.

What does it do? Integrates data derived from remote sensing layers and products including Landsat imagery, the National Land Cover Database (NLCD), Cropland Data Layer, and Monitoring Trends in Burn Severity; as well as reference plots from FIA. Data are available from ~2001 through 2016 for the conterminous US, with the latest data for Alaska and Hawai'i expected by 2021. Updated data through 2019 is planned for release in summer 2021, with annual data releases to follow.

Relevance for NWL inventories: Land use, tree height and disturbance data from LANDFIRE can be combined with FIA data or other field measurements to estimate carbon fluxes in trees and forests on a landscape scale. Advantages over estimates based solely on FIA data include the spatially explicit nature of LANDFIRE data and the ability to attribute forest loss to specific disturbance events.

Limitations: Data processing needs limit the timeliness of LANDFIRE, with a 2- to 3-year time lag between data collection and release. Advances in the vegetation classification scheme in recent releases (e.g. LANDFIRE 2.0) make comparisons to earlier data products more challenging. California found that LANDFIRE under-represented timber harvests in that state.

Resources: LANDFIRE Program, LANDFIRE 2.0 Remap



KEY DATA SOURCE

Active remote sensors (e.g. LIDAR)

Integrate LIDAR/phodar with FIA data

What is it? Sensors that project light or energy to Earth's surface and measure qualities of returned signal (see next page for details on different remote sensors).

- Light detection and ranging (LIDAR) data are typically collected from specialized aircraft, but NASA's recently-launched Global Ecosystem Dynamics Investigation (GEDI) installed a device on the International Space Station to collect space-based LIDAR
- An alternative to LIDAR is digital aerial photography, also known as photogrammetry or "phodar," which constructs composites of overlapping optical imagery to produce 3D images

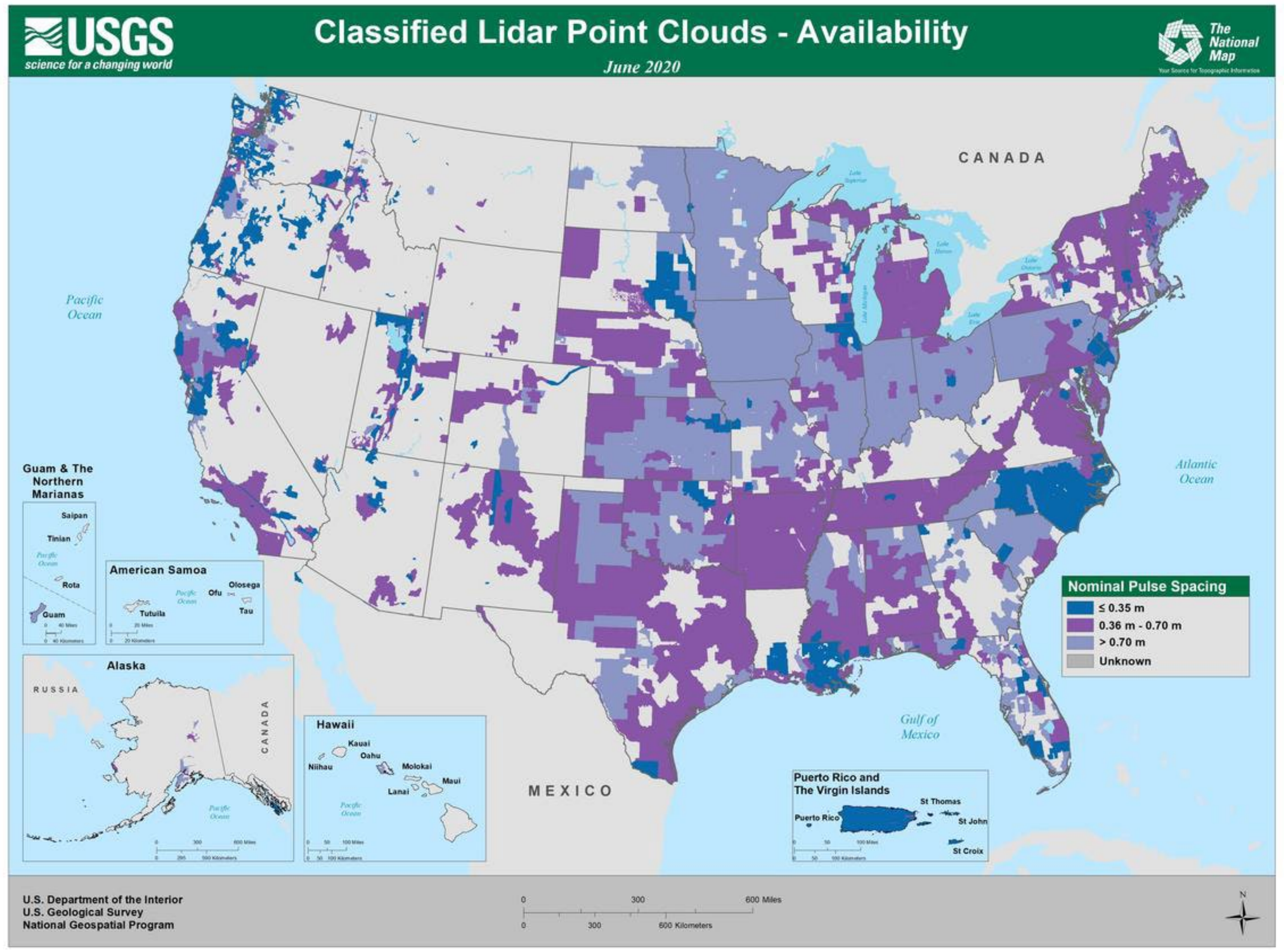
What does it do?

- Provides data on tree height and forest structure along with terrain and elevation
- Can be calibrated with FIA or other field data to produce maps of tree biomass

Relevance for NWL inventories: Many states already have partial or full LIDAR data coverage (see figure at right) and could leverage existing data to create spatially explicit GHG inventories across all land use types.

Limitations: LIDAR and phodar data require costly data processing to be useful for NWL inventories. Existing LIDAR data often comprises a patchwork of collection years and data resolutions, making integration challenging for statewide analysis, while collecting new LIDAR data requires significant investment.

Resources: US Geological Survey 3D Elevation Program, US Army Corps of Engineers LIDAR resource



USGS 2019

KEY DATA SOURCE

Active remote sensors (cont.)

Name	How it works	Typical resolution	Available extent	Data costs (not including processing)	Limitations
Airborne LIDAR	Laser range finder mounted on airplane; complex post-processing of data	Sub-meter to 10m	Custom; already available in many states (see map on previous slide)	$0.50-$3.00/acre for new data; lower for existing data (USGS 3D Elevation Program)	Coverage limited by flight; most datasets are project-specific and may not interface well at the state level (different vintages, resolution, etc.)
Spaceborne LIDAR, e.g. NASA's Global Ecosystem Dynamics Investigation, or GEDI	Same as airborne, but mounted on satellite	25m-1km grid	Entire US (minus Alaska) - between 50 deg. N & 50 deg. S	Free	1-year data collection mission; data format requires different algorithms than airborne LIDAR to assess carbon; limited use for small-scale analysis due to coarse resolution
Synthetic Aperture Radar (SAR), e.g. TanDEM-X	Similar to spaceborne LIDAR, but uses radiowaves instead of laser	1-10m	Global; several sensors in operation >10 yrs	Varies; some processed imagery is free; custom products vary by project	Can require specialized expertise to extract and use data effectively
Photogrammetry or "Phodar"	Aerial photography processed similar to LIDAR data	Sub-meter in many cases	Custom; can access photo archives already available in many states	<$0.01-$0.05/acre	Can't penetrate clouds; can require specialized technical approaches to observe forest structure and account for effects of terrain on observed tree heights

KEY TOOL

i-Tree Eco

Create a field-based inventory for urban trees

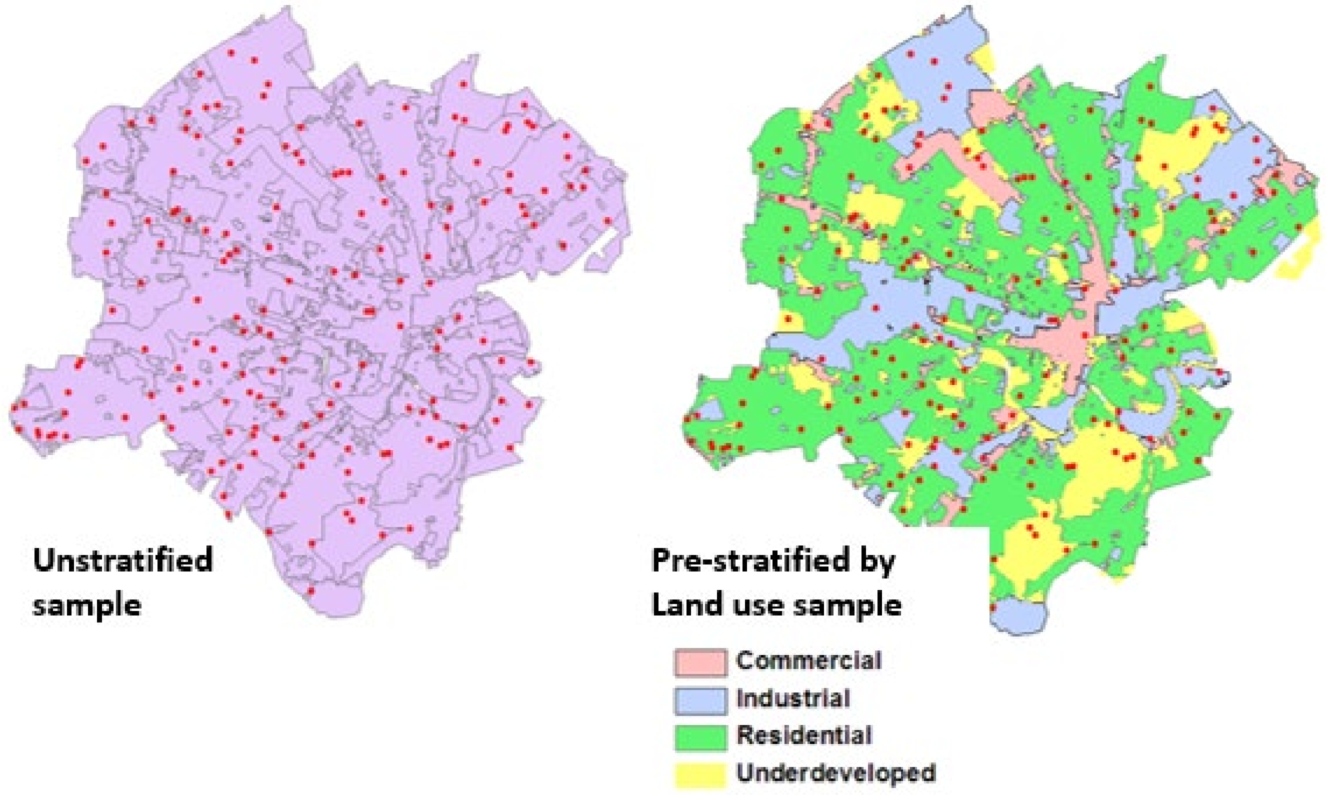
What is it? A software application from the USDA Forest Service designed to use field data collected from single trees, sample plots, or complete inventories to quantify forest structure, carbon sequestration and storage, and other ecosystem services. i-Tree Eco (formerly known as UFORE) is part of the i-Tree suite of peer-reviewed software tools.

What does it do? i-Tree Eco provides sampling and data collection protocols along with a web-based data collection system. i-Tree Eco automatically processes user-entered tree measurements and field data with hourly weather and air pollution data to calculate structural and functional information for the urban forest, including carbon sequestration. i-Tree Eco also includes a new forecast module that can project carbon sequestration and other urban forest benefits into the future.

Relevance to NWL inventories: Results from i-Tree Eco for different municipalities within a state can be paired with land use data from optical imagery to estimate carbon fluxes in urban trees statewide.

Limitations: i-Tree Eco is targeted to the urban forest level and so does not produce state-level results. (Future integration with i-Tree Landscape, a tool that uses National Land Cover Database and US Census data to estimate carbon sequestration at the state level, may address this gap.)

Resources: i-Tree Eco overview; Step-by-step guide to taking urban forest inventory measurements



i-Tree Eco data collection protocols allow for the study area to be subdivided or "stratified" into units that allow for comparisons between land uses, political boundaries, or other units of interest.

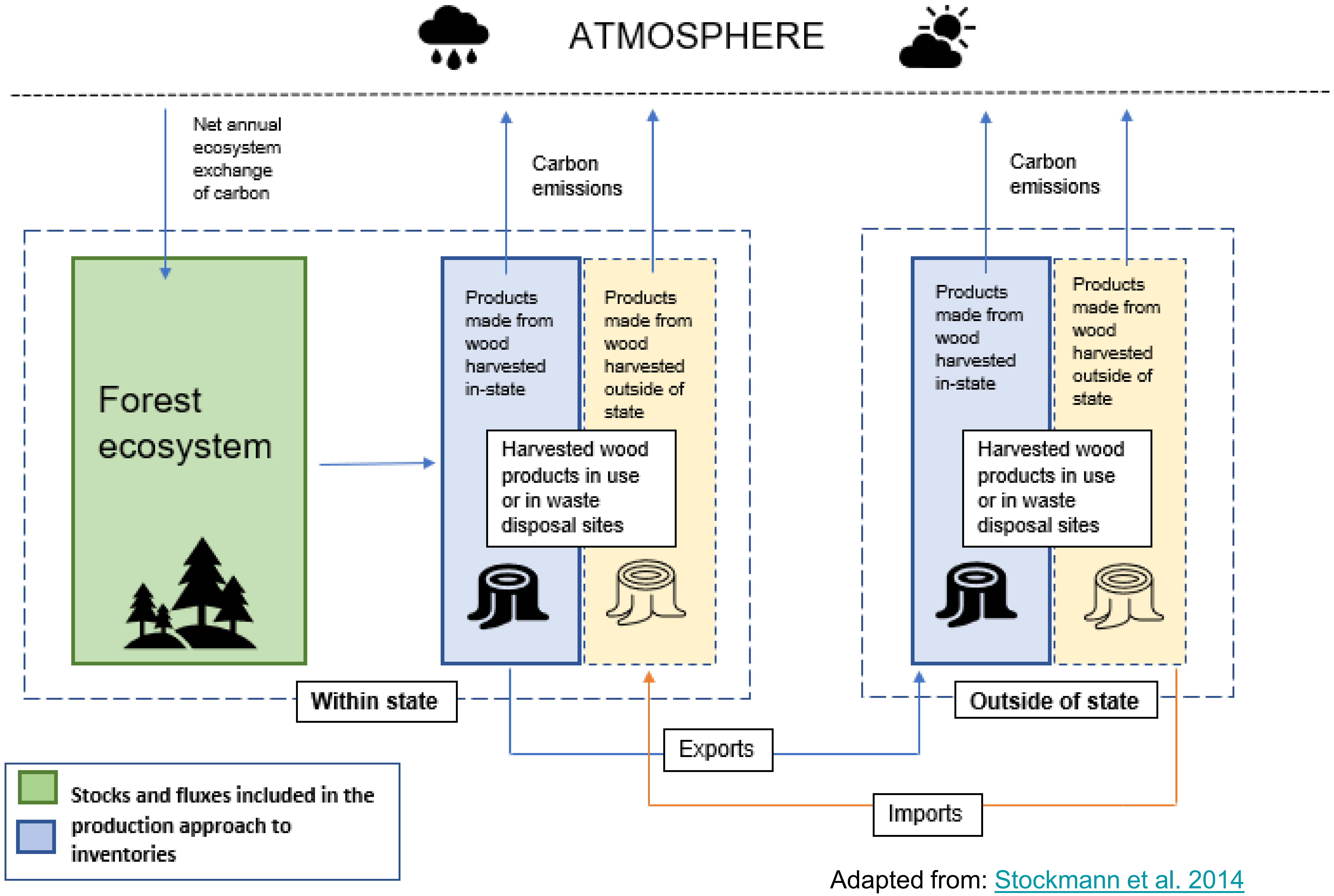
Source: i-Tree Eco Sample Inventories

KEY CONCEPT

Production approach to carbon inventory for HWP

Refine accounting of harvested wood products

The production approach to harvested wood product (HWP) accounting includes carbon emissions and removals from wood that was harvested within the state or region, regardless of where the wood was used or disposed of. This is the standard approach for IPCC reporting.



Adapted from: Stockmann et al. 2014

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CHAPTER 3: CROPLANDS & GRASSLANDS

Guide at a Glance

Chapter	Topic	Purpose
1	Overview	Understand basic concepts and identify inventory priorities for your state *(designed for state policymakers and agency staff)*
2	Trees & Forests	Deep dives into inventory improvement options across land use classes *(designed for agency staff)*
3	**Croplands & Grasslands**	**Deep dives into inventory improvement options across land use classes *(designed for agency staff)***
4	Land Use Change	Deep dives into inventory improvement options across land use classes *(designed for agency staff)*
5	Wetlands	Deep dives into inventory improvement options across land use classes *(designed for agency staff)*
6	Baselines	Deep dive into options for creating a historical or projected inventory baseline *(designed for agency staff)*
7	Federal Action	Overview of inventory improvement options that require action by Congress or federal agencies *(designed for state policymakers)*

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- Improvement 4: Create a network of soil carbon monitoring plots……………………..…....97

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Executive Summary: The Issue

Cropland and grassland soils serve as both a carbon sink and a source of GHG emissions. Including accurate estimates of annual greenhouse gas (GHG) fluxes in cropland and grassland soils in GHG inventories allows states to track progress in enhancing carbon sequestration in these systems and monitor the impacts of Healthy Soils programs or other policies that incentivize climate-friendly land management activities. Currently, however, the United States does not have a monitoring system that directly measures GHG fluxes in croplands and grasslands. Instead, estimates are derived by modeling the GHG fluxes associated with various soil management activities, which are tracked through the National Resources Inventory (NRI). The national data are downscaled and provided to states through the EPA State Inventory Tool (SIT). This approach has several limitations:

- **Margins of error are large.** The uncertainty reported in the National GHG Inventory for carbon flux in croplands and grasslands is many times larger than the estimate itself, making it uncertain whether U.S. agricultural lands are a net sink or source of CO_2 (not including other GHG emissions like N_2O).
- **Activity data on soil management are not timely.** The NRI is only updated every three years and is subject to an additional three-year time lag before data are released. As states encourage growth in climate-friendly agricultural practices, out-of-date activity data in their GHG inventories will become increasingly problematic.
- **Land area coverage is incomplete.** NRI excludes federal lands and lands enrolled in the Conservation Reserve Program after 2012, meaning some states will not be able to monitor all their agricultural lands using this dataset.
- **Land use categories are not disaggregated in SIT.** SIT does not report GHG fluxes according to standardized IPCC land use categories and instead aggregates carbon flux estimates for croplands and grasslands, obscuring different GHG dynamics between those systems.

Executive Summary: Solutions

The expected addition of state-level time series data on croplands and grasslands to the National GHG Inventory by 2022 will subsequently allow SIT to **disaggregate data for croplands and grasslands** in accordance with IPCC land use categories. In the interim, however, states could produce their own disaggregated estimates of GHG fluxes in croplands and grasslands, which would enable them to track the climate impacts of these land uses separately. The easiest way for states to produce their own estimates would be to work with an experienced partner like Colorado State University, which already processes NRI data using DAYCENT for the National GHG Inventory. This improvement would make state inventories more consistent with the reporting structure in the National GHG Inventory.

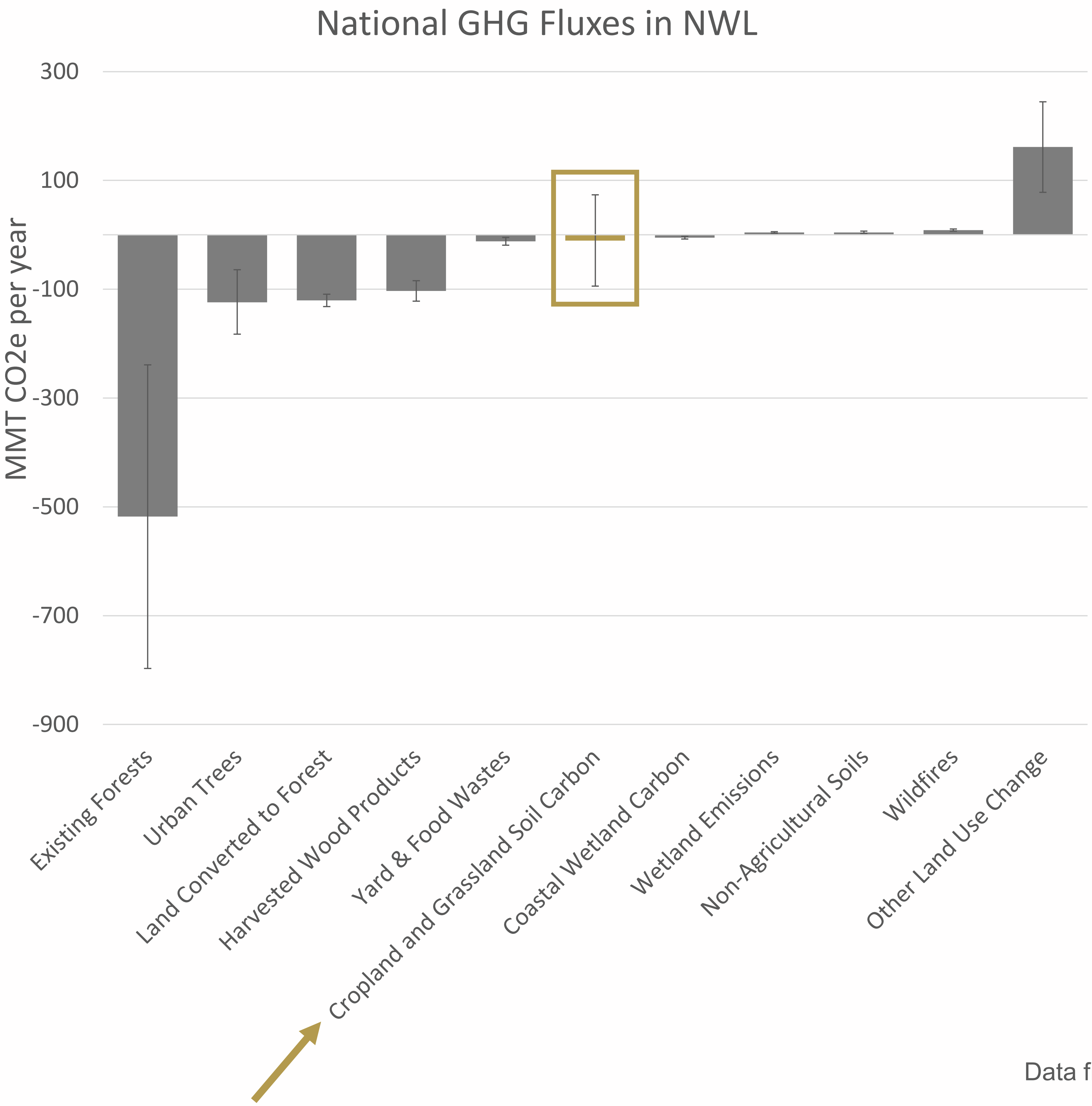
States seeking to use their GHG inventory to monitor and encourage adoption of agricultural management practices like cover cropping or conservation tillage may pursue additional inventory improvements that reduce uncertainty and enhance the spatial resolution of activity data. Possible improvements include **using remote sensing tools for croplands, expanding transect surveys,** or **instituting farm-level reporting** on management activities. This chapter details these improvement options, including examples of how **Minnesota** and **Delaware** have implemented some of these strategies to track adoption of key management practices.

This chapter also details how a state could reduce uncertainty in its own GHG modeling estimates by **creating a plot network for soil carbon monitoring**. This improvement option would be more impactful and cost-effective if pursued at the national level, however, by requesting federal action to **monitor soil carbon through national field networks** as recommended by the National Academy of Sciences. A robust monitoring system could be implemented by sampling and analyzing soil carbon at a subset of existing NRI plots on an annual rotation, similar to the process employed by the Forest Inventory and Analysis (FIA) program to estimate forest carbon stocks. Annual measurements of soil carbon stock changes would improve the accuracy of estimates in the National GHG Inventory as well as state inventories that adhere to the same methodology. This improvement is discussed further in *Chapter 7: Federal Action*.

Prioritizing inventory improvements for croplands & grasslands

While the national GHG flux in **cropland and grassland soils** is small, those soils may represent a significant GHG source or sink for individual states. States with large areas of managed cropland or grassland, or significant potential to reduce net GHG emissions by implementing soil management practices, should consider prioritizing inventory improvements in this chapter.*

*NOTE: GHG emissions from agricultural soil management, manure management, and enteric fermentation are accounted for in the Agriculture section rather than the land use, land use change and forestry (LULUCF) section of the National GHG Inventory and SIT. This Guide therefore does not address estimates for those emission sources, but states may wish to consider them in identifying priorities for inventory improvement.



Data from EPA 2019b

DEFAULT APPROACH

EPA State Inventory Tool

What does it include?

- State-level estimates of carbon flux in cropland and grassland soils downscaled from the National GHG Inventory
    - Soil carbon flux estimates in the National GHG Inventory are produced using land use histories and land management activities (known as “activity data”) from the National Resources Inventory (NRI) and other supplemental federal data, paired with biogeochemical modeling from the Daily Century Model (DAYCENT)
- N_2O and CH_4 emissions in agriculture are estimated with a different, bottom-up approach, and reported separately in the SIT Agriculture module (not addressed in this Guide)

See next page for more information on key concepts, data sources and tools that underlie GHG estimation in SIT.

Major limitations

- No measures of uncertainty provided in SIT, but margin of error is significant at the national level
    - Agricultural land use categories have a combined margin of error of 142 MMT CO_2--equal to 20% of total NWL carbon flux
- Default data are not up-to-date
    - SIT uses NRI data through 2012 from the previous National GHG Inventory and extrapolates 2013-17 data using linear regressions, while most recent National GHG Inventory has been updated with NRI data through 2015
- SIT does not report carbon fluxes in croplands and grasslands according to IPCC land use categories as the National GHG Inventory does
    - Carbon flux from croplands, grasslands, and land use change are reported as a single line item
- Carries over exclusion of federal lands and lands enrolled in the Conservation Reserve Program (CRP) after 2012 from the National GHG Inventory, which may result in incomplete coverage for some states

DEFAULT APPROACH

EPA State Inventory Tool: Data underlying SIT

The methods that SIT and the National GHG Inventory use to estimate GHG fluxes in cropland and grassland soils are complex. The following key concepts, data sources and tools break down the reasons for that complexity and explain how these estimates are calculated:

KEY CONCEPT: Spatial and temporal variability of soils

KEY DATA SOURCE: US Soil Survey

KEY TOOL: DAYCENT

KEY CONCEPT: Direct vs proxy measurement

KEY DATA SOURCE: National Resource Inventory (NRI)

BASIC IMPROVEMENT

Disaggregate National GHG Inventory data

What does it entail?

- The National GHG Inventory team plans to publish soil carbon flux time series data for croplands and grasslands at the state level starting in 2021 or 2022
    - ➢ This improvement will subsequently allow SIT to disaggregate soil carbon flux data between croplands and grasslands, consistent with IPCC land use categories
- In the interim, states could produce their own disaggregated cropland and grassland data by working with an experienced partner like Colorado State University (CSU), which produces GHG flux estimates for croplands and grasslands in the National GHG Inventory
    - ➢ State-level estimates of soil carbon flux in croplands and grasslands for the current inventory year can be found in Annex 3 (Tbl. A-218) of the National GHG Inventory
    - ➢ CSU would require modest additional resources for data processing and validation to extend those estimates over the whole inventory time series (starting in 1990) and calculate the margin of error associated with state-level estimates

What problem(s) will it solve?

- Makes state-level estimates more timely (could use NRI data through 2015 now, or through 2018 after new NRI data are released, expected in late 2021)
- Reports carbon fluxes according to IPCC land use categories, consistent with National GHG Inventory
- Custom analysis could quantify uncertainty around state-level estimates of cropland and grassland soil carbon flux

Major limitations

- This approach carries all the limitations of the NRI program, including:
    - ➢ Lag time in NRI data means that actual data are not available for last 3+ years (National GHG Inventory models these years based on previous data)
    - ➢ No sub-state or spatially explicit estimates of carbon flux
- Scarcity of field data on soil carbon means that GHG flux estimates are modeled, not measured
- Data produced by CSU or another partner may not align exactly with state-level data in the National GHG Inventory

Beyond National GHG Inventory data: Why pursue additional improvements for Croplands & Grasslands?

