USDA Climate Resilience Science Plan

Draft September 14, 2017

TABLE OF CONTENTS

Introduction, Background, and Crosscutting Activities

The U.S. Department of Agriculture (USDA or "the Department") provides leadership to the nation and the world on food, agriculture, natural resources, rural development, nutrition, and related issues, based on sound public policy, the best available science, and efficient management. The Department's science-based climate-change activities are central to achieving these goals. USDA's Strategic Plan states as its second goal to "ensure our national forests and private working lands are conserved, restored, and made more resilient to climate change, while enhancing our water resources."

Agriculture and agriculture-related industries contributed $985 billion to the U.S. gross domestic product in 2014. American farmers each feed an estimated 155 people around the world, and 15% of the entire U.S. workforce is engaged in food-system activities, such as producing, processing, and selling food.

Forests cover approximately one-third of the nation's overall land area and provide critical ecosystem services, such as clean air, clean and ample water, wildlife, biodiversity, carbon sequestration, and outdoor recreation. Forests provide direct employment opportunities and economic benefits through harvested wood and urban forests.

Covering 770 million acres of land area in the United States, grasslands are a dominant landscape across much of the country and provide a number of ecosystem services. These diverse grasslands are either publicly or privately owned and are vital to animal agriculture and livestock production, which represent approximately half of U.S. agricultural exports to the world.

These landscapes are valuable to the United States culturally, environmentally, and economically. Climate change and variability affect all of them. Changing temperatures and precipitation, along with altered pest pressures, influence rates of crop maturation and livestock productivity. Forests are already experiencing increased disturbance, including widespread wildfires and pest-related die-offs, as a result of changing climatic conditions and prolonged drought. The composition and quality of grassland forage is changing and diminishing under elevated atmospheric carbon dioxide (CO_2) concentrations.

At the same time, land use, land cover, and land management contribute to the rate and magnitude of changes in climate around the world. Changes in land use, cover, or management—such as tillage or fertilizer management—affect the release of the greenhouse gases (GHGs), carbon dioxide (CO_2), nitrous oxide (N_2O), and methane (CH_4) into the atmosphere. Land also serves as a sink for the absorption and sequestration of CO_2 back into plants and soils. USDA has made a strong public commitment to reduce emissions from the land sector while meeting the world's needs for food, fiber, feed, and fuel.

Twenty-one agencies and offices at USDA either perform research to support the Department's mission or use scientific information to support specific activities that help the nation adapt to or mitigate climate change. The roles and responsibilities of some of those agencies and offices are listed in Appendix A.

How to Use the USDA Climate Resilience Science Plan

USDA's Science Plan identifies the science that USDA needs to pursue over the next five to eight years for the Department to meet the needs of the nation. This Science Plan was developed as a cooperative effort between USDA research agencies and USDA program/service agencies, many of which are listed in Appendix A. It presents a review of climate-related priorities in an integrated manner across all Research, Education and Economics (REE) agencies and USDA research. It follows the USDA Climate Change Science Plan published in 2010 and drew from key reports and assessments for its development (see Assessments section below). It is intended to help guide future research efforts to best meet the Department's mission and the needs of its internal and external stakeholders. This Plan holds no prescriptive or budgetary power and reflects the agencies' own stated needs for productive scientific progress. If opportunities arise, this document serves to identify the most useful applications of this Plan, which has co-benefits across many of USDA's programmatic and conservation activities. However, because there is no guarantee as to whether or where opportunities may arise, this document is presented without a timeline. In addition, the priorities presented here may be of differing use to different USDA agencies at different stages. Each priority contributes to creating more resilient working lands and land-management activities, and could be of greater or lesser application, depending on agencies' differing needs. This document is intended for USDA internal use to ensure that resources are directed toward the most necessary science for advancing the Department's ability to meet the needs of its stakeholders.

The goals of this Science Plan are as follows:

- Provide guidance for future research needs
- Characterize the role of land management in global challenges such as climate change
- Link research with on-the-ground applications
- Guide co-design, co-development, and co-implementation of research and related activities
- Integrate biophysical and socioeconomic science approaches
- Ensure that the human dimensions are considered
- Enable a clear development-through-application pathway for new information and technologies for on-the-ground application

This Science Plan identifies activities across six substantive chapters:

Effects—changes in human, natural, and managed systems resulting from changes in climate.

Adaptation—adjustment in natural or human systems in response to actual or expected climatic stimuli or their effects, which moderates harm or exploits beneficial opportunities.

Mitigation—an intervention to reduce the sources or enhance the sinks of GHGs.

Decision Support—synthesize scientific information into accessible and meaningful products, applications, and tools for USDA's internal and external stakeholders, a core function of the Department.

Indicators and Metrics—the science needed to develop and support reliable indicators of climate change to support adaptation and mitigation efforts, and to provide decision support.