- **Improve timeliness** of activity data
  - *Particularly important for states experiencing significant growth in soil management practices like cover cropping or no-till, or that want to incentivize such practices through a Healthy Soils program*

- **Reduce uncertainty** around soil carbon estimates
  - *Particularly important for states prioritizing management of soil carbon stocks in croplands and grasslands*

- **Enhance spatial resolution** of activity data
  - *Particularly important for states that want to manage soil carbon stocks at a sub-state level or use their NWL inventory to track project performance, such as for a Healthy Soils program*

- **Improve accuracy of models** that estimate GHG fluxes attributed to land management activities
  - *Particularly important for states with significant spatial variability in soils, or soil management activities that are not common nationally*

CROPLANDS & GRASSLANDS

Additional Improvements

	IMPROVEMENT 1	IMPROVEMENT 2	IMPROVEMENT 3	IMPROVEMENT 4	FEDERAL ACTION
Improvement Objective	Integrate remote sensing for croplands	Expand transect surveys	Institute farm-level reporting	Create a network of soil carbon monitoring plots	Monitor soil carbon through national field networks
Reduce uncertainty	✓	✓	✓	✓	✓
Improve timeliness of activity data	✓	✓	✓		
Enhance spatial resolution for activity data	✓				
Improve accuracy of GHG fluxes modeled from activity data				✓	✓

IMPROVEMENT 1

Integrate remote sensing for croplands

What would it entail?

- Using satellite imagery paired with machine learning algorithms and field data to identify and monitor soil management practices
- Initial upfront investment in developing a remote sensing tool or adapting an existing one (e.g. OpTIS) for state-specific conditions, including crop types and prevailing management practices
- Remotely sensed practice data would feed into a biogeochemical model such as DAYCENT to estimate GHG fluxes

What problem(s) would it solve?

- Provides timely, spatially explicit data on the year-to-year deployment of specific land management activities
- More refined activity data could reduce uncertainty around GHG flux estimates

Major Limitations

- Some error remains in modeled relationship between surface residues and activity data, and in cases where imagery is missing or poorly timed
- Current remote sensing-based systems only track certain management activities (e.g. cover cropping, no/reduced-till)--but other practices may also impact GHG fluxes in soils

Go deeper

KEY TOOL: Operational Tillage Information System (OpTIS)

CASE STUDY: Minnesota

CASE STUDY

Minnesota

What: Minnesota Board of Water and Soil Resources (BWSR) developed a tillage and erosion survey program using satellite imagery and transect survey data to analyze key metrics for agricultural soil and water management (including tillage trends, cover crop adoption, and soil loss due to erosion), replacing a purely field-based transect survey approach.

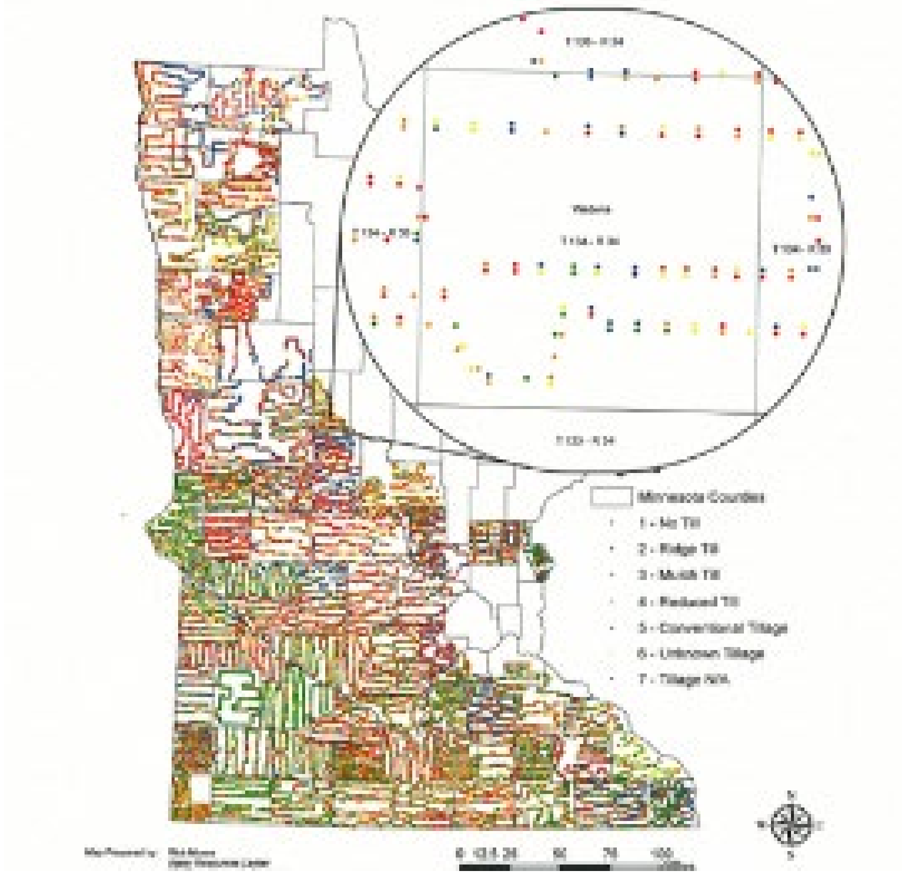
- Historical satellite data allowed Minnesota to fill in gaps for years when transect surveys were not conducted
- Looks at indicators like soil erosion on a daily as well as annual timestep to target need for conservation practices
- The cost of the remote sensing program is similar to the previous transect program—about $150-180,000—but provides better data and saves staff time

Why: Remote sensing integration seen as key for a cost-effective, long-term monitoring program in support of agricultural conservation programs

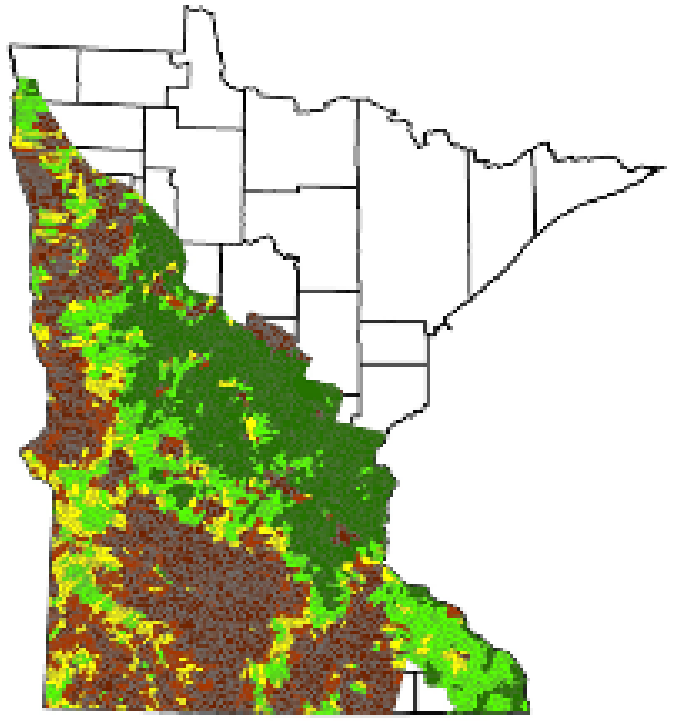
Results: Remote sensing provided greater spatial and temporal resolution, allowing BWSR to track metrics on a watershed scale rather than a county scale (see right) and better analyze trends over time. Costs are comparable to old transect survey program, with less staff time required.

Limitations: Weather variability can challenge spring data collection (after snowmelt, before seedlings emerge, without cloud cover). Activity data could reasonably be used to calculate carbon sequestration but not N_2O emissions from croplands. At this time, the project is not linked to Minnesota’s GHG inventory, which does not estimate carbon sequestration in cropland soils.

Resources: [Assessing Soil Residue Cover, Cover Crops and Erosion using Remote Sensing and Modeling]



Previous transect-based approach



Current remote sensing-based approach

Top: Tillage Transect Survey 2007
Bottom: 2017 Preliminary Crop Residue Data, 12 Digit HUC
Images from Matt Drewitz, BWSR, and Dr. David Mulla, U. of Minn.

IMPROVEMENT 2

Expand transect surveys

What would it entail?

- Creating or enlarging a statistically robust transect network across agricultural lands in the state
    - ➢ Necessary sample size for transects will depend on the number of categories or practices being tracked, the incidence of those practices, and the desired statistical power ([Chesapeake Bay Program 2017])
- Regularly monitoring and recording land management activities observed along transects (annually or as often as needed for GHG Inventory)
    - ➢ Transect surveys would require annual budget and staff time (likely in state Dept. of Ag)
- Using statistical methods to estimate the total area or incidence of management activities within a state based on sample transect data

What problem(s) would it solve?

- Can be used for calibration or validation of remote sensing tools (see Improvement 1) to reduce uncertainty in those outputs
- Can provide more timely activity data than NRI
- Can be deployed for complex or uncommon cropping systems that are difficult to assess with remote sensing tools

Major Limitations

- Statistical extrapolations of activity data from transect surveys are not spatially explicit, making them insufficient for field-level monitoring
- Observer error may introduce bias into results

Go deeper

KEY TOOL:
Transect and "windshield" surveys

CASE STUDY:
Delaware

CASE STUDY

Delaware

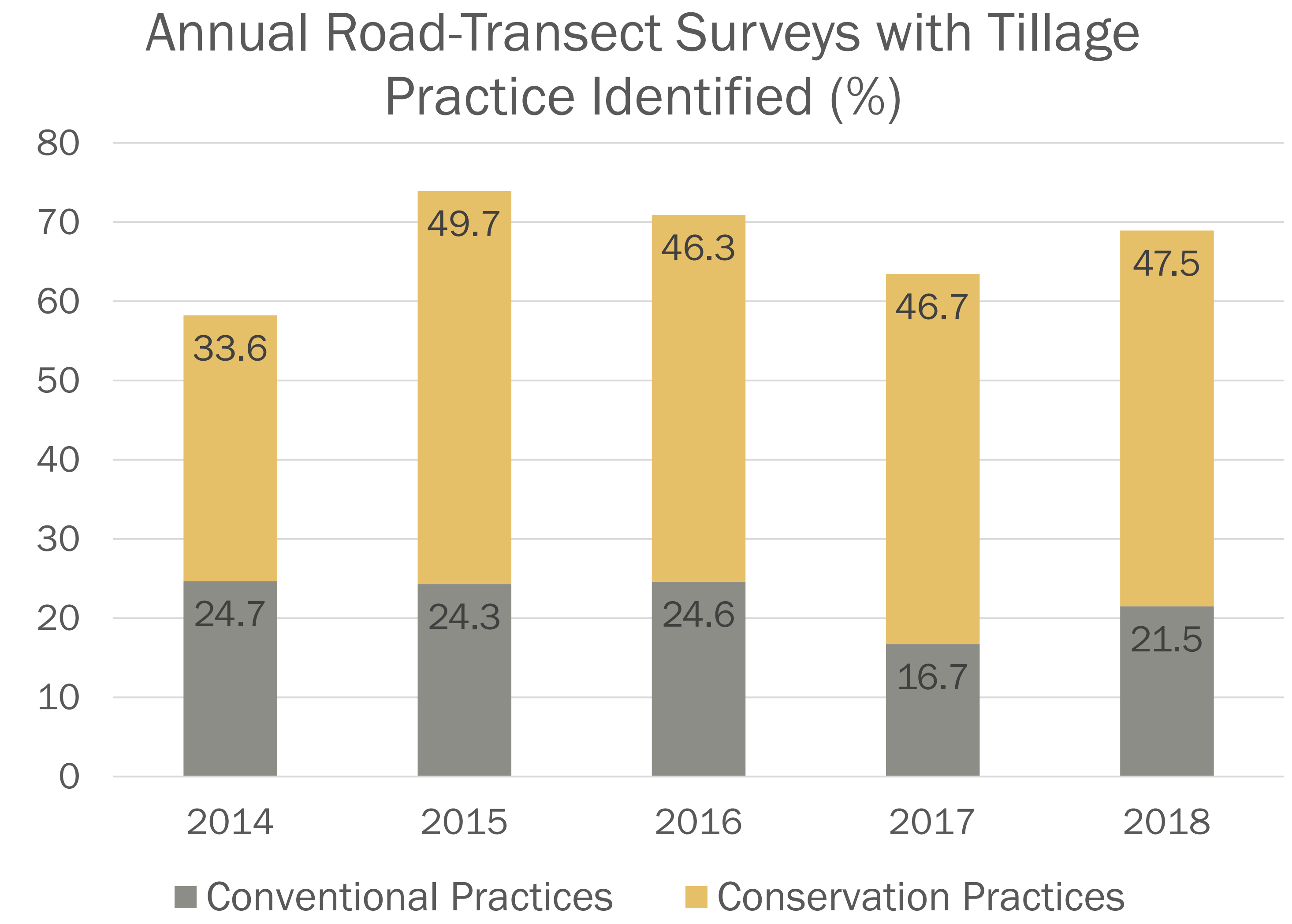
What: Delaware instituted a survey over 1,000 miles of transect with 1,500 observations in 2014, adapting survey methods from the Conservation Technical Information Center (CTIC). Staff from state agencies and soil and water conservation districts (SWCD) participated in data collection.

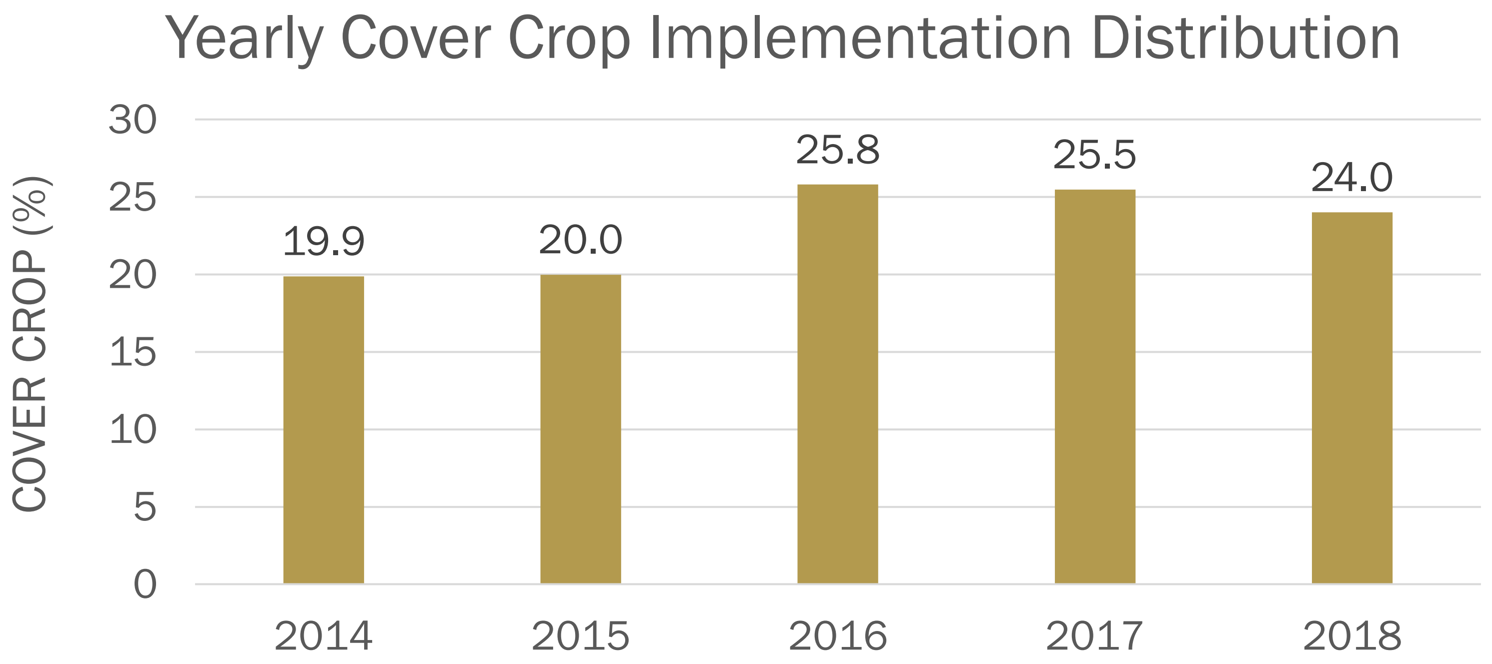
Why: Transect surveys provide data for nutrient reduction credits in the Chesapeake Bay Program. CTIC, where Delaware had previously sourced its data, privatized and stopped updating its data, prompting the state to develop its own program.

Results: Delaware produced county-level data on different tillage practices and cover crop adoption, including novel information like traditional vs. commodity crop type. SWCD staff also provided data on whether the field received cost-share for the practice.

Limitations: Delaware did not model GHG fluxes from its transect data, so it was not used in the state's GHG inventory, which relies on SIT.

Resources: Recommendation Report for the Establishment of Uniform Evaluation Standards for Application of Roadside Transect Surveys to Identify and Inventory Agricultural Conservation Practices





Data from Tyler Monteith, Delaware Dept. of Natural Resources & Environmental Control

IMPROVEMENT 3

Institute farm-level reporting

What would it entail?

- Collecting data on agricultural practices directly from producers through regular surveys (may be mail, phone, online, or in-person); could also utilize new approaches like crowdsourcing data
- Ongoing budget and staff time (likely in state Dept. of Ag) to administer surveys and/or reporting platform
- Sample-based estimation would require statistical models to estimate the total area or incidence of agricultural management practices within a state
- Previous examples have typically supported state incentive programs, such as the Maryland Agricultural Water Quality Cost-Share (MACS) Program

What problem(s) would it solve?

- Provides more timely activity data covering a wider variety of management activities on both croplands and grazing lands (not limited to what is observable from a satellite or windshield survey)
    - ➢ Can collate data with other state and federal programs, such as participation in a cost-share program or use of technical assistance resources
- Can validate results collected from remote sensing tools or transect surveys to reduce uncertainty in activity data

Major limitations

- Not spatially explicit
- Response bias may lead to overestimation of practice adoption
- Administratively intensive

IMPROVEMENT 4

Create a network of soil carbon monitoring plots

What would it entail?

- Establishing a statistically robust network of plots for repeated measurement of soil carbon stocks on agricultural lands, similar to the structure employed by state forest inventories
  - Sample size of 5-7,000 sites is recommended to optimize statistical power of GHG flux estimates with cost of measurements (Spencer et al. 2011)
  - Plots could be co-located with NRI plots to make use of existing data on land-use histories
- Funding for regular data collection and analysis

What problem(s) would it solve?

- Allows state to estimate landscape-level soil carbon flux directly from field measurements rather than only via GHG models, reducing uncertainty in those estimates
- Improves local calibration of biogeochemical models such as DAYCENT by adding empirical data on relationship between land management activities and site-specific GHG fluxes

Major Limitations

- Resource-intensive for a state to undertake alone; could be more efficiently implemented with federal partnership through NRI

This improvement option is also suitable for federal action. For more details, see ***Chapter 7: Federal Action****.*

CROPLANDS & GRASSLANDS

Key Takeaways

- SIT includes an estimate of GHG flux in cropland and grassland soils, but it does not quantify the margin of error around that estimate or report fluxes according to IPCC land use categories.
- The National GHG Inventory publishes state-level GHG flux estimates for croplands and grasslands that align with IPCC land use categories for the current year, and is planning to publish this state-level data for all years by 2022. In the interim, states could develop time series estimates along with their associated margin of error using the same methodology, including by working with the team from Colorado State University that produces the National GHG Inventory estimates. These estimates would be more granular than what SIT currently offers.
- States that wish to track adoption of land management activities or manage agricultural land uses to reduce emissions and promote carbon sequestration may wish to implement additional improvements to their GHG Inventory for Croplands & Grasslands.
- Additional inventory improvements can reduce uncertainty, improve the timeliness, and enhance the spatial resolution of land management activity data; reduce uncertainty around GHG flux estimates; and improve the models that estimate GHG fluxes from specific management activities.
- Additional improvements available to states include using remote sensing tools (e.g. OpTIS), transect surveys, and/or farm-level reporting to track land management activities. Options for reducing uncertainty around GHG flux estimates include creating a field-based soil carbon monitoring system at the state level or requesting federal action to create a national monitoring system, which is likely to be a more robust and cost-effective strategy to collect standardized field data across the landscape.

GOING DEEPER:

Key Concepts, Data Sources and Tools

KEY CONCEPT

Spatial and temporal variability of soils

EPA State Inventory Tool: Data underlying SIT

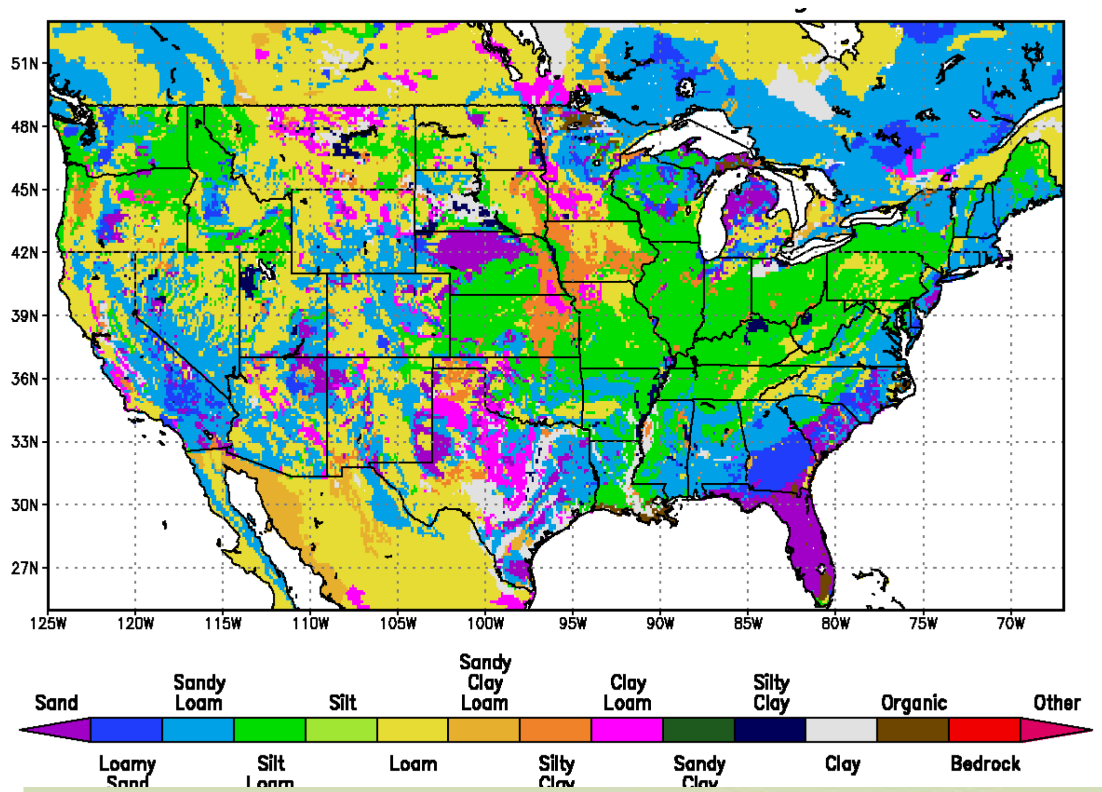
Spatial variability of soils

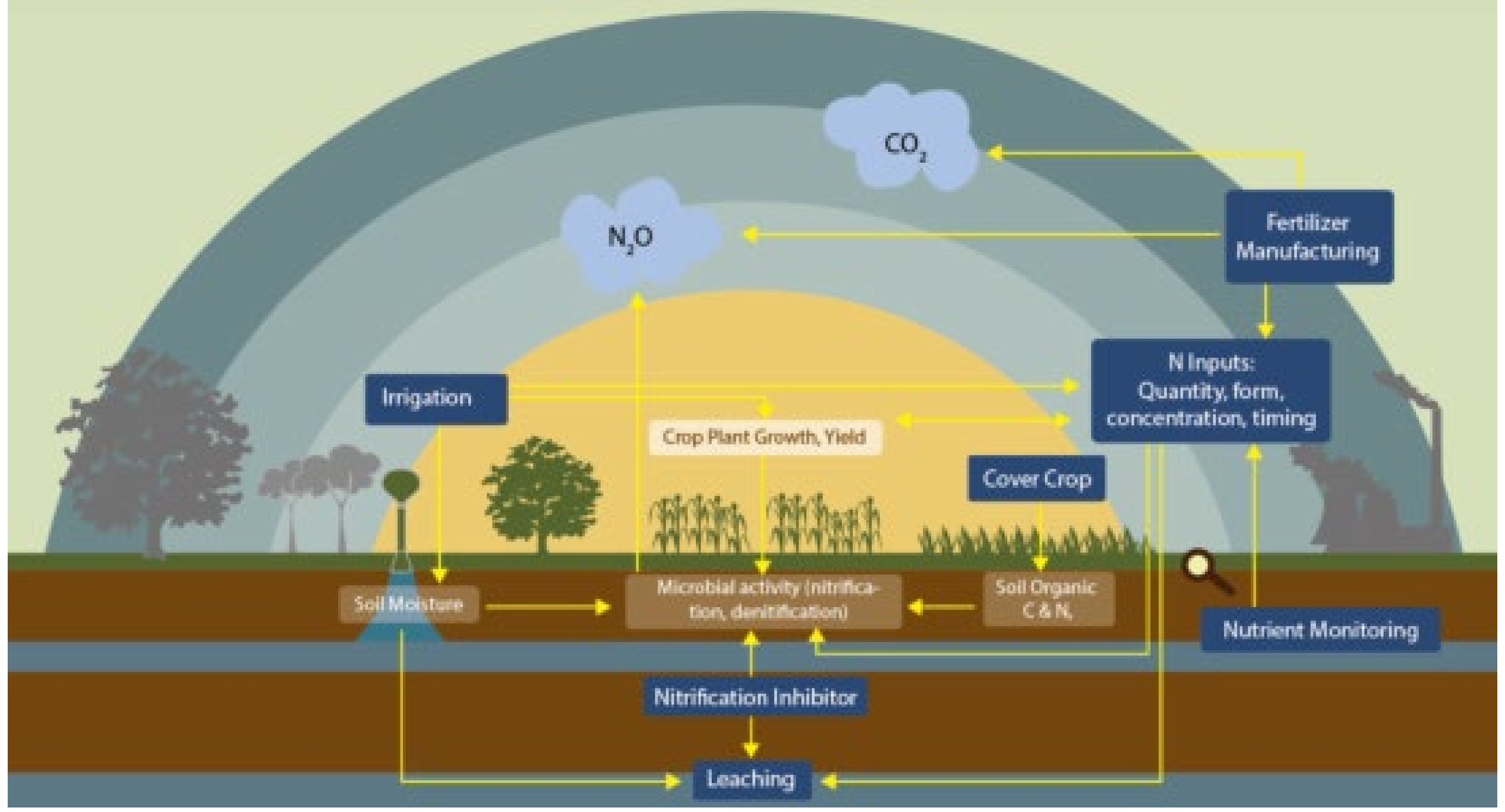
Soil characteristics vary across the landscape as a result of environmental conditions and past management and land use. These effects make each acre of soil unique, even where soil type and landscape is otherwise uniform. For example, rainfall and soil structure can determine how much carbon soils can store.

Temporal variability of soil emissions

Changes in soil conditions, such as moisture content and organic matter content, can affect chemical processes, which in turn lead to changes in GHG fluxes. Emissions of two potent GHGs, CH_4 and N_2O, are highly affected by changes in environment and management over time.*

*This Guide does not address these sources of emissions, but they may account for a significant share of a state's net GHG flux from cropland and grassland soils.





Images from Rachio, UC Sustainable Agriculture Research and Education Program

KEY CONCEPT

Direct vs. proxy measurement

[EPA State Inventory Tool: Data underlying SIT]

Direct measurement

What is it? Collection of carbon flux data through on-site measurement of soil carbon stocks over time.

How does it work? Soil core samples are collected and typically sent to a lab for analysis, where the bulk density (dry weight) and carbon fraction are calculated to estimate the total carbon content per acre.

Relevance to NWL inventories: Direct measurement data are necessary to calibrate models that relate land management practices to soil carbon flux. A robust soil carbon sample network could also underlie inventory estimates without the need for modeling, if one was established at the state or national level.

Limitations: Lab analysis of soil samples is costly, making that technique difficult to scale up to a state or national level. Technologies for on-site measurement of soil carbon are in development but are not yet accurate or precise enough to deploy at scale.

Proxy measurement

What is it? Estimation of inventory data through modeling emissions and removals over time based on observed proxy variables (such as management activities like tillage and fertilizer application).

How does it work? Data on soil characteristics and land management are processed with other environmental data through biogeochemical models, which estimate carbon fluxes as a function of those input variables based on observed relationships from comparable experimental plots.

Relevance to NWL inventories: Estimates of soil carbon flux (and other GHG emissions) in croplands and grasslands in the National GHG Inventory and SIT rely on these methods.

Limitations: The accuracy of models is dependent on the quantity of scientifically robust field measurement data available for calibration. Models can therefore introduce additional uncertainty into carbon flux estimates. They also require technical expertise to run.

KEY DATA SOURCE

US Soil Survey

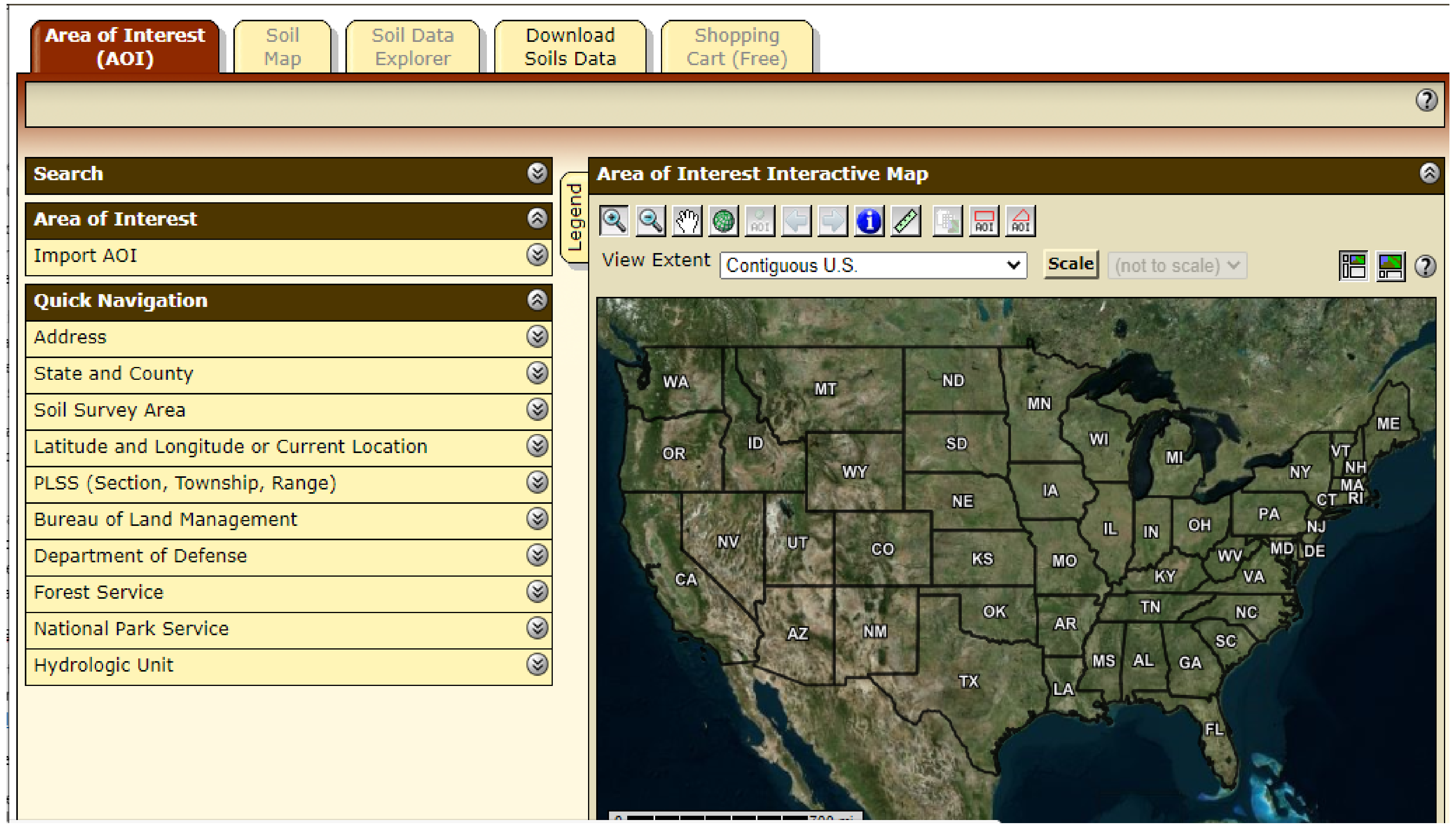
EPA State Inventory Tool: Data underlying SIT

What is it? The US Soil Survey contains physical and chemical attributes of soil including soil depth, bulk density, and organic matter, along with land use and management data. There are two version of the Survey: SSURGO (fine resolution) and STATSGO (coarse resolution). SSURGO provides the most detailed information on a farm- or county-scale; STATSGO data are designed for regional or state-level resource planning.

How does it work? The Survey is assembled based on field transect data, with aerial photographs as the base layer, and it is mapped for the entire US.

Relevance to NWL inventories: The National GHG Inventory uses soil attribute data from SSURGO as an input into GHG flux calculations in the DAYCENT biogeochemical model. The Inventory also uses SSURGO to calculate the extent of organic soils (peatlands).

Limitations: SSURGO does not provide information on land management or carbon stocks, so it must be paired with other data sources (such as NRI and biogeochemical models) to be useful for NWL inventories.



KEY DATA SOURCE

National Resources Inventory (NRI)

EPA State Inventory Tool: Data underlying SIT

What is it? NRI is a statistically-based field inventory of land use, land management, and composition of soil and vegetation for all non-federal land in the US, with nearly 500,000 sample points in agricultural land in the lower 48 and Hawai'i.

How does it work? NRI sampling units are distributed within statistical subdivisions of each county (see diagrams on right). An average sampling unit is 160 acres (0.5 miles on a side), each with ~3 randomly distributed sample plots. Plot data were collected on 5-year cycles from 1982-1997, and annually beginning in 1998.

Relevance to NWL inventories: Provides activity data on agricultural and conservation practices, cropping history, soil properties, irrigation, and other inputs into biogeochemical models to calculate GHG fluxes in croplands and grasslands for the National GHG Inventory

Limitations: Unlike Forest Inventory and Analysis (FIA) data, NRI data are not published yearly, and are time-lagged; the last release in 2018 included data through 2015. Raw NRI data are access-restricted to maintain landowner privacy.

Resources: 2015 NRI Summary Report; NRI Methodology

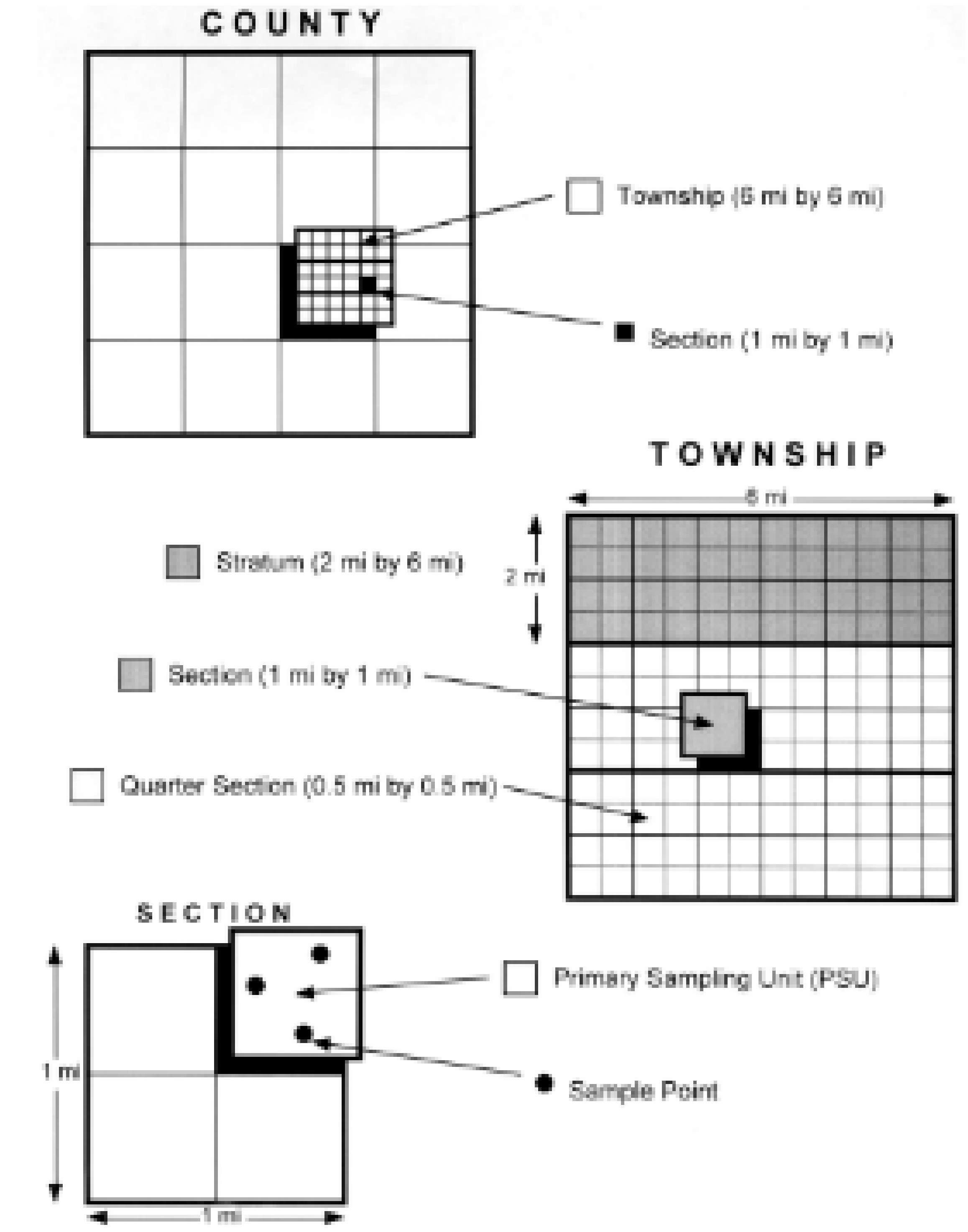


Figure 1. A graphical representation of the political subdivisions of a typical Public Land Survey (PLS) county, and the relationship of PLS subdivisions to a typical NRI primary sampling unit (PSU) and sample points.

Source: Nusser & Goebel 1997

KEY TOOL

DAYCENT Model

[EPA State Inventory Tool: Data underlying SIT](#)

What is it? The Daily Century Model (DAYCENT) is a publicly available process-based biogeochemical model developed by Colorado State University to estimate GHG fluxes from agricultural activity data. It is based on the Century ecosystem model framework, but refined to simulate daily soil dynamics based on weather data, soil properties, and land management activities.

How does it work? The model simulates net primary productivity, soil organic carbon, N_2O emissions, and NO_3 leaching, with results calibrated to field measurements to assess model uncertainties.

Relevance to NWL inventories: DAYCENT outputs the GHG flux estimates for croplands and grasslands in the National GHG Inventory, which are then downscaled to the state level in SIT.

Limitations: The margin of error around GHG flux outputs from the model are typically large, mostly due to imperfections in model algorithms and parameters. Not all management activities (e.g. fertilizer placement and type) are well-represented in the model, making it necessary to continually test and modify DAYCENT's algorithms using new field data.

Resources: DAYCENT; DAYCENT Model Simulations for Estimating Soil Carbon Dynamics and GHG Fluxes from Agricultural Production Systems

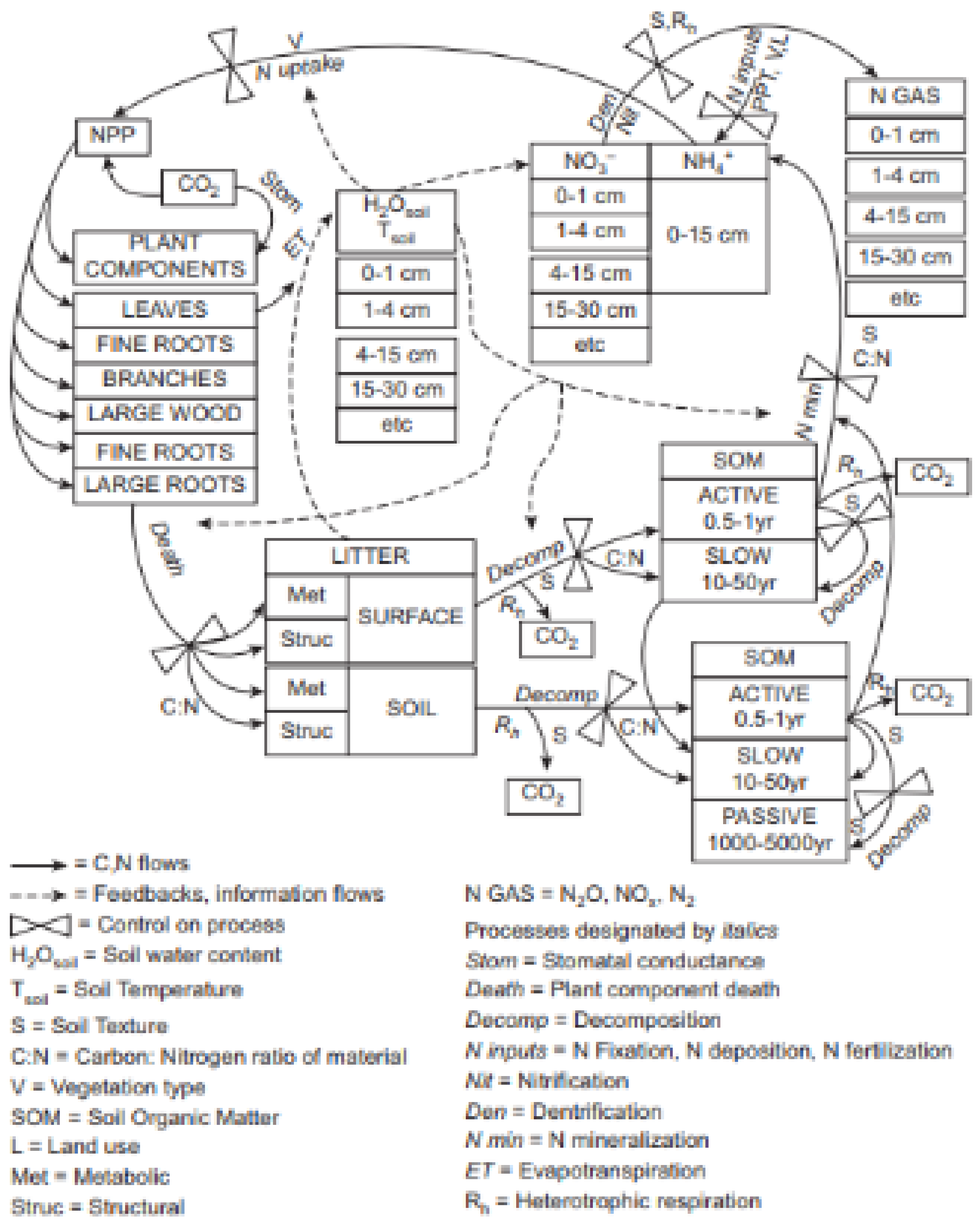


FIGURE 14.1
DayCent model flow diagram.

DAYCENT model flow diagram. Source: Del Grosso et al. 2012

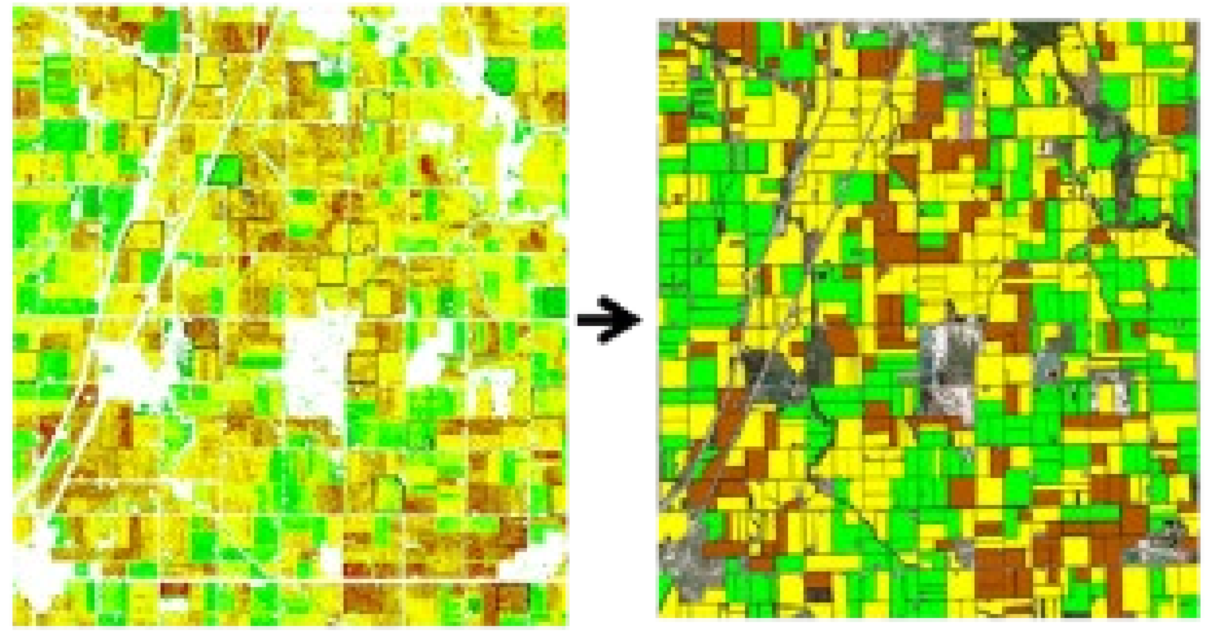
Integrate remote sensing for croplands

KEY TOOL

Operational Tillage Information System (OpTIS)

What is it? OpTIS is a proprietary remote sensing-based tool designed by Applied GeoSolutions (AGS) to map cover crops and conservation tillage practices. It was piloted in Indiana and is now working across the Corn Belt (including Illinois, most of Minnesota, and parts of Wisconsin).

How does it work? OpTIS uses optical imagery data from multiple satellite sensors (Landsat, MODIS) and machine learning to estimate practice distribution across counties based on analysis of ~75% of county area.



Estimate of crop residue cover
(Brown: 0%; Yellow: 40%; Green: 80%)

Field-level Tillage Practice
(Brown: CT; Yellow: RT; Green: NT)

Source: Hagen et al. 2016

Relevance for NWL inventories: OpTIS can provide activity data for specific land management practices with a lower margin of error than the activity data found in transect estimates due to the absence of user error and the replacement of statistical extrapolation with machine learning. Using OpTIS in combination with a biogeochemical model to estimate soil carbon flux could reduce uncertainty, increase timeliness, and enhance the spatial resolution of GHG estimates in state inventories.

Limitations: OpTIS would require adjustments to monitor smaller fields (common in eastern states) or multi-cropping systems (common for fruits and vegetables in California) in order to expand the tool nationally. Not all important land management practices (e.g. fertilizer application) can be detected using remote sensing methods.

Resources: OpTIS

KEY TOOL

Transect and “windshield” surveys

Expand transect surveys

What are they? Transect and windshield surveys are methods to collect field-based activity data on crop species, tillage practice, crop residue cover, and other environmental and site attributes. Windshield surveys add visual estimates of cover crop presence and species.

How do they work? Transects are conducted by collecting periodic GPS-located measurements along a transect line. Windshield surveys are similar but data are collected via visual observations from inside a vehicle driving a designated route.

Relevance to NWL inventories: Field-based activity data provides key inputs to models that estimate GHG fluxes in croplands and grasslands.

Limitations: Transects are sub-sampled within a county, often measuring <10% of fields, so statistical uncertainty may be significant when extrapolating to a county or state scale. Surveys are also subject to significant uncertainty due to observer error, mismatches between field measurements and transect points when transect lies near a field border, and seasonal changes in soil management. Surveys must be conducted twice a year for accurate identification of tillage practices (clearest in spring) as well as cover crops (clearest in fall/winter).

Images from Fox & Monteith

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CHAPTER 4: LAND USE CHANGE

GUIDE TO NWL INVENTORY IMPROVEMENTS

Guide at a Glance

Chapter	Topic	Purpose
1	Overview	Understand basic concepts and identify inventory priorities for your state *(designed for state policymakers and agency staff)*
2	Trees & Forests	Deep dives into inventory improvement options across land use classes *(designed for agency staff)*
3	Croplands & Grasslands	Deep dives into inventory improvement options across land use classes *(designed for agency staff)*
4	**Land Use Change**	**Deep dives into inventory improvement options across land use classes *(designed for agency staff)***
5	Wetlands	Deep dives into inventory improvement options across land use classes *(designed for agency staff)*
6	Baselines	Deep dive into options for creating a historical or projected inventory baseline *(designed for agency staff)*
7	Federal Action	Overview of inventory improvement options that require action by Congress or federal agencies *(designed for state policymakers)*

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Executive Summary: The Issue

Land use change is an important driver of both carbon sequestration and GHG emissions in the US. While land converted to forest and grasslands accounts for one-sixth of the net carbon sequestration from natural and working lands (NWL), roughly the same amount of carbon is emitted from land converted to other uses like croplands and settlements. The balance between sequestration and emissions may vary widely from state to state and could contribute significantly to a state's net NWL carbon balance. States relying on national data and tools for their GHG inventories may find it challenging to accurately quantify the impacts of land use change, however, due to the limitations of federal datasets:

- **Margins of error are large.** Uncertainty in national estimates stems from both sample- and model-based error in calculating both the area and GHG flux associated with land use change. The confidence intervals reported in the 2017 National GHG Inventory range up to more than 200% of the flux estimate for some categories of land use change.
- **Estimates are not specific in time or place.** The National GHG Inventory and the EPA State Inventory Tool (SIT) use Forest Inventory and Analysis (FIA) data from the USDA Forest Service to estimate carbon fluxes from biomass affected by land use change and the National Resources Inventory (NRI) from the USDA Natural Resources Conservation Service for associated soil carbon fluxes. These are the same datasets used to estimate GHG fluxes from forests, croplands and grasslands, and thus impart the same limitations on estimates for land use change: national data are extrapolated from sample plots, so they cannot be used to pinpoint precise locations where land use has changed, and estimates cannot be matched to a specific year.
- **Area estimates of land use change are not timely.** As with croplands and grasslands, the three-year time lag between NRI data collection and release makes the land use change estimates in the National GHG Inventory somewhat out-of-date. Furthermore, FIA does not provide data on land converted to forests until the trees have grown large enough to register as forest land in its remote sensing-based assessment of land use, so recent afforestation or regeneration may not be counted.
- **Land use categories are not disaggregated in SIT.** SIT does not report distinct estimates of GHG flux from land use change separated out by IPCC land use categories, as the National GHG Inventory does. Instead, GHG fluxes from land converted to forest are rolled up into "Forest carbon flux," while fluxes from land converted to other uses are grouped into "Agricultural soil carbon flux." This aggregation makes it challenging for states to track and manage GHG fluxes from land use change.

Executive Summary: Solutions

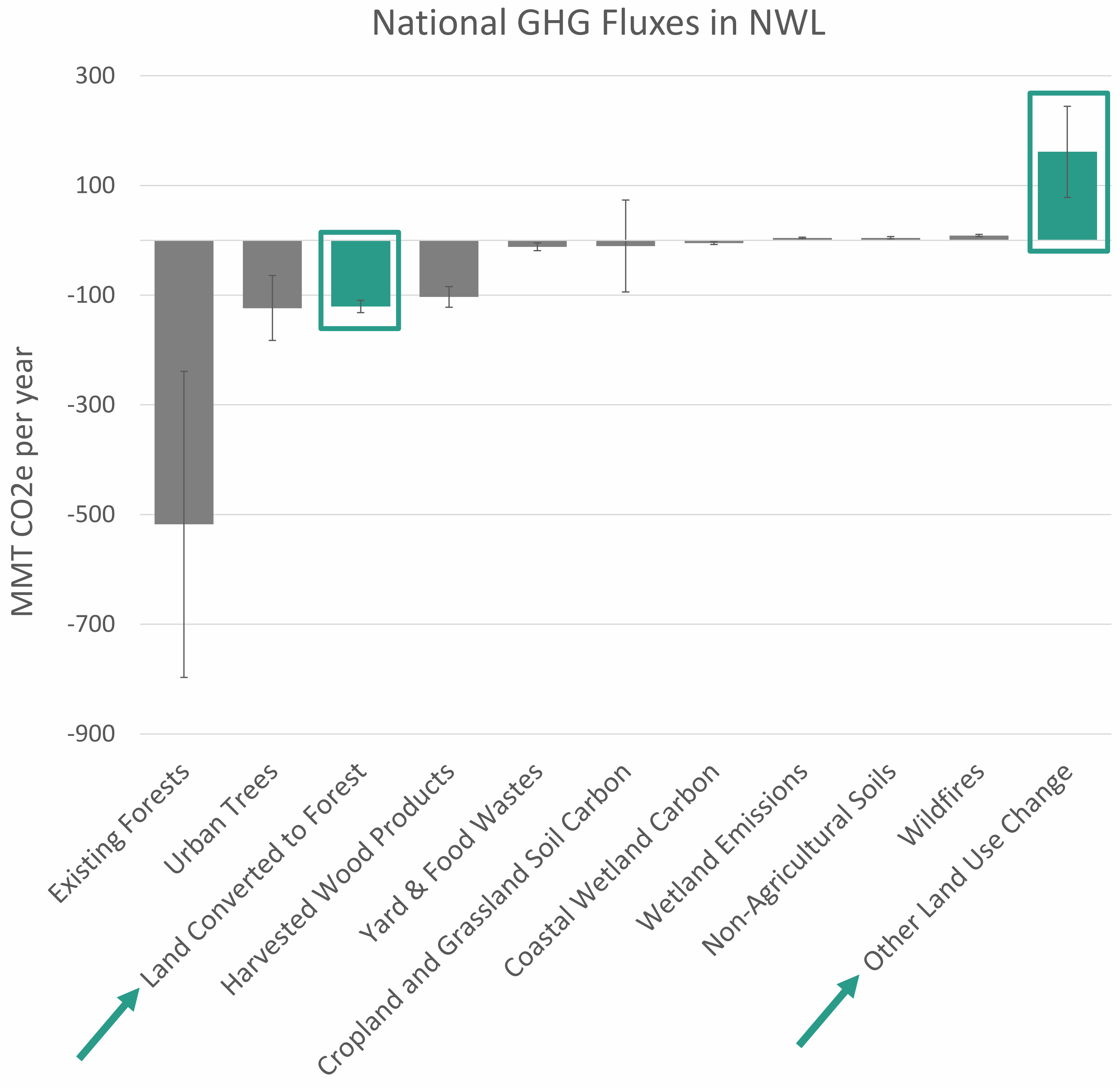
States that currently use the land use, land use change and forestry (LULUCF) module of SIT to estimate carbon fluxes from land use change could immediately make their inventories more granular and timely by using **new state-level FIA data** on carbon flux from land converted to forest and forest converted to other land use types. These data are included in the USDA Forest Service dataset released in 2020 to support the 2018 National GHG Inventory and will be integrated into the 2020 SIT update. Using the new FIA data would align state inventories with the methodology used for the National GHG Inventory, but would not improve the granularity or timeliness of carbon flux estimates for non-forest land use change, such as cropland converted to grassland or grassland converted to settlements.

States could further improve their carbon flux estimates from land use change by **incorporating existing land cover datasets**, such as the National Land Cover Database (NLCD), into their inventories to reduce uncertainty around the estimated extent of land use change and make those estimates spatially explicit. Incorporating a land cover dataset would also allow states to classify all carbon fluxes from land use change—not just those related to forest gain or loss—according to IPCC land use categories. This chapter includes information on how **Massachusetts** is using federal datasets and high-resolution aerial imagery to map land use change and how **Wisconsin** created a land use database from Landsat imagery. With regular updates and the estimation of GHG fluxes associated with land use change, these tools could be integrated into future GHG inventories for those respective states.

Another option for inventory improvement would be to **implement a statewide monitoring system using active remote sensing** like LIDAR, which could reduce uncertainty and enhance the spatial resolution of land use change estimates involving forest gain or loss relative to current FIA data, but may not be effective for monitoring non-forest land use change. Federal action to implement **a national remote sensing-based inventory system** would be another way to improve state-level estimates of land use change; this improvement is covered in *Chapter 7: Federal Action.*

Prioritizing inventory improvements for land use change

Land converted to forests represents a significant carbon sink nationally, while land converted to other land use types represents the largest source of land-based GHG emissions. States experiencing or anticipating significant **afforestation** and/or **loss of natural and working lands** should consider prioritizing inventory improvements in this section to refine their estimates of the GHG impacts of land use change.



Data from EPA 2019a

DEFAULT APPROACH

EPA State Inventory Tool

What does it include?

- SIT implicitly includes carbon fluxes from land use change within “forest carbon flux” and “agricultural soil carbon flux,” using methodologies consistent with the National GHG Inventory
    - ➢ Forest Inventory & Analysis (FIA) data accounts for added or lost sequestration from land use change to/from forests by estimating forest area annually
    - ➢ Land use change to or from croplands or grasslands (non-forest-related) is accounted for through land use data in the National Resource Inventory (NRI)

Major limitations

- GHG fluxes from land use change are not identified separately from other GHG fluxes as in IPCC guidelines. Emissions from forest conversion (land use change) are therefore not differentiated from emissions from disturbance (land use maintained).
- Sequestration on land converted to forest is not accounted for until tree canopy grows enough to qualify as “forest land” under FIA
- Land use change data are outdated: the 2019 version of SIT only includes FIA data through 2014 and NRI data through 2012

Go deeper

KEY CONCEPT: Land-use categories

BASIC IMPROVEMENT

Use current state-level FIA data

What does it entail?

- In April 2020, USDA Forest Service published state-level FIA data on carbon fluxes from land converted to forests and forest land converted to other land use types that aligns with national data in the 2018 National GHG Inventory
- EPA plans to integrate data for Land Converted to/from Forest Land into the next SIT update in late 2020, with added functionality to disaggregate carbon fluxes by land use change category (e.g. Cropland Converted to Forest Land)
- States can also retrieve the data directly from the Forest Service Resource Update

What problem(s) will it solve?

- Explicitly reports carbon fluxes from land use change to and from forests according to IPCC land use categories
- Makes state-level estimates of forest-related land use change more timely (using FIA through 2018, compared to 2014 in the 2019 version of SIT)

Major limitations

- Does not include carbon flux estimates from non-forest land conversion (e.g. wetlands converted to cropland, or grassland converted to settlements)
- Sequestration on land converted to forest is not accounted for until tree canopy grows enough to qualify as “forest land” under FIA
- Does not include sub-state or spatially explicit estimates of carbon flux
- Does not include carbon flux data from land use change for Alaska or Hawai'i

Beyond FIA: Why pursue additional improvements for Land Use Change?

- **Reduce uncertainty** around GHG flux estimates, especially at smaller spatial scales
  - ➢ *Particularly important for small states and those prioritizing reducing emissions from land use change*

- Make estimates **more timely** for carbon flux estimates from land use change
  - ➢ *Particularly important for states seeking to track and manage the impacts of land conservation and/or afforestation efforts*

- **Attribute carbon fluxes** to land use change among non-forest land use categories, such as grassland converted to cropland
  - ➢ *Particularly important for states seeking to limit the loss of agricultural lands or wetlands*

- **Enhance data resolution**—both spatial and temporal
  - ➢ *Particularly important for states that want to effectively target policy or management interventions at the sub-state level*

LAND USE CHANGE

Additional Improvements

	IMPROVEMENT 1	IMPROVEMENT 2	FEDERAL ACTION
Improvement Objective	Incorporate existing land cover datasets, such as NLCD	Implement monitoring system using active remote sensing	Develop a national remote sensing-based inventory
Reduce uncertainty around area estimates of land use change	✓	✓	✓
Improve timeliness of land use change data		✓	✓
Attribute GHG emissions to non-forest land use change	✓		✓
Enhance data resolution	✓	✓	✓

IMPROVEMENT 1

Incorporate existing land cover datasets

What would it entail?

- Collecting state-level estimates of land cover regularly from satellite imagery using datasets like the National Land Cover Database (NLCD) or Global Forest Watch (GFW)
- Developing a transition matrix derived from satellite data (possibly supplemented by other information, such as city and regional development plans) to classify changes between land use categories
    - ➢ Transition matrix should at a minimum include 6 land use categories, consistent with the National GHG Inventory and IPCC guidelines
- Estimating emissions from land use change based on the transition matrix data

What problem(s) would it solve?

- Reduces uncertainty around area estimates of land use change
    - ➢ Estimates of land use change to settlements and croplands have combined uncertainty of +/-40% in National Inventory
- Allows for classification of all land use change according to IPCC land use categories
- Enhances spatial resolution of carbon flux estimates up to the resolution of the land cover dataset (30m for NLCD)

Major limitations

- Land cover datasets may not be updated frequently, leading to lags in data timeliness
- NLCD is only updated every 5 years, with a 3-year time lag from data collection to release
- Land recently converted to forest may not be accounted for, as tree saplings are not always visible in satellite imagery

Go deeper

KEY DATA SOURCES: National Land Cover Database (NLCD)

KEY TOOL: Transition matrix

CASE STUDY: Massachusetts

CASE STUDY: Wisconsin

CASE STUDY

Massachusetts

What: Mass. overlays parcel mapping from local assessors' records on top of high-resolution aerial imagery from the National Agricultural Imagery Program (NAIP) and land cover data from NOAA's Coastal Change Analysis Program (C-CAP; see Wetlands chapter for additional information), divided into 20 land cover categories, to estimate land use change.

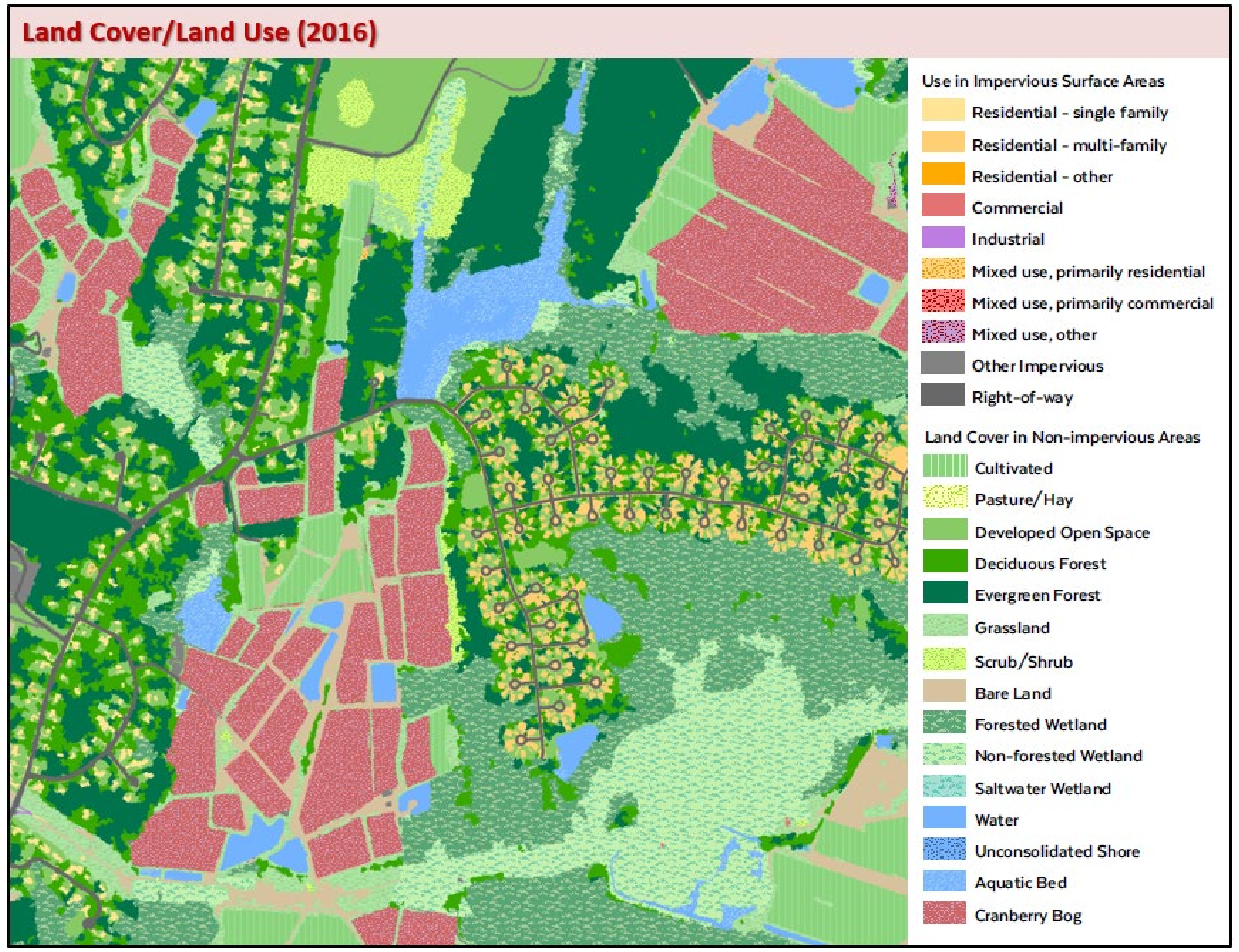
Why: This methodology helps Mass. assess the effectiveness of policies that aim to protect natural and working lands.

Results: Mass. has completed an initial land cover/use map using 2016 data and acquired updated 2019 imagery to begin assessment of land use change.

Limitations:

- Data are not available for previous years, so Mass. cannot track land use change against a (pre-2016) historical baseline using this methodology.
- Methodology for estimating GHG fluxes associated with land use change has not been determined yet; considering FIA data or LANDIS ecological model.
- Future funding to update the analysis regularly, which would be necessary for integration with state GHG inventory, is uncertain.

Resources: 2016 Land Cover/Land Use MassGIS Data



Example of combined land use/land cover data for Massachusetts. Image from MassGIS

CASE STUDY

Wisconsin

What: Wiscland 2 is a state land cover database completed in 2016 from Landsat imagery, validated with field data from FIA and other surveys, with four levels of detail (see below) that include more detailed classifications than NLCD.

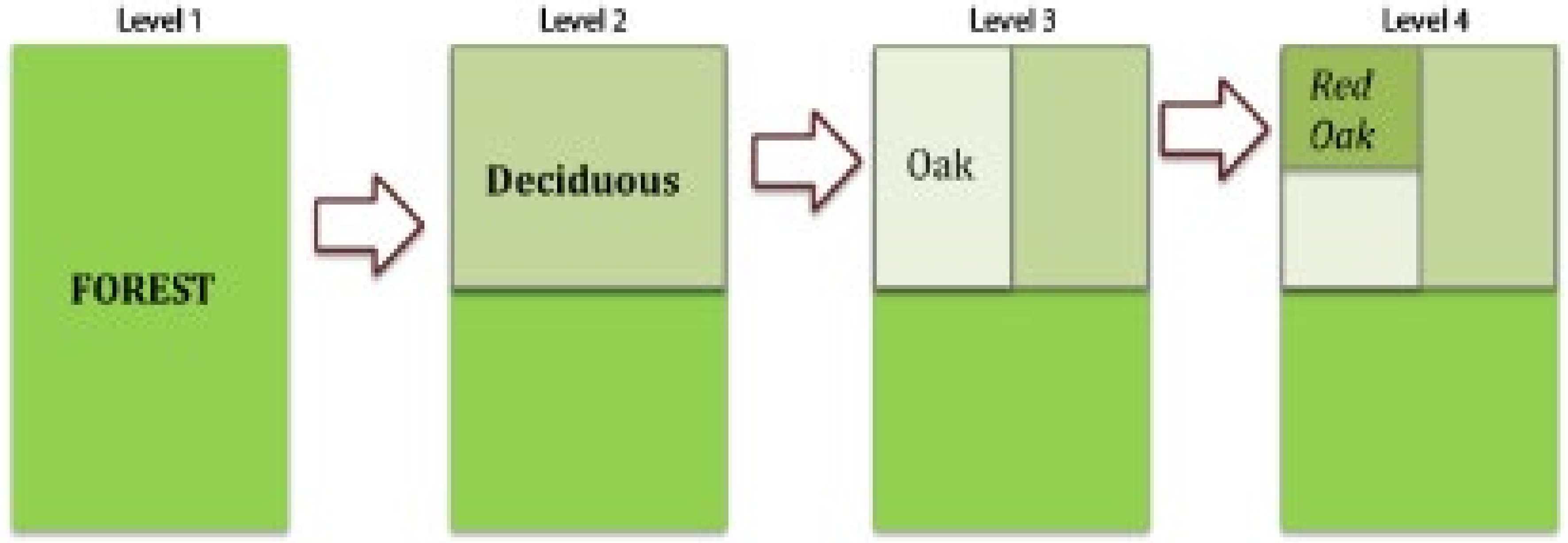
Why: Wisconsin DNR relies on granular land cover data for forests and agricultural lands to inform habitat management, forestry assessments, and watershed planning, among other uses.

Results: Wiscland 2 maps land cover at Level 2 (14 classifications, most similar to NLCD) with an overall accuracy of 86% and at Level 4 (46 classifications) with 66% overall accuracy. Estimated project cost is $850,000.

Limitations:

- Wiscland 2 does not estimate carbon impacts of land use change (and Wisconsin does not yet have a GHG inventory to incorporate Wiscland 2 results).
- DNR does not have funding for regular Wiscland updates to monitor land use change over time.

Resources: Wiscland 2 User Guide



Example of Wiscland’s nested classification structure.
Source: Wiscland 2 Land Cover User Guide

IMPROVEMENT 2

Implement monitoring system using active remote sensing

What would it entail?

- Using active remote sensing tools like LIDAR and digital aerial photography (phodar) to estimate carbon fluxes from forest loss (forest land converted to land) or afforestation (land converted to forest land)
- Calibrating LIDAR or phodar with field data from FIA or other field plots could allow monitoring system to estimate the carbon impacts from that land use change
- Land use change estimates could be a feature within a remote sensing-based monitoring system for all trees and forests (see Chapter 2)

What problem(s) would it solve?

- Reduces uncertainty around estimates of carbon fluxes from land use change to/from forests
- High-resolution active remote sensors can detect areas of land converted to forest at an earlier stage of tree growth than is possible with satellite imagery (which shows canopy cover only) or FIA's long resampling intervals, leading to more timely estimates of land use change
- Enhances spatial resolution of carbon flux estimates associated with changes in forest area

Major limitations:

- Active remote sensors may not be effective for monitoring non-forest land use change, such as grassland converted to cropland or (non-forested) wetland converted to settlements, since their primary value is in observing changes in tree height and forest structure
- LIDAR data are not currently available everywhere, and existing data may be from different collection years or at different resolutions, making integration into a uniform statewide monitoring system challenging; collection of new LIDAR data can be expensive

This improvement option is also suitable for federal action. For more details, see ***Chapter 7: Federal Action*****.**

LAND USE CHANGE

Key Takeaways

- SIT accounts for GHG fluxes from land use change implicitly through FIA data (forest area change) and NRI data (change in cropland and grassland area), but does not include a full accounting of the GHG impacts of land use change according to IPCC land use categories as the National GHG Inventory does.
- USDA Forest Service data published in April 2020 improves upon current SIT default data by estimating GHG fluxes from land converted to or from forest land at the state level using an estimation methodology and reporting framework that is consistent with the National GHG Inventory. The upcoming 2020 SIT update will incorporate this refined data and reporting framework.
- States seeking to manage the GHG impacts of land use change or evaluate the success of policies to promote land conservation or afforestation may wish to make additional improvements to their GHG Inventory for Land Use Change.
- Additional inventory improvements may reduce uncertainty, increase timeliness, and enhance the spatial resolution of land use change estimates.
- Additional improvements available to states include incorporating data from existing land cover datasets or using active remote sensing tools like LIDAR or phodar to monitor changes in forest area and carbon stocks.

GOING DEEPER:

Key Concepts, Data Sources and Tools

KEY CONCEPT

Land use categories

EPA State Inventory Tool

What are they? Definitions of land use within a classification system that can be used to track land uses consistently over time and support estimation of carbon fluxes that arise from land use change.

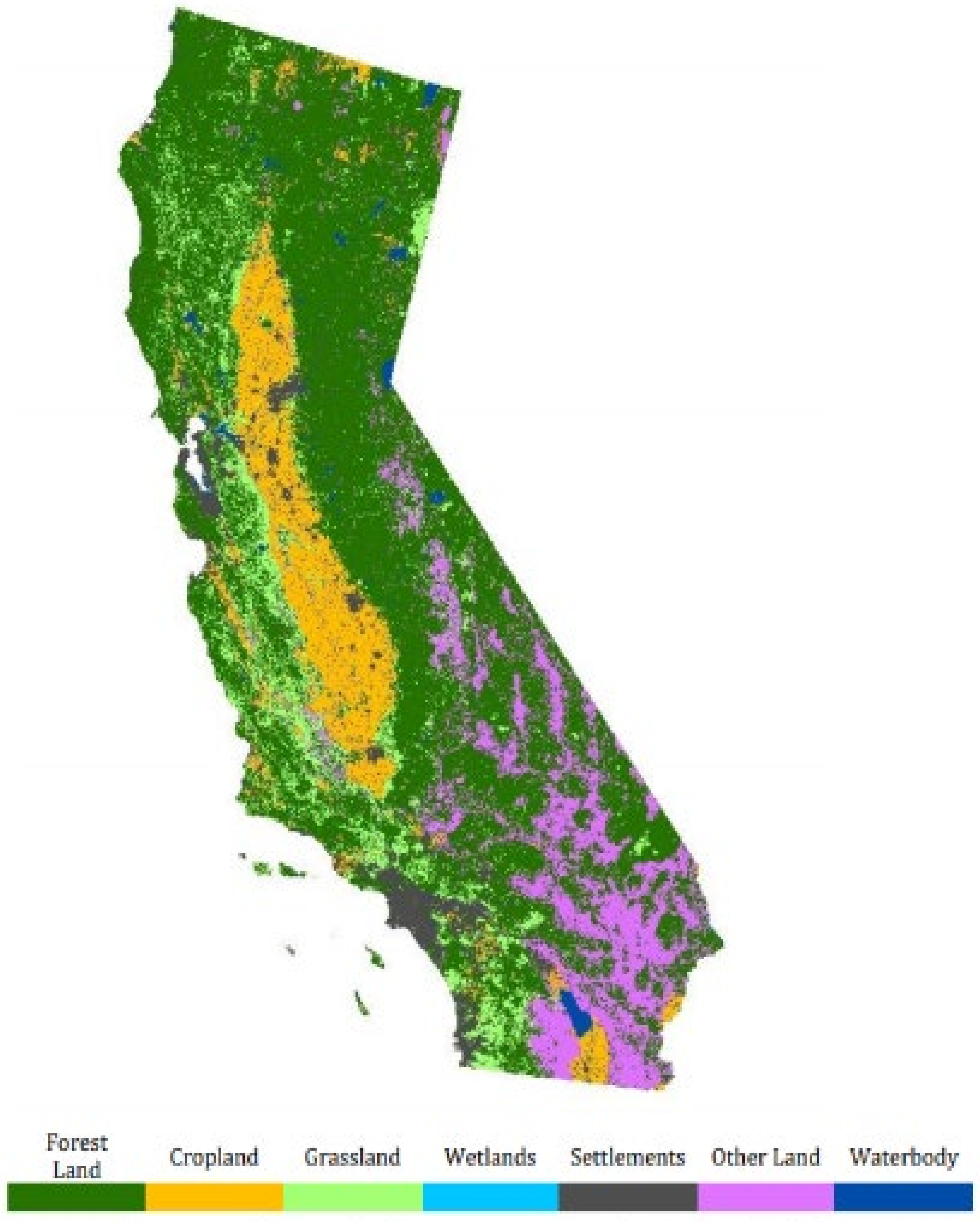
How do they work? Land use is typically categorized based on photo interpretation of aerial or satellite imagery, generally with some validation from field data. IPCC guidelines include six terrestrial land use categories (shown at right applied to California) and are standardized for use in national GHG inventories.

Relevance to NWL inventories:

- Land use categories are necessary to systematically track carbon fluxes from land use change within a GHG inventory.
- Carbon fluxes may be estimated for each type of land use change (e.g. forest land converted to cropland or grassland converted to settlements) using emission and removal factors derived from field data or literature and applied to the relevant area estimated from optical imagery.
- Datasets with more land use categories may produce more refined results—but only if sufficient field data exist to validate the results and estimate carbon fluxes accurately.

Limitations:

- Using land use categories in conjunction with empirical emission/removal factors creates a 2-part process for estimating carbon fluxes, with uncertainties compounding from each step.
- IPCC land use categories are not granular enough to capture some forms of land use change (e.g. natural broadleaf forest converted to conifer plantation, or natural grassland converted to pasture), but increasing the number of land use categories tends to lead to loss of accuracy in classification.



IPCC land use categories applied to California

Incorporate existing land cover datasets

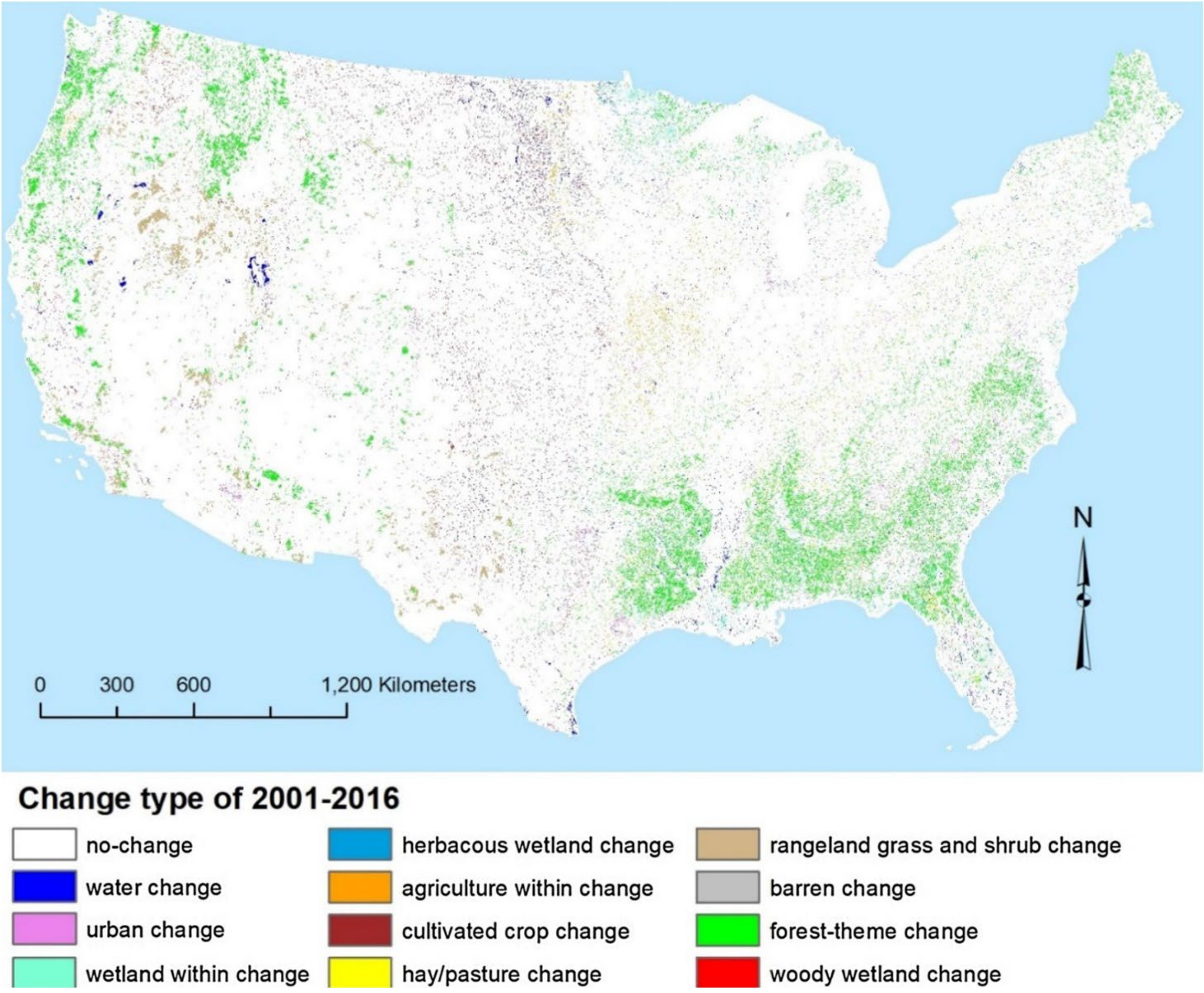
KEY DATA SOURCE

National Land Cover Database (NLCD)

What is it? NLCD is a freely-available spatial dataset managed by the interagency Multi-Resolution Land Characteristics (MRLC) Consortium that classifies land cover across the United States. It is updated every 5 years (though the update schedule may accelerate to 3 years in the future), with a lag of about 3 years from data collection to release.

What does it do? NLCD provides nationwide data on land cover and land cover change based on Landsat imagery and supplementary data sources. NLCD sorts land into 16 land use categories (which are subcategories of the 6 land use categories found in the National GHG Inventory) at a 30m resolution.

Relevance to NWL inventories: The National GHG Inventory uses NLCD to categorize land uses for lands not covered by FIA or NRI, such as federally-owned non-forest land and non-federal lands in most of Alaska. States may also use NLCD to track land use change and estimate associated carbon fluxes for their GHG inventories.



Source: Homer et al. 2020

Limitations:

- Emission and removal factors must be derived from supplementary sources, such as IPCC default data, to calculate carbon flux
- Update frequency and time lag from data collection to release mean the most recent NLCD data may be 3-8 years out of date
- Significant discrepancies in land use classification with other national datasets, for instance where trees are too small to register in 30m resolution imagery (50% of shrub/scrub land identified by NLCD is identified as forest by FIA)
- NLCD land cover classes are not perfectly consistent with land use categories in the National GHG Inventory
- Data for Alaska and Hawai'i are typically released later and updated less frequently than data for the continental United States

Resources: NLCD 2016; Conterminous US land cover change patterns 2001-2016

KEY TOOL

Transition matrix

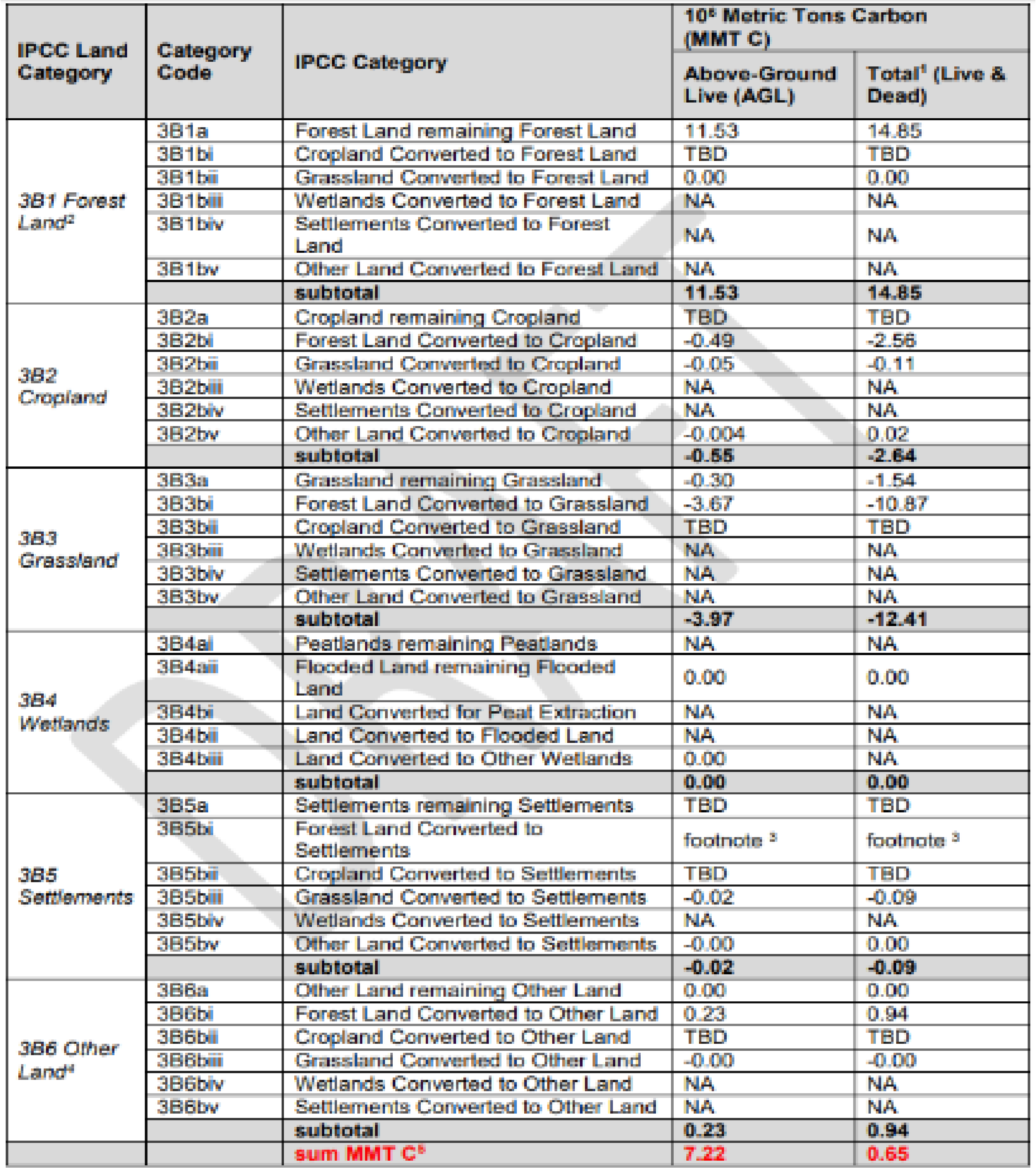
Incorporate existing land cover datasets

What is it? A technique for tracking and reporting changes in land use areas, which can support estimation of GHG fluxes.

What does it do? Shows periodic increases or decreases in areas assigned to different land use categories. Matrices can be developed to include however many land use categories a state has data for.

Relevance to NWL inventories: A transition matrix can be paired with IPCC default stock change factors or other federal or state data sources to calculate carbon fluxes from land use change without requiring spatial data.

Limitations: Transition matrices smooth over spatial variation in land use change impacts, which may contribute to higher levels of uncertainty in statewide carbon flux estimates.



IPCC Land Category	Category Code	IPCC Category	10^6 Metric Tons Carbon (MMT C)	
			Above-Ground Live (AGL)	**Total[1] (Live & Dead)**
3B1 Forest Land[2]	3B1a	Forest Land remaining Forest Land	11.53	14.85
	3B1bi	Cropland Converted to Forest Land	TBD	TBD
	3B1bii	Grassland Converted to Forest Land	0.00	0.00
	3B1biii	Wetlands Converted to Forest Land	NA	NA
	3B1biv	Settlements Converted to Forest Land	NA	NA
	3B1bv	Other Land Converted to Forest Land	NA	NA
		subtotal	**11.53**	**14.85**
3B2 Cropland	3B2a	Cropland remaining Cropland	TBD	TBD
	3B2bi	Forest Land Converted to Cropland	-0.49	-2.56
	3B2bii	Grassland Converted to Cropland	-0.05	-0.11
	3B2biii	Wetlands Converted to Cropland	NA	NA
	3B2biv	Settlements Converted to Cropland	NA	NA
	3B2bv	Other Land Converted to Cropland	-0.004	0.02
		subtotal	**-0.55**	**-2.64**
3B3 Grassland	3B3a	Grassland remaining Grassland	-0.30	-1.54
	3B3bi	Forest Land Converted to Grassland	-3.67	-10.87
	3B3bii	Cropland Converted to Grassland	TBD	TBD
	3B3biii	Wetlands Converted to Grassland	NA	NA
	3B3biv	Settlements Converted to Grassland	NA	NA
	3B3bv	Other Land Converted to Grassland	NA	NA
		subtotal	**-3.97**	**-12.41**
3B4 Wetlands	3B4ai	Peatlands remaining Peatlands	NA	NA
	3B4aii	Flooded Land remaining Flooded Land	0.00	0.00
	3B4bi	Land Converted for Peat Extraction	NA	NA
	3B4bii	Land Converted to Flooded Land	NA	NA
	3B4biii	Land Converted to Other Wetlands	0.00	NA
		subtotal	**0.00**	**0.00**
3B5 Settlements	3B5a	Settlements remaining Settlements	TBD	TBD
	3B5bi	Forest Land Converted to Settlements	footnote [3]	footnote [3]
	3B5bii	Cropland Converted to Settlements	TBD	TBD
	3B5biii	Grassland Converted to Settlements	-0.02	-0.09
	3B5biv	Wetlands Converted to Settlements	NA	NA
	3B5bv	Other Land Converted to Settlements	-0.00	0.00
		subtotal	**-0.02**	**-0.09**
3B6 Other Land[4]	3B6a	Other Land remaining Other Land	0.00	0.00
	3B6bi	Forest Land Converted to Other Land	0.23	0.94
	3B6bii	Cropland Converted to Other Land	TBD	TBD
	3B6biii	Grassland Converted to Other Land	-0.00	-0.00
	3B6biv	Wetlands Converted to Other Land	NA	NA
	3B6bv	Settlements Converted to Other Land	NA	NA
		subtotal	**0.23**	**0.94**
		sum MMT C[5]	**7.22**	**0.65**

Estimated changes in C stocks (flux) in California, 2010-2012. Source: CARB 2018

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CHAPTER 5: WETLANDS

GUIDE TO NWL INVENTORY IMPROVEMENTS

Guide at a Glance

Chapter	Topic	Purpose
1	Overview	Understand basic concepts and identify inventory priorities for your state *(designed for state policymakers and agency staff)*
2	Trees & Forests	Deep dives into inventory improvement options across land use classes *(designed for agency staff)*
3	Croplands & Grasslands	Deep dives into inventory improvement options across land use classes *(designed for agency staff)*
4	Land Use Change	Deep dives into inventory improvement options across land use classes *(designed for agency staff)*
5	**Wetlands**	**Deep dives into inventory improvement options across land use classes *(designed for agency staff)***
6	Baselines	Deep dive into options for creating a historical or projected inventory baseline *(designed for agency staff)*
7	Federal Action	Overview of inventory improvement options that require action by Congress or federal agencies *(designed for state policymakers)*

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Executive Summary: The Issue

Wetlands greenhouse gas (GHG) fluxes are somewhat small nationally but may be important to consider for coastal states or states with sizable inland wetlands or peatlands. Both terrestrial (freshwater) wetlands and tidal (saltwater) wetlands accumulate carbon-rich organic matter in their submerged soils or in the form of peat mosses, and they support the growth of vegetation that captures additional carbon and holds soils in place. Due to seasonal or environmental variations in water level and plant decomposition, wetlands can also act as sources of greenhouse gases, particularly methane. Draining wetlands exposes soils to oxygen, which accelerates the decomposition of organic matter and the release of carbon and methane. GHG inventories can help states to obtain a more accurate estimate of fluxes in wetlands and prioritize protection and management of critical wetlands sites. Currently, there are serious limitations in federal datasets and scientific literature that make it difficult to accurately quantify GHG fluxes in wetlands at the state level. These limitations include:

- **Wetlands are missing from the EPA State Inventory Tool (SIT).** Because SIT does not include terrestrial or tidal wetlands data, states relying on SIT to develop their inventories would not be able to include GHG fluxes from wetlands.
- **The National GHG Inventory does not include data for some types of wetland.** The National GHG Inventory includes peatlands but does not include other terrestrial wetlands due to a lack of available data. While the Inventory includes estuaries, it also does not include carbon fluxes in seagrass beds. The information that is included in the National GHG Inventory is not disaggregated at the state level, making its value limited for informing state inventories.
- **Margins of error are large.** Margins of error tend to be large for national GHG flux estimates for wetlands. In the National GHG Inventory, error margins are as high as 38% for tidal wetlands and higher for peatlands. There are many sources of uncertainty in wetlands flux estimates, including imprecise mapping of wetlands extent and varying GHG emissions and sequestration dynamics in different types of wetlands. Such high levels of uncertainty make it difficult to make policy decisions based on these wetlands data.
- **Existing spatial data are updated infrequently and are of varied resolutions.** The US Fish & Wildlife Service's National Wetlands Inventory (NWI) compiles federal-level wetlands spatial data, of which only 2% is updated each year. NWI data do not have sufficient resolution to be useful for tracking change in wetlands size or quality. For example, NWI does not reliably differentiate between forest and forested wetlands, leading to a potential underestimation of terrestrial wetlands extent. The National Land Cover Database (NLCD) has more timely and higher-resolution spatial data that are updated every five years, but data are only available for private land and do not provide as much detailed information on wetland type and management.
- **Data on wetland GHG fluxes are not place-specific.** Wetlands flux estimates obtained from field sampling may not be applicable to all wetlands since wetlands fluxes can vary greatly with region and wetland type.

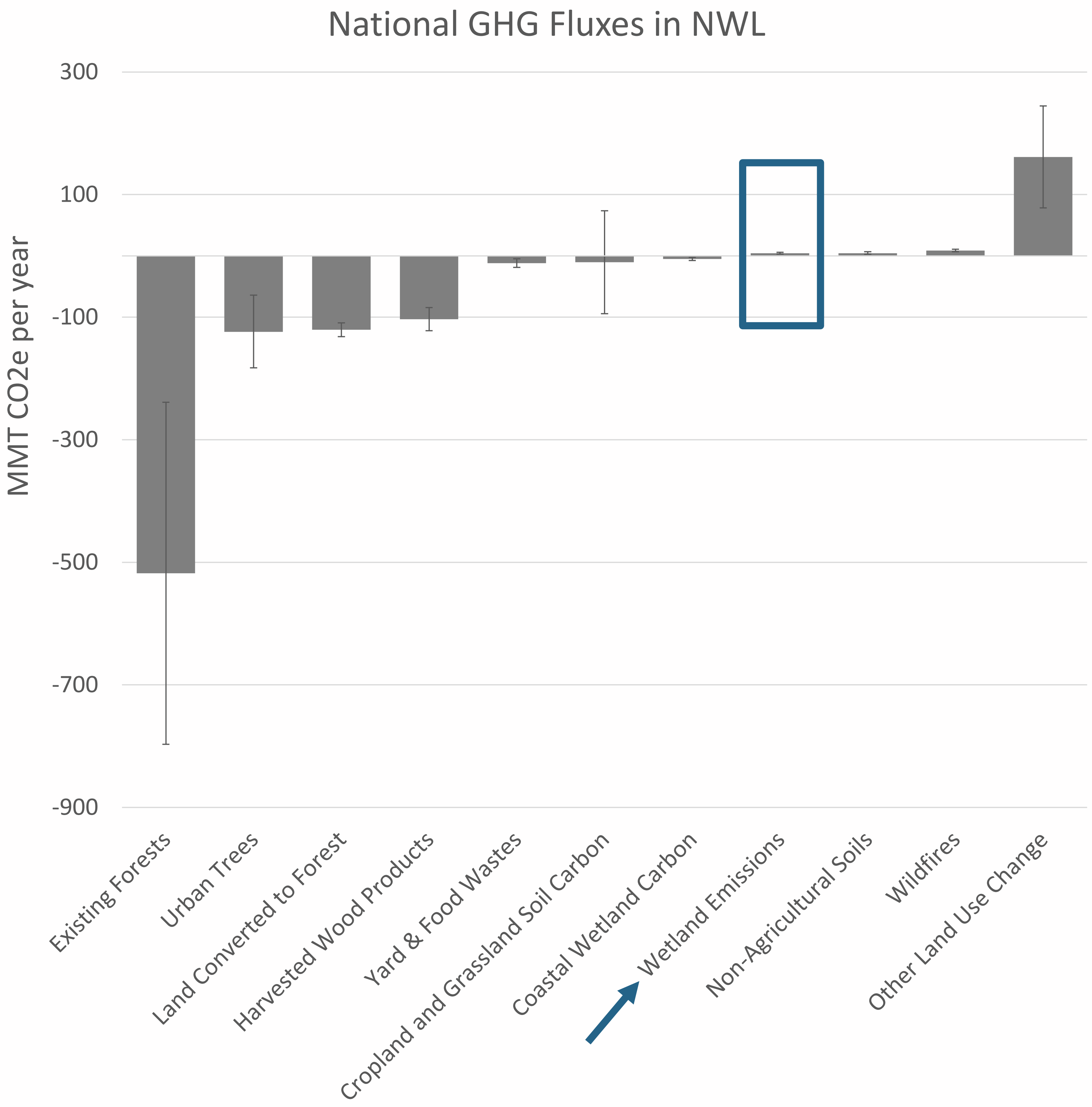
Executive Summary: Solutions

States wishing to add wetlands to their GHG inventories could take the initial step of **analyzing NWI or NLCD spatial data to estimate the extent of tidal and terrestrial wetlands** within the state and applying flux estimates from existing national or global data sources such as the IPCC Wetlands Supplement or the Second State of the Carbon Cycle Report (SOCCR2). This would allow states to establish a general approximation of both wetland extent and GHG fluxes. This method would still include high levels of uncertainty for the reasons mentioned previously and may include spatial data that are not timely, but it would fill the data gap in SIT. This chapter details this improvements and highlights the work that **New York** has done to develop GHG flux estimates for wetlands in its inventory using this method.

To more comprehensively address issues of uncertainty and timeliness in wetlands inventory data, states could 1) **integrate state-specific remote sensing data with NWI or NLCD data** and 2) **conduct field studies to obtain more regionally specific flux data** for wetlands. Integrating spatial data with or NLCD data would allow states to create a more accurate and updated base map for wetlands type and extent. Higher-resolution spatial data will also create a foundation for updated flux estimates using site-specific flux studies. Conducting analyses of GHG fluxes using on-site gas sampling would help states create a database of verified regionally specific flux measurements. This place-specific data could be combined with spatial data to establish a more accurate GHG flux estimate for wetlands.

Prioritizing inventory improvements in wetlands

While the national GHG flux in **wetlands** is small, wetlands may represent a significant source or sink of GHG emissions for individual states. States with significant areas of tidal or terrestrial wetlands may consider prioritizing inventory improvements in this section to quantify the GHG impacts of carbon sequestration and methane emissions in wetlands.



Data from EPA 2019

DEFAULT APPROACH

Not included in SIT

What does it include?

- The EPA State Inventory Tool (SIT) does not estimate GHG fluxes for either tidal or terrestrial wetlands
- Data in the National GHG Inventory on peatlands and tidal wetland soils and vegetation are not broken down at the state level; other types of terrestrial wetlands and seagrass beds are excluded entirely

Major limitations

- Absence of state-level information about wetlands makes it difficult for states to monitor GHG fluxes due to changes in management or expansion and contraction of wetland areas

Go deeper

KEY CONCEPT: Tidal wetlands vs. terrestrial wetlands

KEY CONCEPT: Wetland GHG sources and sinks

BASIC IMPROVEMENT

Develop GHG estimates using federal spatial data

What would it entail?

- Using spatial data from federal datasets such as the National Wetlands Inventory (NWI), National Land Cover Database (NLCD) or NOAA's Coastal Change Analysis Program (C-CAP), which uses NLCD data, to estimate extent and type of wetlands at the state level
- Applying estimated rates of GHG emissions and removals per unit of area (GHG emissions and removal factors) for different types of wetlands from published data sources, such as the Second State of the Carbon Cycle (SOCCR2) report or the IPCC Wetlands Supplement, to estimate state-level GHG fluxes

What problem(s) would it solve?

- Provides first-order approximation of GHG flux in wetlands for states that currently lack default data, since wetlands are excluded from SIT

Limitations

- This approach would limit state estimates to spatial data available at the federal level, which vary in resolution and vintage year across datasets
- Federal datasets may not accurately record changes in wetland management, such as draining/re-wetting or vegetation change
- Wetland emission factors such as those in the SOCCR2 report may not be well-calibrated to wetlands in different states or regions and may not be transferable to different sub-types of wetlands

Go deeper

KEY DATA SOURCE: National Wetlands Inventory (NWI)

KEY DATA SOURCE: C-CAP

KEY DATA SOURCE: SOCCR2

KEY DATA SOURCE: IPCC Wetlands Supplement

CASE STUDY: New York

CASE STUDY

New York

What: The NWL inventory developed by the New York State Energy and Research Development Authority (NYSERDA) used NWI spatial data to identify the extent of New York's terrestrial and tidal wetlands, and paired those data with emissions/removals data from site-specific studies in the region, as well as data from the Terrestrial Wetlands chapter of the 2018 Second State of the Carbon Cycle Report (SOCCR2), to calculate corresponding GHG fluxes.

Why: The wetlands analysis allowed NYSERDA to include a more complete assessment of GHG fluxes in its NWL GHG Inventory. It will also help the state prioritize wetlands management interventions and areas in need of protection.

Results: The NYSERDA Inventory estimated that New York State's wetlands contribute emissions of 4.79 MMT CO$_2$e/year, compared to emissions of 8.38 MMT CO$_2$e/year from agriculture and sequestration of -25 MMT CO$_2$e/year from forests.

Limitations: Wetland emission and removal data from the SOCCR2 report were based on a small number of studies, including some over 15 years old and conducted in states and regions outside NY. NYSERDA's inventory also uses NWI data, which may be out of date. Therefore, the GHG flux estimates in NYSERDA's inventory may not reflect current wetland extent or precise emissions and removal rates for wetlands in the state.

Resources: Sources and Sinks of Major Greenhouse Gases Associated with New York State's Natural and Working Lands: Forests, Farms, and Wetlands; SOCCR2 Chapter 13: Terrestrial Wetlands

Image: New York State Energy and Research Development Authority (NYSERDA). 2020. "Sources and Sinks of Major Greenhouse Gases Associated with New York State's Natural and Working Lands: Forests, Farms, and Wetlands" NYSERDA Report Number 20-06. Prepared by E&S Environmental Chemistry, Inc., Corvallis, OR. nyserda.ny.gov/publications.

Beyond national data: Why prioritize additional improvements for Wetlands?

- **Fill gaps** in existing federal wetlands extent and GHG flux data
    - *Particularly important for states prioritizing wetlands in their NWL plans*

- **Reduce uncertainty** in flux estimates
    - *Particularly important for states managing significant terrestrial and/or tidal wetland resources*

- **Enhance data resolution** to accurately determine spatial distribution of various wetland types across the state
    - *Particularly important for states with limited historical state-level wetlands mapping*

- **Improve timeliness** of wetlands spatial data
    - *Particularly important for states with high rates of wetland change or conversion*

WETLANDS

Additional Improvements

	IMPROVEMENT 1	IMPROVEMENT 2	FEDERAL ACTION
Improvement Objective	Integrate updated remote sensing data with federal spatial data	Refine state-specific stock and flux estimates	Develop a national spatial inventory of wetland GHG fluxes
Fill gaps in federal wetlands data	✓	✓	✓
Reduce uncertainty in flux estimates		✓	✓
Enhance spatial data resolution	✓		✓
Improve timeliness of spatial data	✓		✓

IMPROVEMENT 1

Integrate updated remote sensing data with federal spatial data

What would it entail?

- Integrating up-to-date remote sensing data such as LIDAR/phodar or optical imagery and soil maps such as those in the US Soil Survey (see Croplands & Grasslands chapter) with NWI/NLCD data to create more accurate maps of wetlands types and distribution.
- Using existing LIDAR/phodar data, like those that already exist for many coastal areas, or collecting new data if none exists (See Trees & Forests chapter for available LIDAR databases). Both scenarios would require significant technical capacity for data processing and analysis.
- A LIDAR base map could be updated regularly with phodar or optical imagery to track changes in wetland extent and management over time.

What problem(s) would it solve?

- Gives states visibility into wetlands type and extent using the best available remote sensing data for each state, which could include regional or state-specific data not available at the federal level
- Improves timeliness by integrating more recent remote sensing data than what NWI and NLCD include
- Reduces uncertainty around identification of wetlands soil type, vegetation type, and elevation

Limitations

- Existing LIDAR datasets within a state may have different resolutions and data formats, posing challenges for creating statewide wetlands maps using existing LIDAR data
- Remote sensing cannot directly measure GHG fluxes in wetlands, and requires integration with flux data from IPCC or other sources to produce data for a GHG inventory

Go deeper

KEY CONCEPT: Wetlands policy and management

*This improvement option is also suitable for federal action. For more details, see **Chapter 7: Federal Action**.*

IMPROVEMENT 2

Refine state-specific stock and flux estimates

What would it entail?

- Conducting field-based studies to replace national-level and/or regional emissions factor estimates with state-specific estimates.
- Field studies could use established GHG sampling methods such as direct air sampling to directly test gas fluxes.
- Established sampling methods can be expensive ($30,000-$50,000 per sampling device), but devices can be used for multiple sites, so costs are distributed. The costs for devices are also projected to decrease.
- Each site study would require multiple years of sequential data to derive robust emissions and removal factors.

What problem(s) would it solve?

- More robust field data reduces uncertainty in nationally aggregated GHG flux estimates
- Fills gaps in federally available flux data by establishing accurate local datasets for wetlands fluxes

Limitations

- Given the site-specific nature of field studies, results would not necessarily be transferable to other wetland types or regions

Resources: USGS Ecology of Greenhouse Gas Emissions from Coastal Wetlands

WETLANDS

Key Takeaways

- SIT does not provide information about GHG fluxes in wetlands.
- States can use spatial data and with flux data to create state-level estimates of GHG fluxes in wetlands.
- States with significant tidal and/or terrestrial wetland resources may want to prioritize additional wetland inventory improvements to establish more accurate GHG estimates and to better prioritize management interventions in wetlands.
- Improvements to wetland inventories will reduce the uncertainty, enhance the resolution and improve the timeliness of existing wetlands data while filling gaps in current federal datasets.
- States can improve their GHG inventories for wetlands by integrating up-to-date remote sensing data and soil maps with NWI/NLCD data, and by establishing state and regionally-specific removal and emissions factors through targeted field studies that will refine state-level GHG flux estimates.

GOING DEEPER:

Key Concepts, Data Sources and Tools

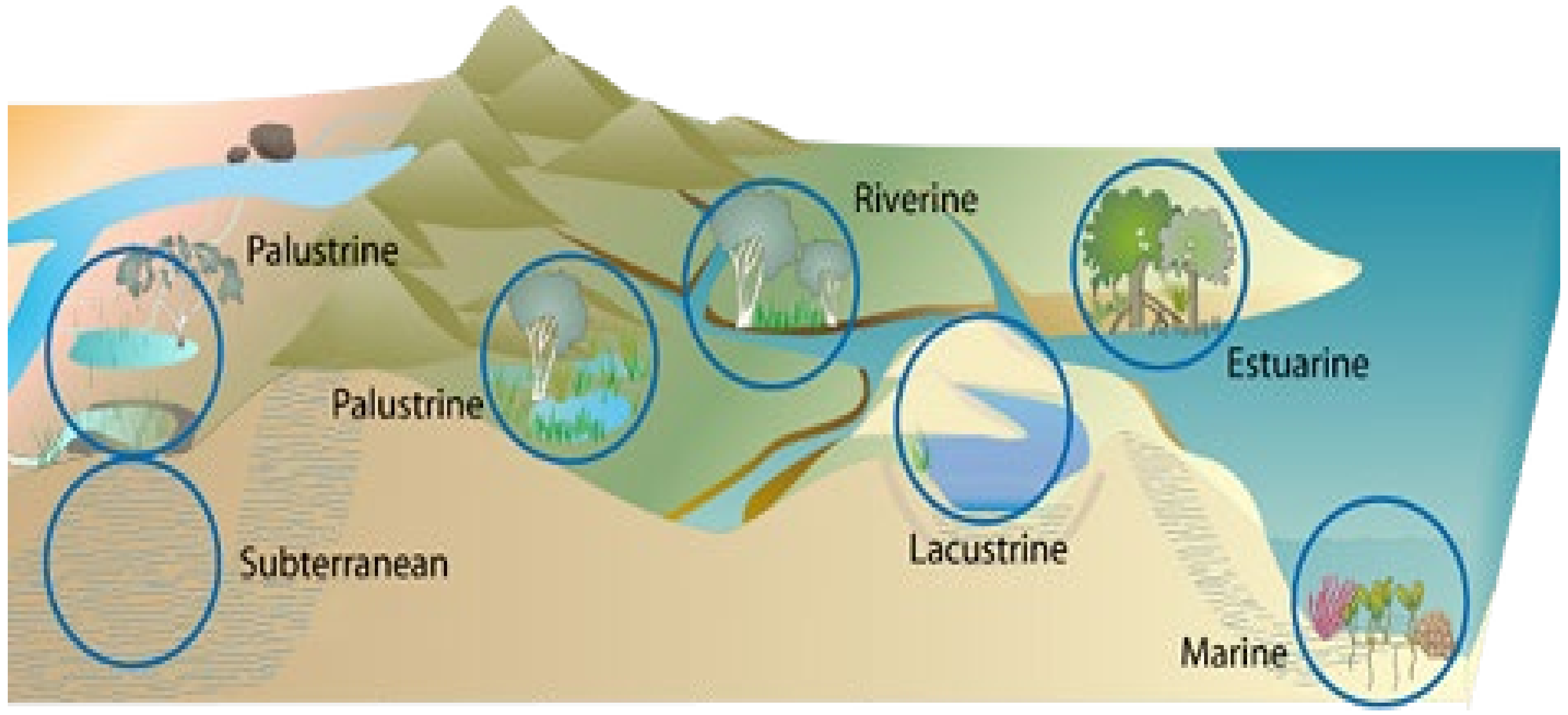
KEY CONCEPT

Tidal vs. terrestrial wetlands

Not included in SIT

What are they? Wetlands are generally categorized as either tidal (estuarine) wetlands, which are flooded with ocean water and freshwater runoff, or terrestrial (palustrine, lacustrine, riverine) wetlands, which are saturated with fresh water from precipitation or groundwater. Within these two categories there are many sub-categories of wetlands that exist under different conditions. In all cases, wetlands are defined by their 1) water tolerant plant community, 2) anaerobic organic or mineral soil, and 3) wetness or saturation.

Resources: SOCCR2, EPA Wetlands Protection and Restoration



Source: WetlandInfo

Why do they matter for NWL inventories? Tidal and terrestrial wetlands have different geographic and physical characteristics, meaning that their GHG fluxes can be dramatically different. This will affect GHG inventories and underscores the value of states and/or the federal government compiling more granular, site-specific data on wetlands.

Major wetlands categories for NWL inventories	**General Location**	**Wetland Types**	**General Soil Type**
Tidal Wetlands			
Estuarine	Bays, deltas, lagoons, tidal zones. Saltwater or brackish water.	Estuaries (submerged by shallow water), mangroves, sea grass beds, intertidal marshes (periodically submerged by tides)	Mineral
Terrestrial Wetlands			
Riverine	River channels and floodplains	Bottomlands, freshwater marshes adjacent to rivers	Mineral
Lacustrine	Lakes and deltas	Reservoirs, lakes	Mineral
Palustrine	Ponds, peatlands, groundwater seepage areas	Peatlands (fens, bogs), marshes (wet meadows, prairie potholes, vernal pools, playa lakes), springs, forested swamps	Organic (peatlands), mineral (other palustrine wetlands)

KEY CONCEPT

Wetlands GHG sources and sinks

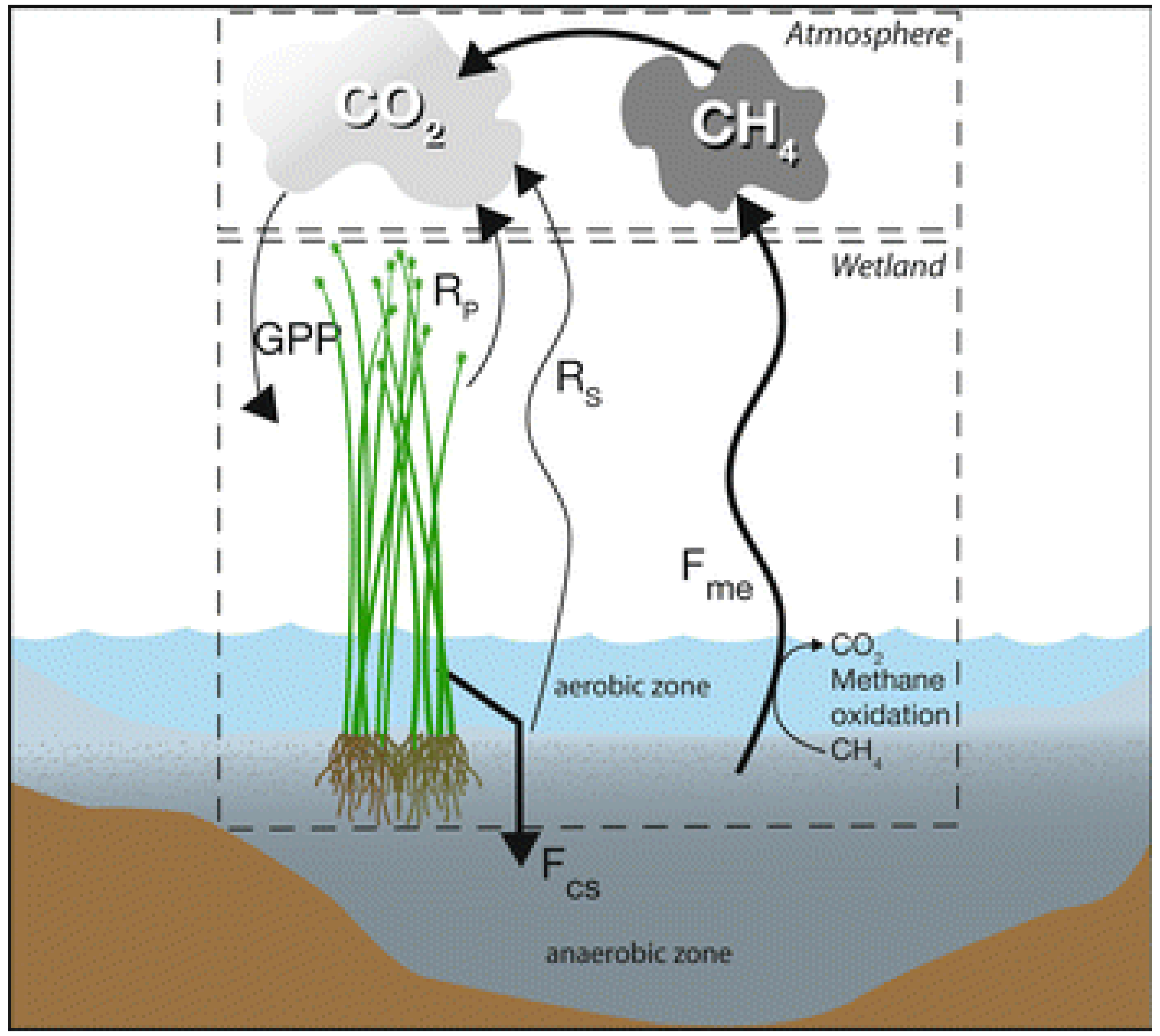
Not included in SIT

What are they? Both tidal and terrestrial wetlands can be greenhouse gas sources and sinks depending on environmental factors and their management.

	GHG Sources	**GHG Sinks**	**Other Ecosystem Functions**
Tidal Wetlands	1) Draining causes soil oxidation and accelerated decomposition, releasing CO_2 and CH_4 and causing vegetation to die 2) Releases methane as organic matter decomposes 3) Releases more methane when salinity decreases	1) Stores organic CO_2 through accumulation of organic matter, which decomposes slowly under water	Buffers storm surges, slows shoreline erosion, provides habitat for fish, invertebrates, and birds
Terrestrial Wetlands	1) Draining causes soil oxidation and accelerated decomposition, releasing CO_2 and CH_4 and causing vegetation to die 2) Releases methane as organic matter decomposes 3) Fluxes vary seasonally and are both a source and a sink of CO_2 and CH_4	1) Stores organic CO_2 through accumulation of organic matter, which decomposes slowly under water 2) Peatlands store more CO_2 than marshes and swamps, which accumulate less organic matter	Recharges groundwater, provides water in times of drought, reduces flood damage, can take up excess nutrients from fertilizer runoff

Sources: SOCCR2, EPA Wetlands Protection and Restoration

Why do they matter for NWL inventories? Wetlands have relatively complex and fluctuating GHG exchanges that merit more regionally-specific study.



Conceptual model of GHG exchange in a wetland. F_{cs} carbon sequestration; F_{me} methane emissions; *GPP* gross primary productivity; R_P plant respiration; R_S soil respiration. Source: Wetlands, Carbon, and Climate Change

KEY DATA SOURCE

National Wetlands Inventory (NWI)

Develop GHG estimates using federal spatial data

What is it? The NWI is a spatial database of wetland areas for all 50 states, established and maintained by the US Fish & Wildlife Service (USFWS) and now provided as an online mapping tool maintained by US Geological Survey (USGS).

What does it do? NWI maps identify wetlands and riparian areas and classifies wetlands by type. Maps can also be filtered by data source type, image scale, and image year and can display wetlands projects in progress.

Relevance to NWL Inventories: Because NWI data captures most wetland types, NWI can provide a base map for wetlands type and extent. States could apply wetlands emissions and removal factors to the NWI spatial base map to develop a GHG inventory for wetlands.

Limitations:

- Although some wetland project areas have been updated more recently, the NWI base maps were made in the 1970s and '80s and are updated at a rate of approximately 2% per year. Some wetlands data are therefore significantly out-of-date, and may not reflect changes in wetland size or vegetation.
- Data resolution varies, so NWI may not capture relatively small wetlands or small changes in wetlands extent

Resource: National Wetlands Inventory

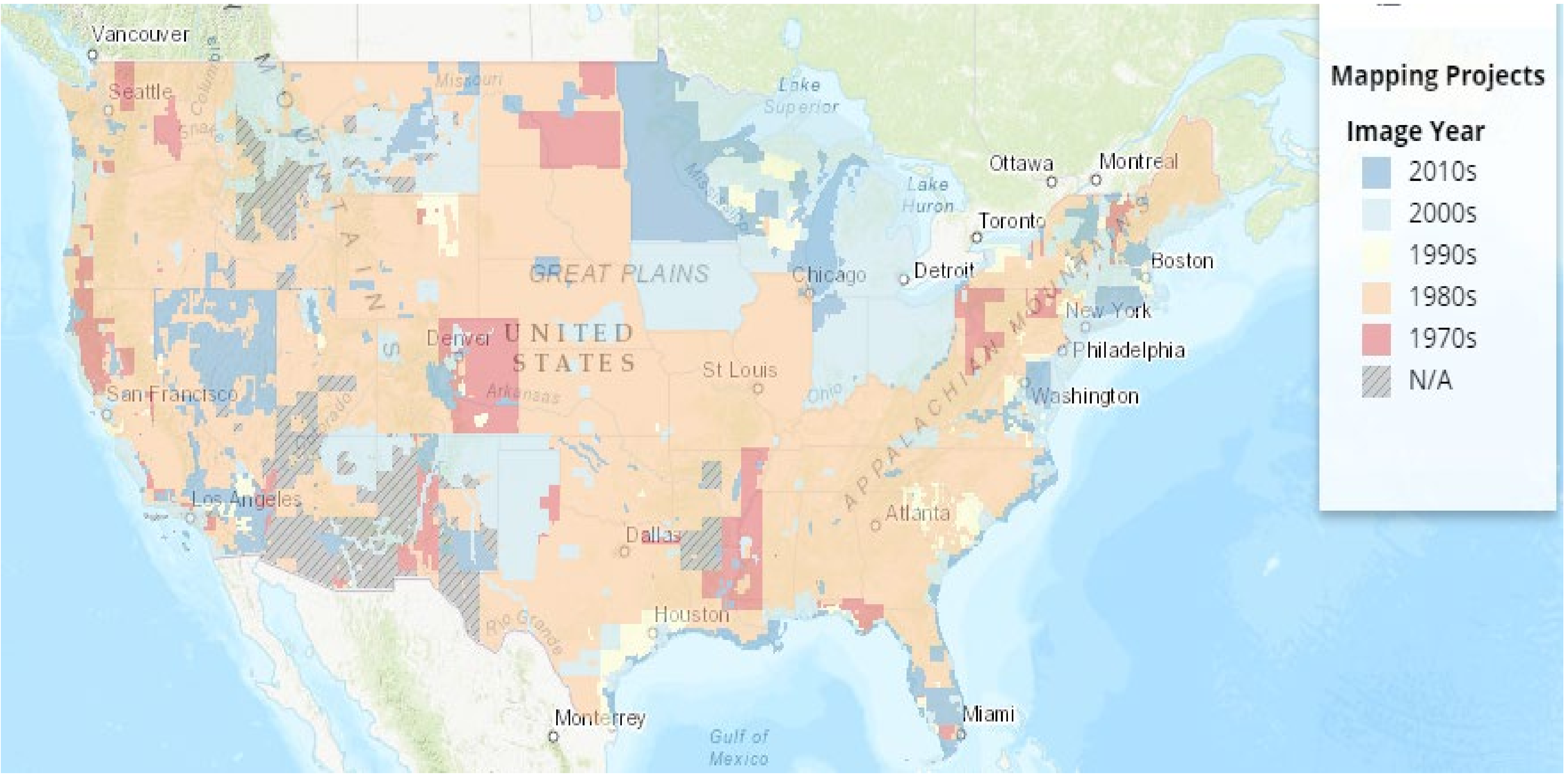


Image year for data underlying the NWI. Source: https://fws.gov/wetlands/data/Mapper.html

Develop GHG estimates using federal spatial data

KEY DATA SOURCE

Coastal Change Analysis Program (C-CAP)

What is it? NOAA's C-CAP provides coastal land cover and land cover change data in a user-friendly Land Cover Atlas data viewer. It includes both high (1-5m) and medium (30m) resolution data on extent and vegetation type for both terrestrial and tidal wetlands in coastal counties, counties bordering the Great Lakes, and coastal areas in US territories. C-CAP draws from NLCD data for regional medium-resolution data. It is updated at least every five years when NLCD is updated. High resolution data developed by non-federal partner organizations are available for certain projects and areas.

What does it do? C-CAP includes data on forest type and wetlands type by geographic location as well as land cover changes and trends, including changes in wetlands extent. Users can download relevant datasets.

Relevance to NWL Inventories: C-CAP and NLCD data underlie the Wetlands sections of the National GHG inventory. Due to its high-resolution and frequently updated data***,*** coastal states may choose to use C-CAP as a spatial data source for their wetlands inventories.

Limitations:

- Only encompasses coastal counties and territories, so landlocked states will not be able to use it. Most states do not have full coverage under C-CAP.
- Only includes data on private land. Federal and state land is excluded.

Resources: C-CAP

Website Owner: Office for Coastal Management - Last Modified 08/26/2020

Source: https://coast.noaa.gov/ccapatlas/

Develop GHG estimates using federal spatial data

KEY DATA SOURCE

2nd State of the Carbon Cycle Report (SOCCR2)

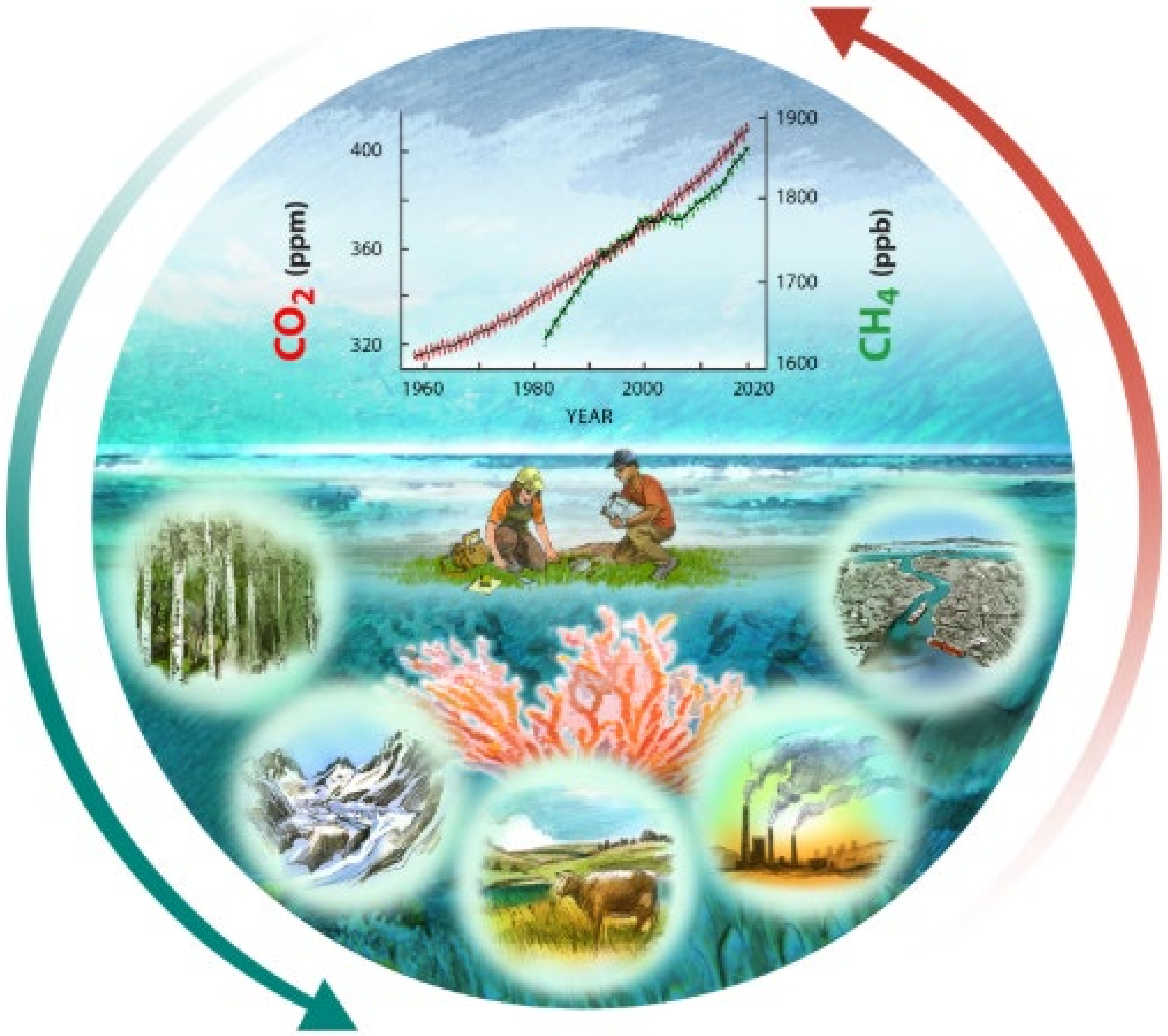
What is it? SOCCR2 is a report published by the Carbon Cycle Interagency Working Group under the auspices of the US Global Change Research Program. The report focuses on “North American carbon cycle processes, stocks, fluxes, and interactions with global-scale carbon budgets and climate change impacts.” Ch. 13 contains data on GHG fluxes in terrestrial wetlands and Ch. 15 contains data on tidal wetlands and estuaries.

What does it do? Offers in-depth explanations of GHG sequestration and emissions in wetlands and provides aggregated data on GHG fluxes in various types of wetlands across the country. Appendix 13B contains terrestrial wetland flux estimates drawn from a review of wetland GHG studies across North America.

Relevance to NWL Inventories. In the absence of flux data specific to wetlands within a certain state, the data in Appendix 13B could be used in conjunction with spatial data to estimate GHG fluxes in a state’s terrestrial wetlands.

Limitations:

- While it cites studies conducted in specific states, averaged flux and stock estimates in the Terrestrial Wetlands chapter are not state-specific.
- Due to a lack of data, flux estimates in the Tidal Wetlands chapter are only available for very broad regions of North America and thus may not be useful for state-level analyses.
- Many studies reviewed are 5-20 years old and may need to be updated.



Resources: SOCCR2, Terrestrial Wetlands, Tidal Wetlands

KEY DATA SOURCE

2013 IPCC Wetlands Supplement

Develop GHG estimates using federal spatial data

What is it? The Supplement is intended to offer detailed methodology for countries and sub-national entities to calculate GHG fluxes in wetlands. This methodology underlies wetlands flux estimates in the National GHG Inventory.

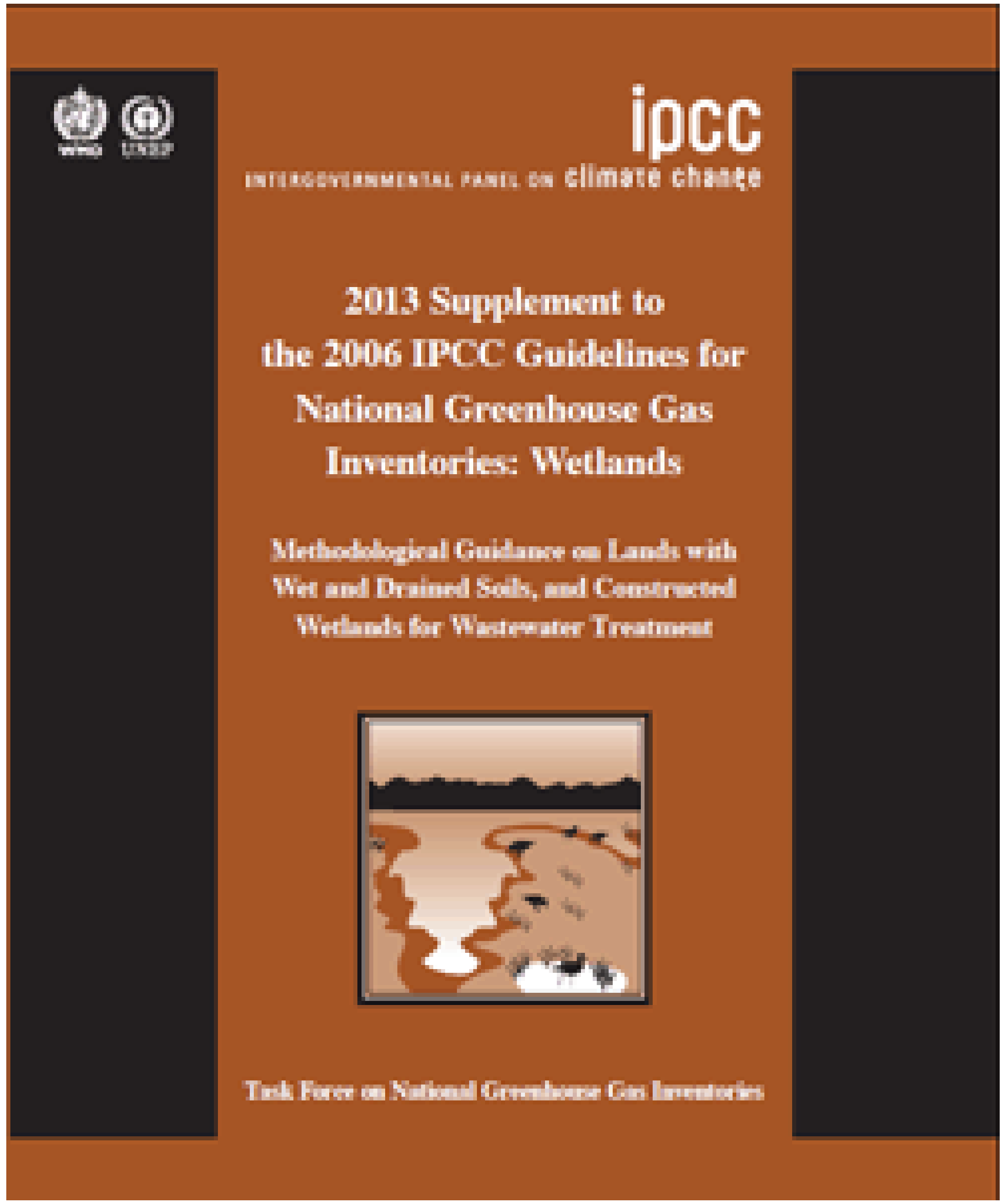
What does it do? It suggests GHG flux estimation methodology using emissions and removal factors as well as soil carbon stocks for various types of wetlands, such as coastal (tidal) wetlands, inland (terrestrial) wetlands, and human-made wetlands such as reservoirs. It also accounts for management activities such as re-wetting and draining wetlands.

Relevance to NWL Inventories: If states have adequate data on wetlands extent, type, and management activities, they could use the Wetlands Supplement to calculate emissions and removals for inventory purposes.

Limitations:

- To generate accurate wetlands GHG estimates, the Wetlands Supplement requires detailed and timely input data on wetland soil type, vegetation cover, and management activity, which may not be available at the state level.
- Due to the complexity of the methodology, states would need significant technical capacity to calculate fluxes using the suggested equations.

Resources: IPCC Wetlands Supplement



WMO UNEP

ipcc

INTERGOVERNMENTAL PANEL ON climate change

2013 Supplement to
the 2006 IPCC Guidelines for
National Greenhouse Gas
Inventories: Wetlands

Methodological Guidance on Lands with
Wet and Drained Soils, and Constructed
Wetlands for Wastewater Treatment

Task Force on National Greenhouse Gas Inventories

KEY CONCEPT

Wetlands policy and management

Integrate updated remote sensing data w/ federal spatial data

What are they? The Clean Water Act prohibits the net loss of wetlands. The US Army Corps of Engineers, EPA, USFWS, NOAA, and USGS each play a role in tracking the status of wetlands. Because multiple agencies track wetlands at a national level, there is no single data repository for states to document local changes in wetland extent and management status using this national data. Incomplete spatial documentation of wetlands can in turn make GHG flux estimates less precise.

What do they do? Wetlands can be modified or even destroyed under law, as long as these activities are balanced by restoration and/or establishment of other wetlands. Nevertheless, changes in the geographic locations or management of these wetlands may have large implications for GHG emissions. Since federal spatial datasets are updated with varying frequency, changes in wetlands management and/or extent may not be immediately recorded.

Relevance to NWL Inventories: Wetland emissions -- especially of non-CO_2 gases -- are highly dependent on the management history and conditions of the wetlands. Drainage and re-wetting of wetlands soils, as well as burning and vegetation removal such as peat harvesting have significant implications on the GHG emissions and removals from wetlands. This kind of activity data is required to use the IPCC Wetlands supplement, but currently these kinds of management and condition changes are not captured in a single federal database.

Limitations: Accurately estimating changes in flux from these activities requires spatially explicit information about changes in wetlands and their management, which may not be easily available to states. Gathering this information would require a dedicated research effort organized by states or conducted at the federal level.

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CHAPTER 6: BASELINES

Guide at a Glance

Chapter	Topic	Purpose
1	Overview	Understand basic concepts and identify inventory priorities for your state *(designed for state policymakers and agency staff)*
2	Trees & Forests	Deep dives into inventory improvement options across land use classes *(designed for agency staff)*
3	Croplands & Grasslands	Deep dives into inventory improvement options across land use classes *(designed for agency staff)*
4	Land Use Change	Deep dives into inventory improvement options across land use classes *(designed for agency staff)*
5	Wetlands	Deep dives into inventory improvement options across land use classes *(designed for agency staff)*
6	**Baselines**	**Deep dive into options for creating a historical or projected inventory baseline *(designed for agency staff)***
7	Federal Action	Overview of inventory improvement options that require action by Congress or federal agencies *(designed for state policymakers)*

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Executive Summary: The Issue

Baselines are used to represent what GHG emissions would be in the absence of any actions to reduce emissions or increase carbon sequestration. Including accurate baselines in a natural and working lands (NWL) inventory gives states the ability to benchmark progress over time, set ambitious but achievable GHG goals for the sector, and implement policies to address key opportunities for GHG reduction.

Baselines within GHG inventories typically take the form of reported emissions data from a single historical year—often 1990 or 2005—that is before the jurisdiction began implementing climate change policies. Most default sources of state inventory data, such as the EPA State Inventory Tool (SIT) and state-level data from the National GHG Inventory, include historical baseline data, typically going back to 1990. Comparing current GHG inventory data to a historical baseline from these “default” data sources can give states a reasonable picture of their trends in GHG flux over time, but there are important limitations to this approach:

- **Historical baselines provide limited guidance for goal-setting and policymaking.** Evaluating policy approaches by comparing current inventory data to an historical baseline implicitly assumes that GHG emissions would have remained constant in the absence of policy action. This assumption overlooks the effects of natural processes and climate change on GHG fluxes from NWL. For example, looking at historical GHG data from US forests would show a stable and slowly growing carbon sink, while forward-looking projections show the sink peaking and declining as forests age and climate change increases the risk of severe disturbances. Goals and policies based on projected baseline data would therefore be better targeted toward future risks and opportunities across all land uses than those based only on historical baseline data.

- **Default data sources used to construct an historical baseline are not spatially explicit.** While historical state-level GHG flux data from SIT would be sufficient to track progress toward state goals, the absence of high-resolution data limits the utility of these baselines for other purposes that may support the state’s NWL objectives, such as informing policymaking, land use planning and progress tracking at the local level.

- **The accuracy of historical baselines is limited by the robustness of underlying data sources.** Missing or sparse data for the base year can increase the margin of error around the historical baseline. For example, of the three primary federal datasets that inform NWL inventories, the Forest Inventory and Analysis (FIA) program published periodic rather than annual data prior to 2001, while the National Resources Inventory (NRI) only collected data every 5 years until 1997 and the National Land Cover Database (NLCD) only published complete national data once before 2000—in 1992. Therefore, the GHG flux estimates going back to 1990 in both the National GHG Inventory and SIT are subject to greater uncertainty than more recent estimates, though this historical uncertainty is not quantified. Moreover, as states adopt new methods to improve the accuracy of their NWL inventories, historical baselines calculated with older methods will become less appropriate for comparisons with current inventory data.

Executive Summary: Solutions

States can increase the value of their inventory for goal-setting and policymaking by incorporating a projected baseline that forecasts GHG fluxes from NWL under likely future conditions. The **2020 Resources Planning Act (RPA) Assessment** led by the USDA Forest Service will include probabilistic spatial projections down to the county level of GHG fluxes in forests and rangelands through 2070 under a range of climate change and socioeconomic scenarios. States could easily incorporate these data, which will be published by early 2021, into their own inventories. This chapter includes information on **projected baselines for US forests and rangelands** using data from the previous 2010 RPA Assessment.

While data from the 2020 RPA Assessment would provide clear value to state inventories, they would not cover all land uses that states may wish to target through GHG goals and policies; for example, GHG fluxes are not projected for croplands, wetlands, or grasslands other than rangeland. The RPA Assessment is also updated infrequently—by law, it undergoes a full update every decade, with a coarser refresh of the projections after 5 years—which means it will not be as timely for state goal updates and policymaking processes later in the decade. An alternative solution would therefore be for states to **create a custom projected baseline** using national and/or state-specific land use data and GHG models. This would allow states to include all land uses of interest and customize the assumptions and update frequency for their projected baseline. A custom model would, however, require significant time and resources to develop and validate. This chapter details how this approach has been applied in **Hawai'i** to develop a projected baseline across land uses and in **Maryland** to project carbon stocks in trees and forests.

States considering improvements to the data sources and/or methodologies underlying their NWL inventories may also find value in **back-casting an updated historical baseline** using their new data and methods. A back-casted historical baseline would be equivalent to a custom projected baseline where GHG fluxes are modeled backward rather than forward in time. This historical baseline improvement would allow states to make apples-to-apples comparisons between their historical baseline data and current year inventory data for progress tracking by removing any disparities that may arise from changes to the inventory methodology. However, this approach may result in historical data that do not match state-level data derived from the National GHG Inventory or previous iterations of the state's GHG inventory.

Historical vs. Projected Baselines

> *The baseline (or reference) is the state against which change is measured.* —IPCC Data Distribution Centre

	Historical Baseline	**Projected Baseline**
What is it?	GHG emissions recorded in a previous "base" year, used as an initial condition for measuring absolute changes in GHG flux over time ("what the atmosphere sees").	GHG emissions modeled in future year(s) based on current policies, used as a reference scenario for estimating changes in GHG flux due to new policies or management actions. A projected baseline is *not* the same as an opportunity assessment, which projects the maximum possible emission reduction from a specific mitigation pathway.
Suitable application(s)	Track progress toward a goal relative to a base year (e.g. "50% below 1990 levels")	Evaluate policy impacts or ambition of sectoral goals compared to a reference scenario
Key considerations for NWL inventories	GHG inventory must cover the base year(s), either with historical data or by back-casting a modeled relationship over time.	Projection model must include clear and consistent assumptions (e.g. for development trends, forest growth) that match the baseline's policy application(s).
Limitations	• Does not identify relative contributions of natural processes and anthropogenic factors (like land use change or management) to changes in GHG flux • Provides no information on how GHG fluxes may shift due to climate change or socioeconomic trends	• Necessary assumptions around future conditions can lead to significant uncertainty in projected estimates • Changes in GHG flux relative to a projected baseline are not "what the atmosphere sees" and may not correspond to actual reductions in net GHG emissions

DEFAULT APPROACH

EPA State Inventory Tool

What does it include?

- Historical baseline data for land use, land use change and forestry (LULUCF) starting in 1990
- No projected baseline for LULUCF (though the Projection Tool module of SIT includes a projected baseline through 2050 for other sectors)

Major limitations

- SIT does not attribute GHG flux in historical baseline to natural processes (such as natural forest regrowth or insect outbreaks) versus anthropogenic factors (such as land use change or forest harvest), limiting the utility of the historical baseline for land management and policy decisions
- The absence of a projected baseline for LULUCF makes it difficult to set sectoral GHG targets or policy goals that account for expected future changes in climate and socioeconomic trends

BASIC IMPROVEMENT

Projected baselines using federal data

What will it entail?

- The 2020 Resource Planning Act (RPA) Assessment, led by the USDA Forest Service, will include county-level projections and accompanying spatial data at a 90-meter resolution for GHG fluxes from forests, rangeland and land use change under different scenarios in 10-year increments through 2070
- Data expected to be published by early 2021, with the full report to follow later in the year

What problem(s) will it solve?

- Projects impacts of climate change and development on carbon storage in NWL
- Identifies major drivers of projected changes to forest carbon sink, e.g. harvests and fire
- Provides consistent framework for projecting land uses and carbon flux across states

Limitations

- RPA Assessment projects GHG fluxes in forests and rangelands but not in croplands, managed pasture lands or wetlands. Non-forest land use categories are modeled only to assess land use change projections (between all IPCC land use categories)
- RPA Assessment typically updated only every 10 years, with a coarser refresh after 5 years, limiting the timeliness of the projections to inform ongoing policy and management processes
- Projections do not account for impacts of existing state policies

KEY CONCEPT: Methods for calculating a projected baseline

KEY DATA SOURCE: Resource Planning Act (RPA) Assessment

CASE STUDY: Forests in the RPA Assessment

CASE STUDY: Rangelands in the RPA Assessment

CASE STUDY

Forests in the RPA Assessment

What: The 2010 RPA Assessment uses FIA data and the same methodology that underlies the National GHG Inventory to quantify and project carbon stocks, emissions, and removal in US forests. The carbon baseline data in this assessment builds on climate and land use change scenarios in the larger RPA Assessment.

Why: Updated baseline data makes it possible to more accurately track changes in forest carbon stocks due to management changes and to establish projected baselines that account for the effects of climate change. This can help inform management of forests for carbon sequestration in the future and to help prioritize conservation and restoration in certain areas.

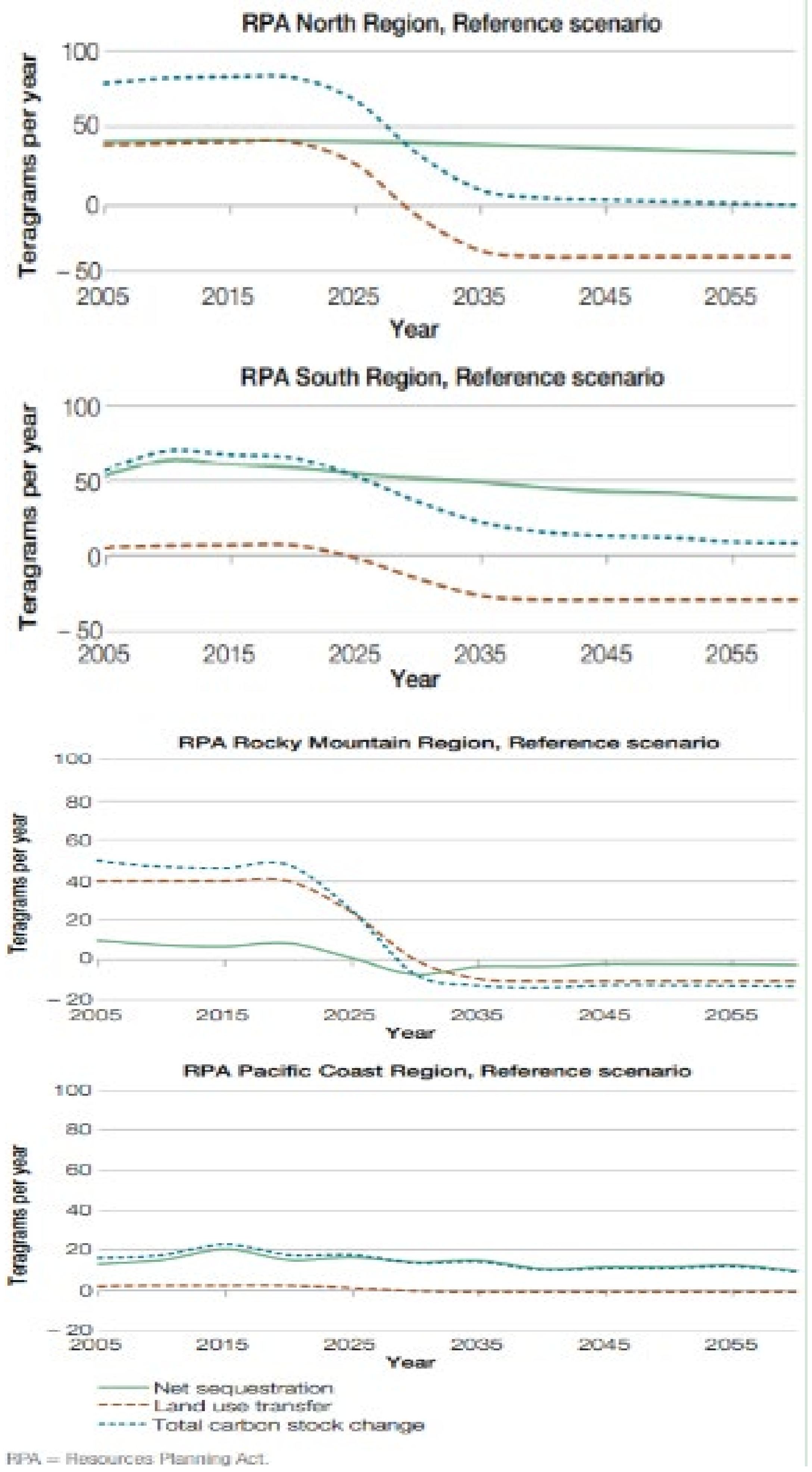
Results:

- The rate of carbon sequestration in forests, accounting for land use change, is expected to decline significantly in all regions except the Pacific Coast from 2020-2050
- Difference between 2005 stock change (historical baseline) and 2050 stock change (projected baseline) by region: North - 95%, South - 80%, Rocky Mountains - 120%, Pacific - 30%

Limitations:

- There is uncertainty surrounding the effects of climate change on future forests, which creates some uncertainty in RPA Assessment projections
- The 2010 RPA Assessment included regional but not state-level analyses

Resources: Update to the 2010 RPA Assessment



RPA = Resources Planning Act.

Source: RPA Assessment

CASE STUDY

Rangelands in the RPA Assessment

What: The 2010 RPA Assessment estimates rangeland extent and uses soil organic carbon flux data from the National GHG Inventory and stock data from the USGS Land Carbon Project to establish baselines for carbon in rangelands and project future sequestration.

Why: Estimating soil organic carbon baselines and projections can inform land management policy and make it possible to observe departures from projections and attribute changes to land management activities. It also can shape policy and management decisions that may help rangelands retain and/or sequester carbon in the future.

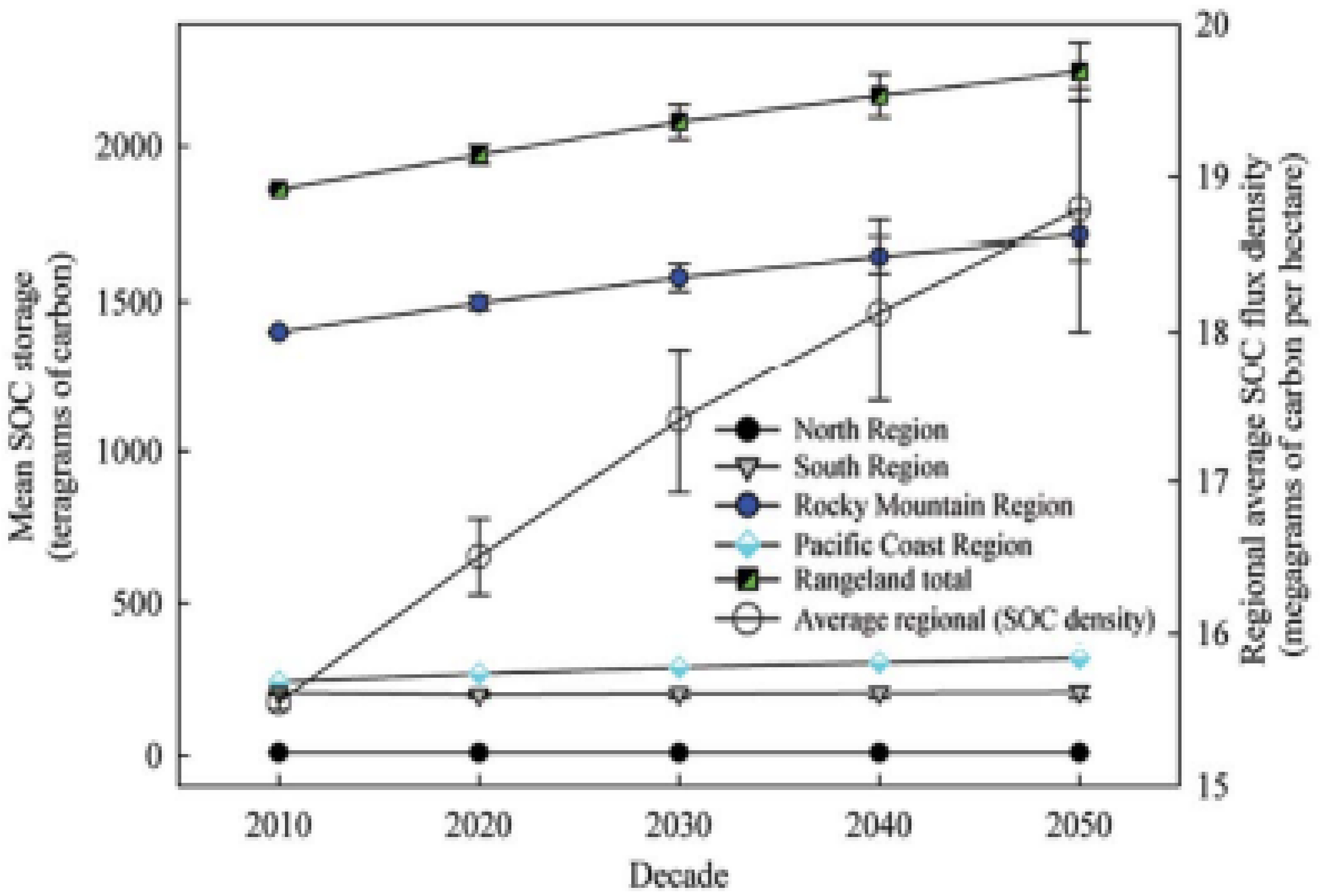
Results:

- Soil carbon stocks in rangeland are projected to increase in the west while remaining relatively stable in the east
- A projected baseline would provide the greatest value for Rocky Mountain states, with a projected stock change of 30% from 2010-2040; projected stock changes in other regions are less significant

Limitations:

- Because there is no equivalent of FIA for rangelands, there is limited nationally consistent data on rangeland extent. This may make carbon stock baselines imprecise.
- High levels of uncertainty in EPA GHG Inventory models
- The RPA Assessment only includes soil carbon projections for rangelands, not croplands or other grasslands

Resources: Update to the 2010 RPA Assessment, USGS Land Carbon Project



Mean soil organic carbon (SOC) storage (primary y-axis), by RPA region, and mean SOC flux density (secondary y-axis) for conterminous U.S. rangelands, 2010 to 2050. Source: RPA Assessment

Beyond RPA: Why might states prioritize additional improvements for Baselines?

- Include **projections for all non-forest land uses**
  - ➢ *Particularly important for states that want to set goals or track progress on GHG reductions specifically within croplands, grasslands or wetlands*

- Provide **customized updates** of projected baseline to incorporate new or proposed policies or refresh projections more frequently
  - ➢ *Particularly important for states that want to project policy impacts or use state-specific data sources*

- **Enhance spatial resolution** of baseline to allow data to be parsed at the local level
  - ➢ *Particularly important for states seeking to facilitate local climate action planning on NWL*

- **Update historical baseline** to track progress toward GHG goals using new data sources
  - ➢ *Particularly important for states that plan to integrate remote sensing-based methods into their NWL inventory and wish to track their progress against a baseline using the same methodology*

BASELINES

Additional Improvements

	IMPROVEMENT 1	IMPROVEMENT 2
Improvement Objective	Create a custom projected baseline	Back-cast updated historical baseline
Expand projected baseline to include all land uses	✓	
Make updates to baseline data more timely and more reflective of current policies	✓	
Enhance spatial resolution of baseline data	✓	✓
Reduce uncertainty around historical baseline by reconciling old and new data sources		✓

IMPROVEMENT 1

Create a custom projected baseline

What would it entail?

- Identifying national or state-specific data sources that can be used to map current land uses (such as optical imagery or LIDAR)
- Projecting future land use change using socioeconomic models that relate population and GDP growth to land use and/or spatial data sources like development records and plans
- Modeling future carbon flux across land uses of interest under projected future climate and socioeconomic conditions, as well as other policy scenarios if desired
    - ➢ May be time- and resource-intensive to develop projections from custom data sources or models

What problem(s) would it solve?

- Projecting a baseline with state-specific and high-resolution spatial data allows for more targeted actions and policies affecting land use planning at the state and local levels

What problem(s) would it solve? (cont.)

- Would enable a state to update the projection on any desired frequency
- State could build a custom projected baseline to include land uses that are not addressed in the RPA Assessment, such as croplands and wetlands

Limitations

- Socioeconomic and climate models used for national and global projections may have larger inherent uncertainties when applied on a smaller spatial scale
- Many remote sensing data products that may be useful for projected baselines don’t have sufficient historical data to model GHG fluxes for a base year—for example, NLCD was first produced in 2001, while most airborne LIDAR data collection began in late 2000’s

Go deeper

CASE STUDY: Hawai’i

CASE STUDY: Maryland

CASE STUDY

Hawai’i

What: Hawai’i partnered with the USGS LandCarbon project to establish an updated inventory and a projected baseline for NWL carbon fluxes and storage. The report relies on several data sources for the projected baseline, including:

- Vegetation mapping using Landsat-based optical imaging and on-the-ground surveys;
- A state-specific LANDFIRE product that is merged with NLCD data to provide land use and land cover data;
- Soil carbon data from the NRCS gridded Soil Survey Geographic (gSSURGO) database; and
- Original USGS research to provide temporally and spatially explicit estimations of GHG stocks and fluxes.

Why: Because of its unique ecosystems and geography, Hawai’i wanted to create a state-specific, comprehensive and up-to-date projected baseline for carbon storage and fluxes so it could predict how future changes in climate and land use would affect carbon cycling and storage.

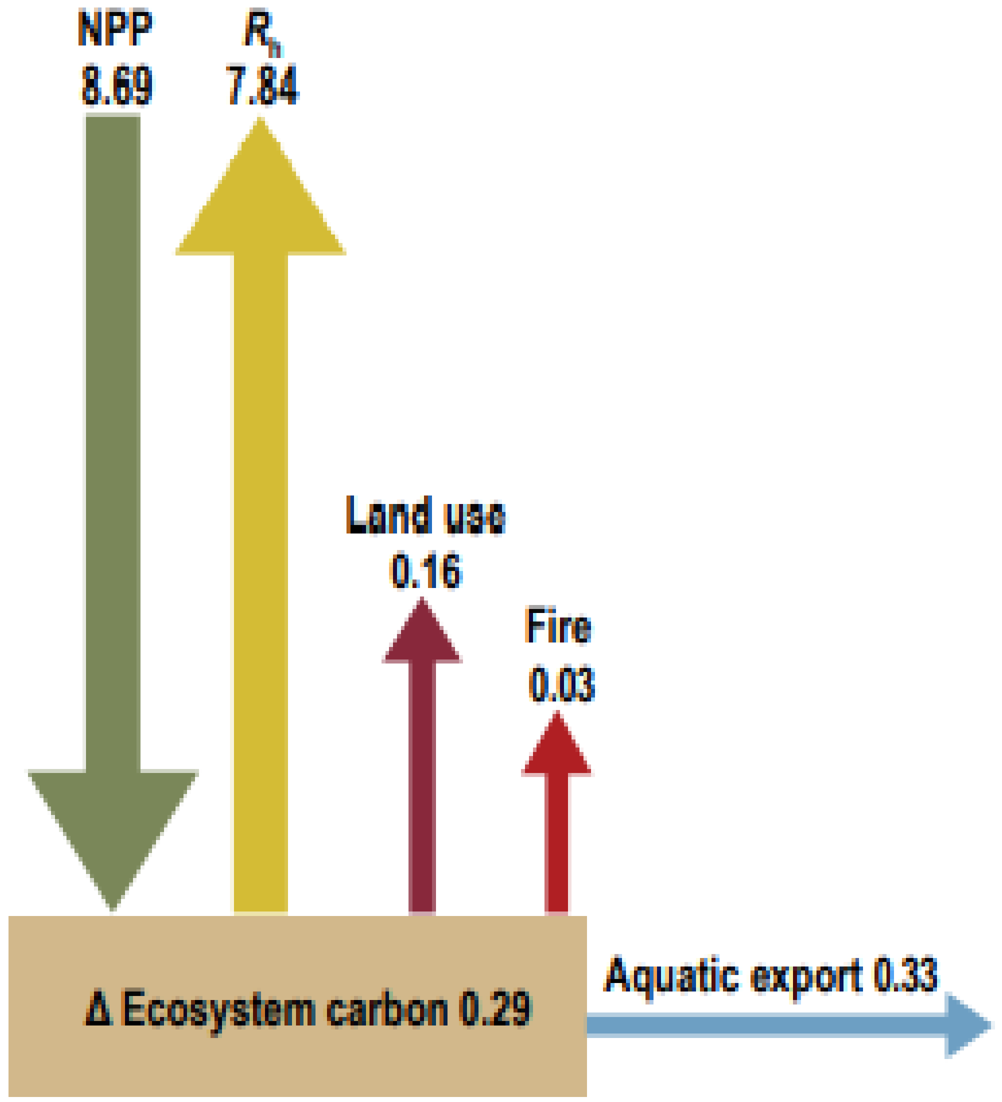
Results:

- During the projected future period (2012–2061), Hawai’i’s terrestrial carbon sequestration would decrease by more than 30 percent (from 1.25 to 0.81 MMT CO_2/yr) because of a decrease in net primary productivity (NPP) and land use change
- Area of developed land was projected to more than double by 2061, accounting for a net annual loss of 0.37 MMT CO_2/yr in the state’s net carbon ecosystem balance

Limitations:

- High uncertainty for estimates of vegetation carbon fluxes because out-of-state data were used for flux estimates.
- Optical imagery used to initialize the land use/land cover projections was collected in 2005, so projected baseline is not based on the most timely data.

Resources: Baseline and Projected Future Carbon Storage and Carbon Fluxes in Ecosystems of Hawai‘i, USGS LandCarbon Project, (gSSURGO)



Projected future mean annual carbon fluxes and change in ecosystem carbon storage for the State of Hawai‘i averaged across the 50-year future simulation period (2012–2061). NPP = net primary production; Rh = heterotrophic respiration; in MMT C/yr.
1 MMT C = 3.67 MMT CO_2.
Source: https://pubs.usgs.gov/pp/1834/a/pp1834.pdf

CASE STUDY

Maryland

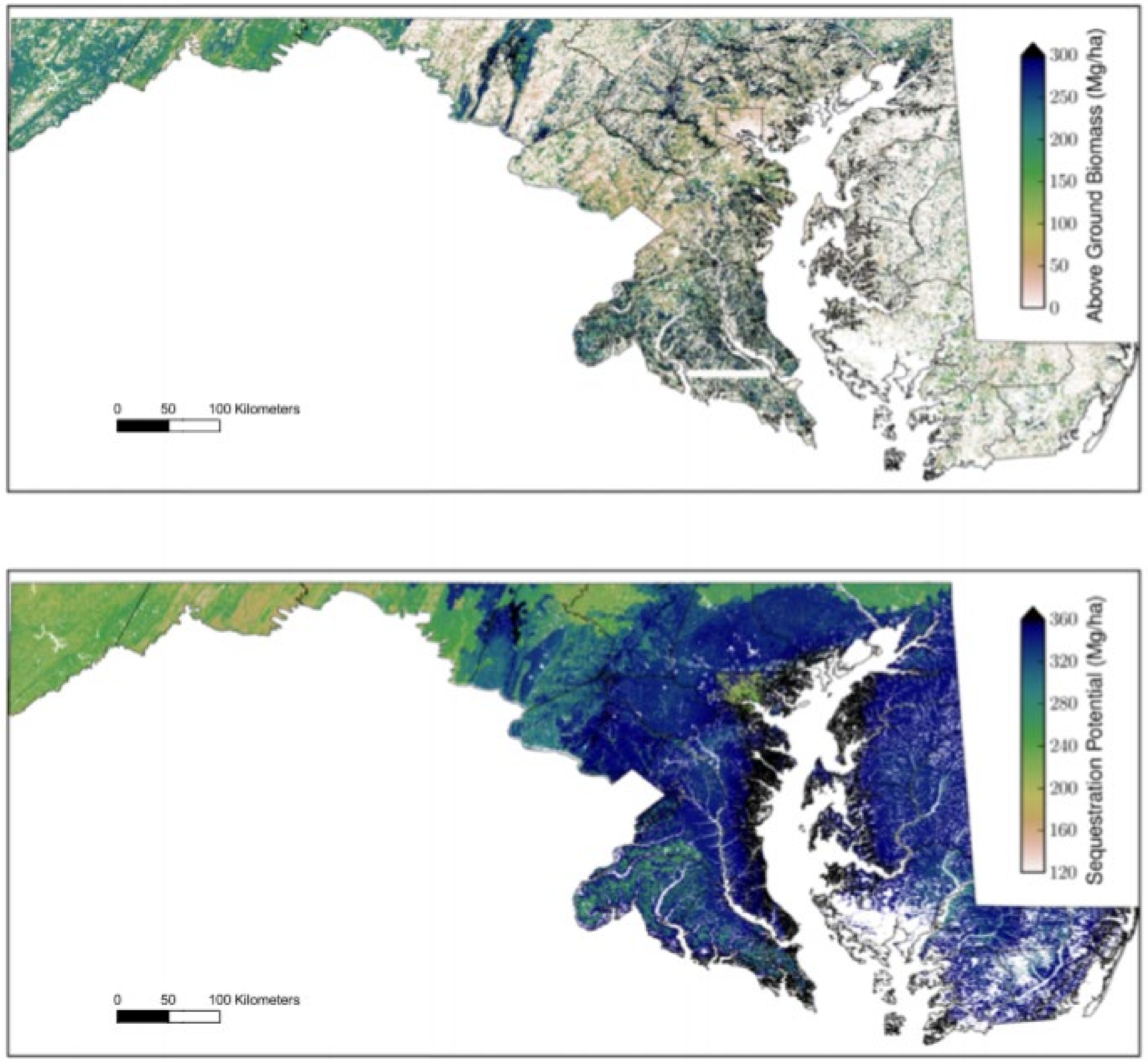
What: University of Maryland paired their current spatial data on trees and forests in Maryland (see “Trees & Forests” case study) with ecosystem modeling to project forest growth in the state and corresponding carbon sequestration potential over the next 300 years

Why: Maryland wanted to consider site-specific carbon sequestration potential in their forest planting and management plans. Spatial data on carbon potential will also guide the state’s conservation and restoration priorities.

Results: The maximum potential aboveground carbon storage for Maryland forests was estimated to be 3 times as large as current carbon storage, with the largest potential gains per acre occurring in eastern Maryland. Half of the state’s additional carbon potential could be sequestered within 80 years.

Limitations: Modeling did not account for projected impacts of climate change on forest growth rates or disturbance. Projected changes to other land uses including agriculture, wetlands and urban development were not considered.

Resources: [Beyond MRV: high-resolution forest carbon modeling for climate mitigation planning over Maryland]()



Top: Current forest carbon storage in aboveground biomass as estimated from LIDAR data
Bottom: Modeled carbon storage potential within 300 years
Source: [Hurtt et al. 2019]()

IMPROVEMENT 2

Back-cast updated historical baseline

What would it entail?

- Using modeling methods akin to those for projected baselines to model GHG flux in a historical year from new data sources
  - ➢ IPCC has long-standing guidance on general approaches for ensuring time-series consistency in data, even when methods change
- Comparing "back-casted" historical baseline to a baseline for the same year derived from traditional data sources (e.g. FIA, NRI) and reconciling any observed difference between methods (e.g. accounting for trees outside of forests, or refining estimates of agricultural practice adoption)

What problem(s) would it solve?

- Allows states that have already set targets using a historical base year to update their inventories with new and improved datasets, even when those datasets do not include data for the historical base year, without a discontinuity in historical GHG flux estimates
- Allows states to develop an historical baseline using spatial data, which facilitates progress tracking at sub-state and local levels

Limitations

- May produce historical data that is inconsistent with state-level data derived from the National GHG Inventory
- May cause significant changes in reported GHG flux for historical years from one inventory to the next due to changes in methods

Go deeper

KEY TOOL: IPCC Guidelines on timeseries consistency

BASELINES

Key Takeaways

- SIT includes historical baseline data starting in 1990 for LULUCF, but does not provide a projected baseline for that sector.
- The 2020 Resources Planning Act (RPA) Assessment, to be released by early 2021, will include high-resolution spatial projections for GHG fluxes from forests, rangelands and land use change.
- States seeking to develop projected baselines for other land uses or under other policy assumptions, and states that wish to compare a remote sensing-based inventory with a historical baseline, may wish to make additional improvements to their GHG Inventory baseline.
- Additional inventory improvements may increase the sectoral coverage and timeliness of a projected baseline, enhance the spatial resolution of baseline data, or synchronize new data sources (e.g. remote sensing data) with a historical baseline.
- Additional improvements available to states include creating a custom projected baseline or back-casting a historical baseline using new data sources.

GOING DEEPER:

Key Concepts, Data Sources and Tools

KEY CONCEPT

Methods for calculating a projected baseline

Projected baselines using federal spatial data

What are they? A projected baseline can be calculated using simple methods like extrapolating future GHG emissions from historical trends in emissions or activity data, or using more complex and robust methods like modeling future GHG emissions based on a set of input variables.

Why do they matter for NWL inventories? The choice of method, data source and assumptions for calculating projected baselines affects how the baseline can be used to inform state policymaking, planning and goal-setting.

	Extrapolation from historical data	**Modeling based on projected scenarios**
Inputs	Historical data on GHG emissions from land use, land use change and forestry (LULUCF), and/or historical land use and activity data	Forecast scenarios for climate change, population and economic growth
Possible data sources	State or National GHG Inventory; Census of Agriculture; Forest Service reports	Representative Concentration Pathways (RCPs) and Shared Socioeconomic Pathways (SSPs) in the IPCC Fifth Assessment Report; US Census Bureau reports
Types of models that may be used	Linear or nonlinear regressions to extrapolate historical trends; if activity data are used, biogeochemical model to estimate GHG fluxes in soils	Econometric model to relate socioeconomic projections to land use; forest dynamics model; trade model to estimate demand for wood products; biogeochemical model to estimate GHG fluxes in soils
Outputs	Single projected baseline reflecting historical climate and socioeconomic trends	Multiple projected baseline scenarios reflecting different future climate and socioeconomic assumptions
Example	EPA State Inventory Tool (for sectors other than LULUCF)	RPA Assessment

Projected baselines using federal spatial data

KEY DATA SOURCE

Resource Planning Act (RPA) Assessment

What is it? Decadal assessment by the Forest Service (with intermediate updates) on resource conditions and trends in US forests and rangelands.

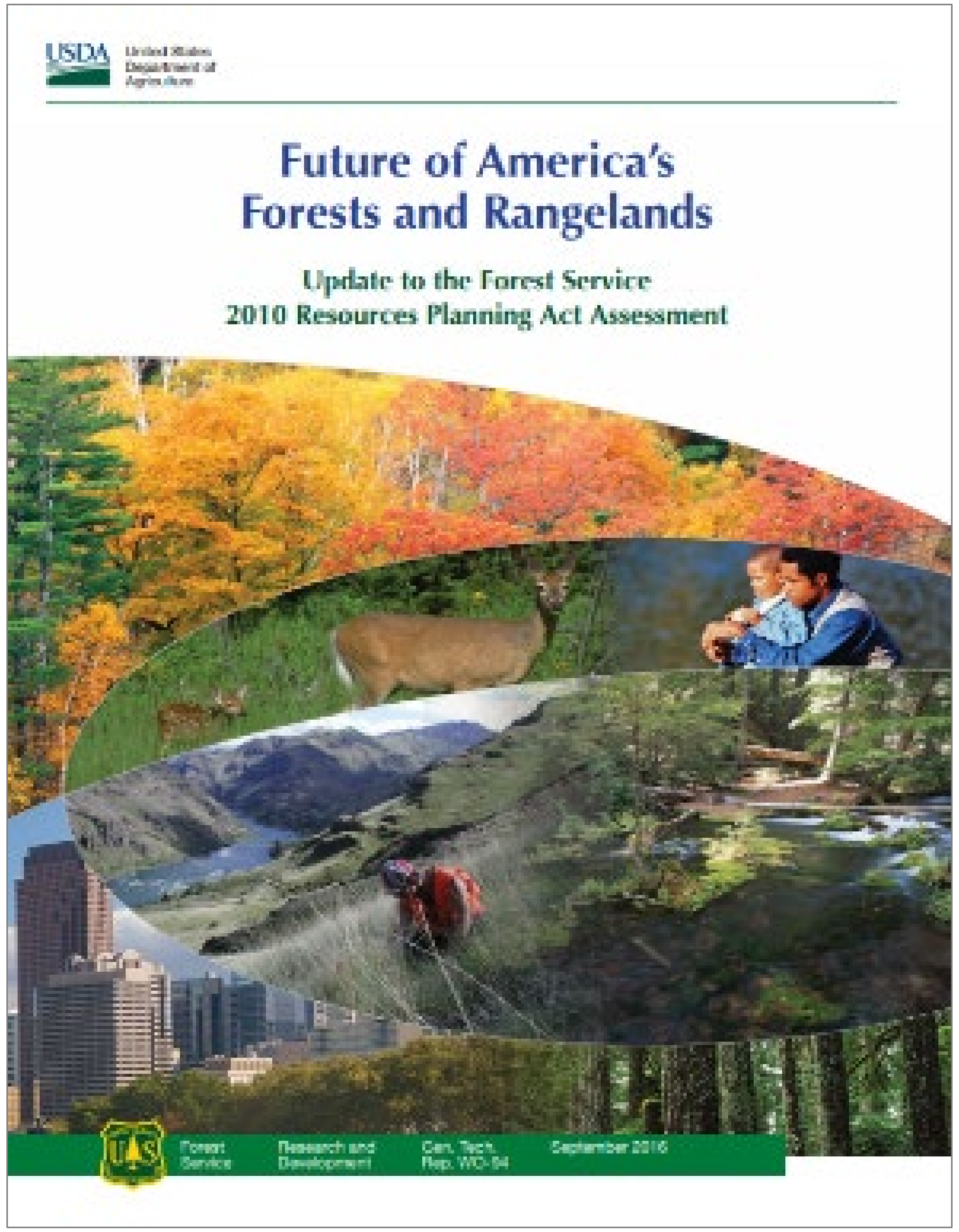
What does it do? Projects carbon fluxes from forests, rangelands, and land use change 50 years forward at 10-year timesteps based on FIA and NRI data and global trade models. RPA projections correspond to different IPCC scenarios for climate change, population and economic growth.

Relevance to NWL inventories: The 2020 RPA Assessment will include county-level projections for land use change and GHG fluxes in forests and rangelands and accompanying spatial data that could be integrated into state inventories as a projected baseline.

Limitations:

- Doesn't include detailed projections on croplands or wetlands (other than projected land use change)
- No projection data available for Alaska or Hawai'i
- 2020 Assessment will not be available until late 2020 or 2021, too late for some states' climate planning deadlines

Resources: Update to the 2010 RPA Assessment; About the RPA Assessment



Future of America's
Forests and Rangelands

Update to the Forest Service
2010 Resources Planning Act Assessment

Forest Service | Research and Development | Gen. Tech. Rep. WO-94 | September 2016

Forest Service 2016

KEY TOOL

IPCC Guidelines on time series consistency

Back-cast updated historical baseline

What is it? International guidance on bridging historical datasets with newer datasets for GHG flux estimation. This preserves the consistency of inventory estimates over time.

What does it do? The 2006 IPCC Guidelines for National GHG Inventories, Volume 1, Chapter 5 provides instructions for using data overlap techniques to increase consistency with emissions data that may have been collected or estimated using different methods at different times. This chapter recommends methodology and approaches that are most appropriate for different applications such as adding new categories or identifying changes in activity levels.

Relevance for NWL Inventories: Consistent methodology and/or careful recalculation is essential to ensure that changes in recorded GHG emissions over time are due to actual changes, not changes in methodology. This is important for states looking to establish accurate historical baselines.

Limitations:
- Choosing and employing the various approaches to time series consistency addressed in these guidelines can require significant technical expertise
- Historical emissions data may have been collected with methods or technology that have greater uncertainty or lower spatial or resolution than current approaches, making it challenging to accurately bridge time series data.

Resources: IPCC Time Series Consistency

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CHAPTER 7: FEDERAL ACTION

GUIDE TO NWL INVENTORY IMPROVEMENTS

Guide at a Glance

Chapter	Topic	Purpose
1	Overview	Understand basic concepts and identify inventory priorities for your state *(designed for state policymakers and agency staff)*
2	Trees & Forests	Deep dives into inventory improvement options across land use classes *(designed for agency staff)*
3	Croplands & Grasslands	Deep dives into inventory improvement options across land use classes *(designed for agency staff)*
4	Land Use Change	Deep dives into inventory improvement options across land use classes *(designed for agency staff)*
5	Wetlands	Deep dives into inventory improvement options across land use classes *(designed for agency staff)*
6	Baselines	Deep dive into options for creating a historical or projected inventory baseline *(designed for agency staff)*
7	**Federal Action**	**Overview of inventory improvement options that require action by Congress or federal agencies *(designed for state policymakers)***

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Executive Summary: The Issue

While states can pursue a variety of inventory improvements that exceed the capabilities of existing federal datasets and tools, some inventory improvements could be more effective if implemented at the federal level. This is true for improvements that would leverage existing infrastructure, processes or technical expertise within federal agencies. Federal implementation also makes sense for inventory improvements that would require funding or staff capacity beyond the means of most state agencies. Finally, federal action is warranted where state-level inventory improvements could also materially enhance the quality of the National GHG Inventory and the EPA State Inventory Tool (SIT), including by:

- **Reducing uncertainty around GHG flux estimates for land use, land use change and forestry (LULUCF) in the National GHG Inventory.** The margin of error around the net GHG flux estimate for LULUCF is by far the highest of any sector in the National GHG Inventory; as a percentage of net flux, LULUCF has a margin of error 15 times greater than energy use. Improving the LULUCF inventory methodology to reduce that error would give the U.S. more confidence in the emissions data it reports under international agreements, and could also provide stronger support for a national strategy to reduce GHG emissions in natural and working lands.

- **Making datasets that underlie the LULUCF section of the National GHG Inventory more timely.** Estimates of forest carbon flux in the National GHG Inventory are derived from the field-based Forest Inventory and Analysis (FIA) program, which collects plot data on a rotating basis once every 5-10 years and cannot therefore account for carbon impacts from sudden forest disturbances in a timely fashion. Data on wetland extent in the National GHG Inventory are derived from the National Land Cover Dataset (NLCD), which is updated every 5 years and thus does not capture more recent changes in wetland management. More timely data sources could improve the quality of both of these components of the National GHG Inventory.

- **Enhancing the spatial and temporal resolution of data presented in the National GHG Inventory.** Estimates of forest carbon flux derived from FIA data smooth over year-by-year changes and geographic variations. For wetlands, available federal datasets such as the National Wetlands Inventory (NWI) and NLCD-based products such as NOAA’s Coastal Change Analysis Program (C-CAP) vary in their spatial resolution, making it difficult to track localized changes in wetlands management and GHG flux. Integrating more spatially and temporally explicit data sources into the National GHG Inventory could produce more granular flux estimates to inform adaptive land management and policy decisions.

- **Allowing GHG fluxes from LULUCF to be attributed to specific causes with greater precision.** The plot-based FIA system does not provide information to link forest carbon fluxes to specific causes like wildfire or timber harvest. While national GHG flux estimates for cropland and grassland soils are estimated as a function of specific land management activities, those estimates are based on models that are only as accurate as the experimental field data used to calibrate them. Incorporating additional information that links GHG fluxes to specific causes or activities could enhance the functionality of the National GHG Inventory for informing land management and policy.

- **Filling gaps in current National GHG Inventory data.** While the National GHG Inventory presents a far more comprehensive accounting of GHG flux from LULUCF than the state-level data provided by SIT, there remain gaps in the national accounting. These include fluxes from trees in agroforestry systems, terrestrial wetlands (aside from peatlands), flooded lands and coastal seagrass beds. New data sources for the National GHG Inventory could fill some if not all of these data gaps.

Executive Summary: Solutions

The federal government could address current limitations of the FIA program for carbon flux estimation in the National GHG Inventory by **developing a national remote sensing-based forest and land use inventory.** Such an inventory would entail integrating regularly updated LIDAR and/or phodar data to map carbon stocks and fluxes in trees and forests and layering in optical imagery-based tools to identify areas of disturbance and land use change. Implementing that improvement would require coordination between the USDA Forest Service, which manages the FIA program, and NASA, which manages multiple LIDAR and satellite imagery products, along with other federal agencies and programs for certain aspects of the inventory.

Another improvement to the National GHG Inventory could come from **monitoring soil carbon through national field networks**, which would reduce uncertainty around GHG flux estimates in cropland and grassland soils and improve the precision of models that estimate these fluxes based on land management activities and environmental factors. This improvement could be achieved by sampling soil carbon on a subset of existing plots monitored through the National Resources Inventory (NRI), as has been recommended by the National Academies of Sciences. Soil carbon measurements could also be linked to activity data on land management through the Conservation Effects Assessment Project (CEAP). The USDA Natural Resources Conservation Service (NRCS) would have the responsibility to implement this improvement, given the necessary appropriations from Congress.

The federal government could further improve the National GHG Inventory through the creation of a **high-resolution wetlands spatial dataset** that could register changes in wetland extent, vegetation, and management. This dataset could be regularly updated using LIDAR/phodar data, which generally captures wetland vegetation type better than optical imaging. A spatial dataset could be paired with the development of a **network of field-based sample plots** to measure GHG fluxes in various types of wetlands and to establish locally-specific flux values for wetlands. With spatially explicit data on wetlands type and management and verified flux values, the National GHG Inventory could more effectively use the methodology from the IPCC Wetlands Supplement to estimate national GHG fluxes, including for wetland types that are currently excluded from the National GHG Inventory. Given that a number of federal agencies including the US Fish & Wildlife Service, the National Oceanic and Atmospheric Administration (NOAA), the Army Corps of Engineers, and the US Geological Survey all monitor wetlands, this improvement could best be achieved through coordination between agencies.

Inventory improvements and federal action

An inventory improvement may be appropriate for federal action if:

- It would leverage existing infrastructure, processes, or expertise in federal agencies
- It would require funding or staff capacity beyond the means of most state agencies
- It would materially improve the quality of GHG flux estimates for land use, land use change and forestry (LULUCF) in the National GHG Inventory and EPA State Inventory Tool (SIT)

How can states promote federal action?

- Communicate with relevant federal agencies about the need for specific inventory improvements (and the value they would provide to states)
- Contact their representatives in Congress to request federal funding for inventory improvements through agency appropriations or legislation
- Join with other states to call for federal action to improve national inventory capabilities

Why pursue inventory improvements at the federal level?

- **Reduce uncertainty** around national and state-level estimates of GHG fluxes in the LULUCF section of the National GHG Inventory
  - ➢ *Important for increasing confidence in LULUCF emissions data reported under international agreements and for developing a national strategy to reduce GHG emissions from natural and working lands (NWL)*
- Make **more timely** national data available to calculate GHG fluxes in LULUCF
  - ➢ *Important for reflecting current land use, forest dynamics and wetland management in the National GHG Inventory*
- **Enhance data resolution**—both spatial and temporal
  - ➢ *Important for informing adaptive land management and policy decisions at national and sub-national levels*
- Allow GHG fluxes to be **attributed to specific causes** with more precision through better spatial data on land management activities and disturbances and improved GHG models for soils
  - ➢ *Important for informing land management and policy decisions*
- **Expand the scope** of GHG inventory data available at the national and state level by filling current data gaps, including for trees outside forests and terrestrial wetlands
  - ➢ *Important for ensuring that national and state NWL inventories are comprehensive*

FEDERAL ACTION

Inventory improvements

	FEDERAL ACTION 1	FEDERAL ACTION 2	FEDERAL ACTION 3
Improvement Objective	Develop a national remote sensing-based forest and land use inventory	Monitor soil carbon through national field networks	Develop a national spatial inventory of wetland GHG fluxes
Reduce uncertainty in GHG flux estimates	✓	✓	✓
Improve timeliness of underlying datasets	✓		✓
Enhance data resolution	✓		✓
Refine attribution of GHG fluxes to specific causes	✓	✓	
Expand scope of GHG inventory	✓		✓
Relevant land use categories	Trees & Forests; Land Use Change	Croplands & Grasslands	Wetlands

FEDERAL ACTION 1

Develop a national remote sensing-based forest and land use inventory

What would it entail?

- Collecting annually-updated national LIDAR data, such as from NASA’s Global Ecosystem Dynamics Investigation (GEDI), and/or phodar data, such as from the National Agricultural Inventory Program (NAIP)
- Calibrating the LIDAR/phodar data with field measurements from the Forest Inventory and Analysis (FIA) program to map biomass and carbon stocks in trees and forests
- Estimating annual carbon flux based on the change in LIDAR/phodar-derived carbon stocks from one data collection period to the next
- Creating an annually-updated map of forest disturbance and land use change from Landsat-based products and supplementary data sources, such as by enhancing the LANDFIRE tool
- Layering the LIDAR/phodar-based carbon flux maps with the Landsat-derived disturbance maps to attribute carbon fluxes to specific causes
- Updating methodology in National GHG Inventory and SIT for carbon flux in forest land remaining forest land, land converted to/from forest land, and settlements remaining settlements (urban trees)
- Making all spatial data available to state and local policymakers and scientific researchers

What problems would it solve?

- Reduces uncertainty of forest carbon stock estimates by pairing FIA plots with LIDAR data
- Reduces uncertainty of urban tree carbon stock estimates by replacing the current literature-based methodology with a remote sensing-based approach consistent with forest carbon estimation
- Makes estimates of forest-related land use change more timely by identifying areas of forest loss or gain in regularly-updated satellite imagery
- Enhances the spatial resolution of carbon flux estimates by calibrating high-resolution remote sensing data to FIA plot measurements
- Enhances the temporal resolution of carbon flux estimates by moving from the “rolling average” annualized flux approach in FIA to modeled annual flux estimates based on annually updated remote sensing data
- Attributes GHG fluxes to specific causes by identifying areas of wildfire, harvest and other disturbances in satellite imagery
- Fills gaps in National GHG Inventory data around certain trees outside forests, such as trees in cropland

FEDERAL ACTION 1

Develop a national remote sensing-based forest and land use inventory (cont.)

Why federal action?

- Federal agencies already produce remote sensing products like LANDFIRE and GEDI that could be used to underlie a spatially explicit annual carbon inventory for trees and forests, including attribution of carbon fluxes
- Federal agencies are better equipped than states with the research funding, staff capacity, and technical expertise to develop and maintain such a product
- Federal action would promote consistency in methodology and results between states

Which agencies or federal programs would be involved?

- USDA Forest Service - FIA program
- NASA - GEDI program, Landsat program
- LANDFIRE program (joint USDA Forest Service and US Dept. of Interior)
- Multi-Resolution Land Characteristics Consortium (interagency consortium that manages the National Land Cover Database)
- US EPA – National GHG Inventory

Relevant state improvements:

- Integrate optical imagery with FIA (Trees & Forests Improvement 1)
- Integrate LIDAR/phodar with FIA data (Trees & Forests Improvement 2)
- Implement monitoring system using active remote sensing (Land Use Change Improvement 2)

FEDERAL ACTION 2

Monitor soil carbon through national field networks

What would it entail?

- Building out soil carbon sampling on 5-7,000 National Resource Inventory (NRI) survey sites with 5-7 year sampling intervals, on an annual rotating basis similar to the FIA system
    - ➢ Cost for the federal government to augment its existing NRI system is estimated at $5 million per year (National Academies of Sciences 2019)
- Updating the Conservation Effects Assessment Project (CEAP) more regularly and collating results with soil carbon field measurements to improve scientific understanding of the links between land management activities and soil carbon fluxes
- Soil carbon data could improve National GHG Inventory either by improving calibration of DAYCENT model or replacing modeling approach altogether with direct statistical estimation of soil GHG fluxes, akin to FIA approach for forest carbon fluxes

What problems would it solve?

- Reduces uncertainty around GHG flux estimates for cropland and grassland soils by incorporating significantly more field data into estimation methodology
- Improves precision with which GHG fluxes are linked to land management activities by making standardized soil carbon data available across a range of geographies and environmental conditions

Why federal action?

- Economy of scale could drive down cost of soil carbon monitoring technologies
- Federal soil carbon monitoring effort could leverage existing NRI plot network
- Federal action would promote consistency in soil carbon estimation methodology between states

Which agencies or federal programs should be involved?

- USDA Natural Resources Conservation Service (NRCS) – NRI program, CEAP

Relevant state improvement:

- Create a network of soil carbon monitoring plots (Croplands & Grasslands Improvement 4)

Go deeper

KEY DATA SOURCE: CEAP

FEDERAL ACTION 3

Develop a national spatial inventory of wetland GHG fluxes

What would it entail?

- Using LIDAR/phodar to establish a comprehensive and high-resolution wetlands spatial dataset at the national level that is updated every 1-5 years to register changes in wetland extent, vegetation, and management activities such as draining/rewetting
- Overlaying data from the US Soil Survey and vegetation databases to enhance wetlands identification
- Consolidating wetlands management data from appropriate federal agencies such as the US Fish & Wildlife Service, NOAA, and the Army Corps of Engineers
- Establishing a robust network of field-based sample plots in various regions and wetlands types to record GHG fluxes and validate LIDAR data
- Using the combination of field data and remotely sensed spatial data to develop a national inventory of wetland carbon storage and GHG fluxes using the methodology from the IPCC Wetlands Supplement
- Updating the National GHG Inventory to include all types of terrestrial wetlands and sea grass beds on both public and private lands
- Adding GHG fluxes from tidal and terrestrial wetlands to SIT

What problems would it solve?

- Reduces uncertainty in national GHG flux estimates for wetlands by establishing a field sampling program to measure local-level GHG fluxes
- Makes data on wetland extent and vegetation more timely by using regularly-updated remote sensing data
- Enhances national-level spatial and temporal resolution of wetlands data by resolving the geographic variation in data resolution and update frequency in existing federal wetland datasets
- Attributes GHG fluxes to specific management changes by using LIDAR imaging to identify land cover changes associated with wetland management
- Fills gaps in National GHG Inventory and SIT by producing data on GHG fluxes for wetlands categories that are currently omitted

FEDERAL ACTION 3

Develop a national spatial inventory of wetland GHG fluxes (cont.)

Why federal action?

- Estimating GHG fluxes in wetlands requires a dedicated research effort that may be beyond the capacity of many states with wetland resources
- Federal action could produce more granular and regionally-appropriate emission factors for wetlands than are currently available from the IPCC wetlands supplement or the 2nd State of the Carbon Cycle Report (SOCCR2)
- Federal action could facilitate coverage of wetlands in SIT, which currently provides no state-level data
- Federal action would promote consistency across federal and state estimates and would enable consolidation of existing federal wetlands data

Which agencies or federal programs should be involved?

- US Fish & Wildlife Service - National Wetlands Inventory Program
- NOAA - Coastal Change Analysis Program (C-CAP)
- Smithsonian Institution - Smithsonian Environmental Research Center
- US Geological Survey- Wetland and Aquatic Research Center
- US Army Corps of Engineers – Regulatory Branch

Relevant state improvement:

- Integrate updated remote sensing data with federal spatial data (Wetlands Improvement 1)

Key Takeaways

- Federal action may be appropriate for NWL inventory improvements that would make use of existing federal infrastructure or capacity, exceed the financial or technical resources of most states, or improve the quality of GHG flux estimates in the National GHG Inventory and SIT.
- States can promote federal action by communicating the need for inventory improvements to relevant federal agencies or requesting funding for inventory improvements from their representatives in Congress. Joint requests from multiple states may increase the likelihood of a federal response.
- Federal action to improve national datasets and methods for NWL inventories can reduce uncertainty around GHG flux estimates in the National GHG Inventory, improve the timeliness of underlying data, enhance data resolution, allow for the attribution of GHG fluxes to specific causes with greater precision, and fill gaps where data are currently lacking in the National GHG Inventory and/or SIT.
- Inventory improvements that are suitable for federal action include developing a national remote sensing-based forest and land use inventory, monitoring soil carbon through national field networks, and developing a national spatial inventory of wetland GHG fluxes.

GOING DEEPER:

Key Concepts, Data Sources and Tools

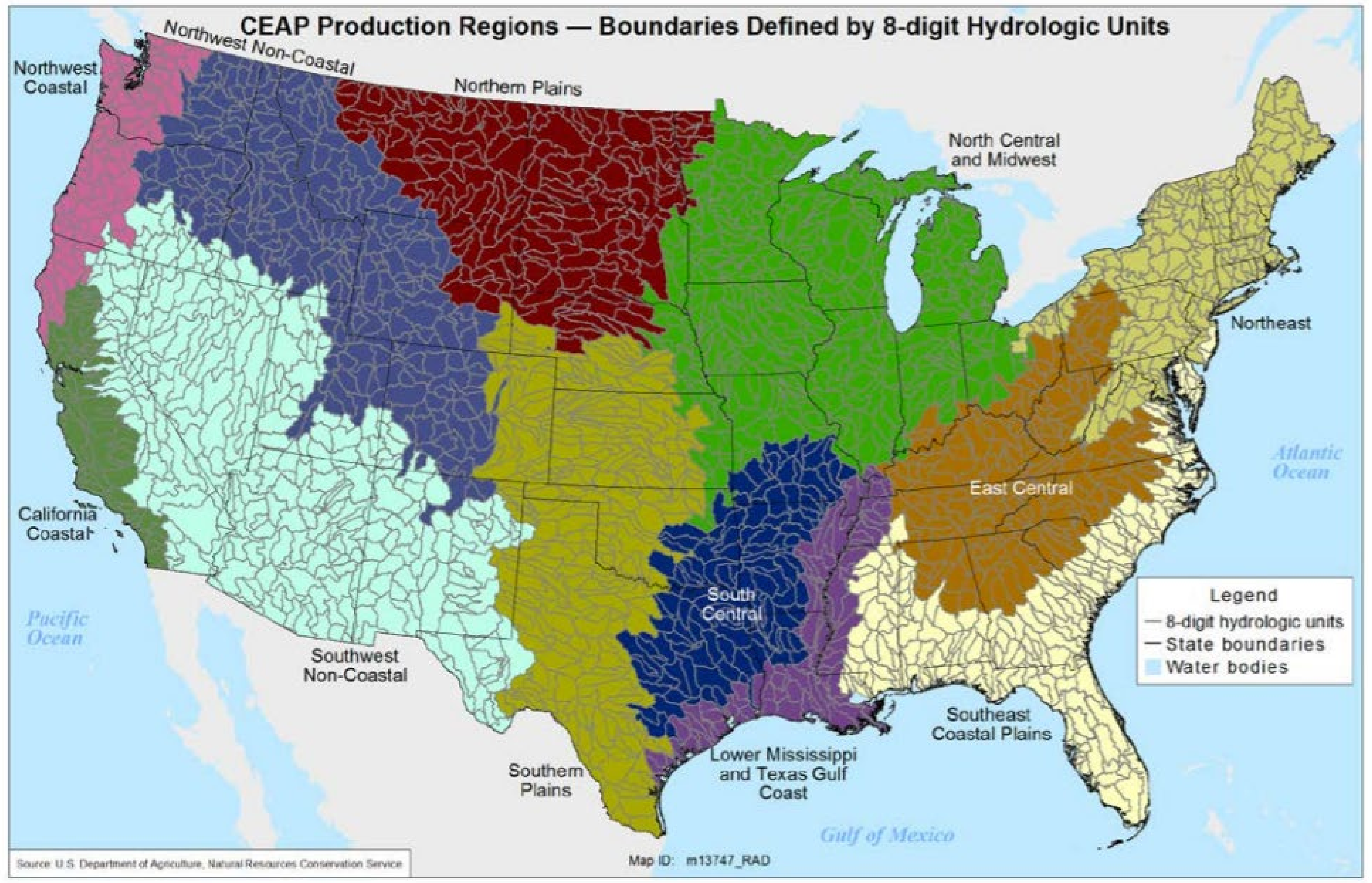
KEY DATA SOURCE

Cropland Effects Assessment Program (CEAP)

What is it? CEAP is a collaboration between NRCS, the Agricultural Research Service (ARS), and the Cooperative State Research, Education, and Extension Service (CSREES). Its goal is to establish scientific evidence for the benefits of conservation practices at the watershed scale and estimate impacts on regional and national levels. The first round of data collection was completed in 2006. A second round of data collection was completed in 2016, but results from "CEAP-2" have not yet been published due to concerns over data collection methods.

What does it do?

- CEAP uses a statistical approach to assess adoption of soil management practices by sampling 20,000 NRI plots across 98% of US cropland; each sample point is assigned an acreage weight to extrapolate results nationally
- Data comes from NRI database, NRCS field offices, and farmer surveys conducted for CEAP
- CEAP models erosion, sediment and nutrient loss, organic carbon stocks, and water quality for each sample point under a "current conservation practices" scenario and a counterfactual "no-practices" scenario
- Benefits of conservation practices are estimated as the difference between scenarios



Source: NRCS 2017

Relevance to NWL inventories: Concurrent data on adoption of land management activities and soil carbon fluxes can help advance scientific understanding of the links between activity data and soil carbon across different soils, climate conditions, and cropping systems, allowing for improvements to the GHG models that estimate soil carbon flux in croplands and grasslands for the National GHG Inventory and SIT. CEAP will be most relevant to inventories moving forward if data are published in a timely manner and updated regularly.

Limitations:

- Long period between updates and the current time lag in publishing data for CEAP-2 have compromised the timeliness of CEAP data, with the only published data now 14+ years old
- Benefits of conservation practices for GHG emissions and carbon sequestration are not analyzed
- Results are aggregated and presented at the level of "production regions" (see right) rather than states

Resources: CEAP-Cropland National Assessment; CEAP-Grazing Lands National Assessment (yet to be released)

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Appendix

Key Contacts for Federal Data

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Acronyms

- BAU - business-as-usual
- CARB – California Air Resources Board
- CEAP - Conservation Effects Assessment Project
- CO_2e – carbon dioxide equivalent
- COMET – Carbon Management & Emissions Tool
- DAP - Digital Aerial Photogrammetry
- DayCENT – Daily time-step CENTURY model
- DNR - Department of Natural Resources
- EPA - US Environmental Protection Agency
- FIA - Forest Inventory and Analysis
- GEDI - Global Ecosystem Dynamics Investigation
- GFW - Global Forest Watch
- GHG - greenhouse gas
- HWP - harvested wood products
- IPCC - Intergovernmental Panel on Climate Change
- LANDFIRE – Landscape Fire and Resource Management Planning Tools
- LIDAR - Light Detection and Ranging
- LULUCF – Land Use, Land Use Change and Forestry
- MMT – million metric tons
- MODIS – Moderate Resolution Imaging Spectroradiometer
- NAIP - National Agricultural Inventory Program
- NLCD - National Land Cover Database
- NRI - National Resource Inventory
- NOAA - National Oceanic and Atmospheric Administration
- NWI - National Wetlands Inventory
- QA/QC - quality assurance/quality control
- RPA - Resource Planning Act
- SAR - Synthetic Aperture Radar
- SIT - State Inventory Tool
- SSURGO – Soil Survey Geographic Database
- STATSGO – State Soil Geographic Database
- UNFCCC – United Nations Framework Convention on Climate Change
- US ACE - United States Army Corps of Engineers
- USFWS - United States Fish and Wildlife Service
- USGS - United States Geological Survey

Glossary

- **Active remote sensing:** a sensor emits radiation and records the intensity and characteristics (e.g. timing) of the reflected signal
- **Activity data:** data on human activities that result in GHG emissions or removals (e.g. forest harvest or soil management practices)
- **Back-cast:** a historical projection based on current data trends
- **Baseline**: any data against which change is measured; can include historical data and/or projected future data
- **Bulk density**: the dry weight of a known volume of soil
- **CENTURY:** biogeochemical model used for analysis of carbon and nutrient flows in agricultural soils
- **CH_4:** methane, a potent greenhouse gas
- **Confidence interval:** a measure of estimation uncertainty, defined as a range of values that has a specified probability (often 95%) of containing the true value of the parameter; a 95% confidence interval is 1.96 times the standard error of the sample
- **Direct measurement:** measuring outcome variables in the field
- **Flux:** changes in stocks
- **Land use categories:** classifications used to disaggregate natural and working lands, including forests, croplands, grasslands, and wetlands
- **Landsat:** NASA satellite program that gathers images of Earth's land surface
- **N_2O:** nitrous oxide, a potent greenhouse gas
- **Passive remote sensing:** a sensor records intensity and characteristics of reflected radiation (visible and non-visible) from a distance (e.g. a satellite)
- **Phodar:** Photogrammetric Detection and Ranging (also known as Digital Aerial Photogrammetry)
- **Proxy measurement:** Estimating outcome variable based on field measurements of other related variables
- **Sequestration**: Removing carbon from the atmosphere and storing it in biomass, soils, or geologic formations
- **Spatially explicit:** Location information (e.g. GPS coordinates) tied to other data attributes
- **Spatial resolution:** Smallest area that can be accurately portrayed by the sensor or dataset
- **Standard error**: A measure of statistical uncertainty, equal to the standard deviation of the sample divided by the square root of the sample size
- **Stocks:** Total storage volume
- **Transect survey:** Data collection method where observer records data attributes measured along a linear path
- **"Windshield" survey:** Data collection method where observer drives a preset route and records data attributes observed from the vehicle