Coordination and Implementation—a plan for sharing progress across agencies to ensure research is used and applied.

Key elements of this Plan, within the context of climate change, are shown in Figure 1.

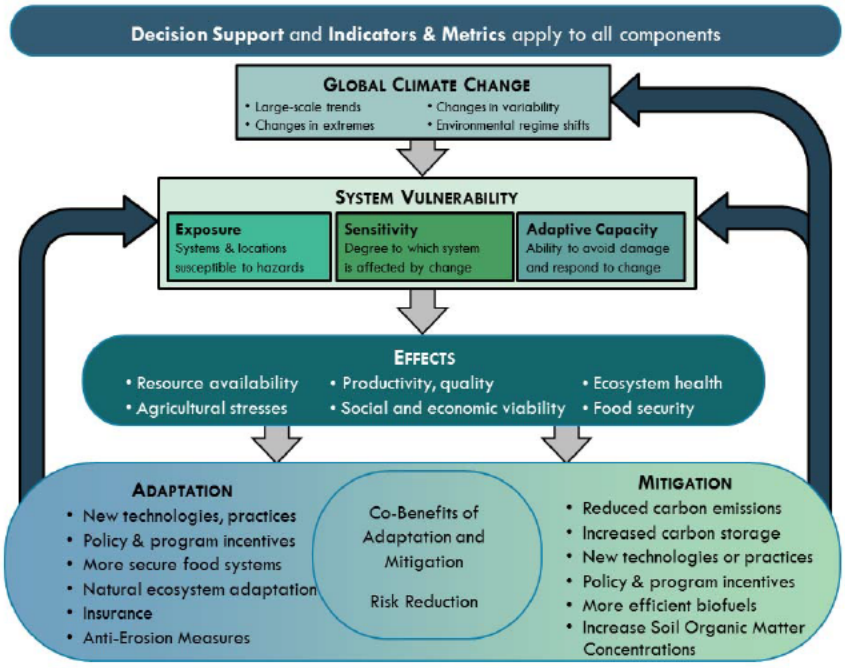

Figure 1. Key elements of the USDA Climate Resilience Science Plan

Changes in climate, such as trends in temperature, precipitation, wind, and humidity, lead to agricultural vulnerabilities. Those vulnerabilities are a function of the system's exposure, sensitivity, and adaptive capacity. The direct and indirect effects of these vulnerabilities result in increased risks and stresses to agricultural production and environmental, social, and economic systems. The effects of climate change motivate actions to manage and reduce impacts through two major strategies: adaptation and mitigation. Adaptation involves adjustment to actual or expected climate change and its effects. Mitigation encompasses a range of human interventions designed to reduce the sources or enhance the sinks associated with GHG emissions and sequestration. The Science Plan's key elements rely on indicators and metrics combined with decision support as part of each element.

Crosscutting Activities

A wide variety of USDA activities address multiple key elements of this Science Plan. This ability to address multiple elements simultaneously is referred to as "crosscutting" in this document. This section identifies nine such program or service areas.

USDA Climate Hubs. The USDA Climate Hubs is a strategic initiative designed to work with and support internal and external stakeholders and to rapidly transform USDA into a climate-ready agency, while responding to external stakeholder needs. Although climate change is a global phenomenon, its manifestations vary from region to region, and GHG emissions vary based on location, production type, and methods. USDA Climate Hubs were created to address regional differences in climate-change effects and adaptive strategies. The Hubs are an example of close interagency collaboration on climate change at the regional level, delivering tools, strategies, management, and technical solutions to farmers, ranchers, forestland owners, and resource managers to inform better decision making in a changing climate. The Hubs also present a unique opportunity to collect information directly from farmers, ranchers, forestland owners, and resource managers that, in turn, can inform USDA science, including research activities and priorities of both climate and social science.

Domestic Partnerships. Scientific discoveries are made across many institutions in multiple sectors, and land managers receive information in a number of ways. For these reasons, USDA maintains active relationships with land-grant universities; cooperative extension; researchers; the private sector; state, local, and regional governments; the National Oceanic and Atmospheric Administration (NOAA) and Department of the Interior (DOI) regional experts and efforts; tribal entities; private entities and Small Business Innovation Research; and nonprofit organizations engaged in providing assistance. USDA works with other agencies within the federal government through the United States Global Change Research Program (USGCRP) to leverage its resources to meet USDA's needs, such as the production of regional climate projections. USDA scientists also engage in monitoring networks that provide important information in support of the Department's mission, such as the National Ecological Observatory Network (NEON), the Long Term Ecological Research (LTER) network, the Long-Term Agroecosystem Research (LTAR) network, and Ameriflux.

Assessments. Evaluating how USDA's sectors are influenced by climate change is an important step in managing the Department's efforts going forward. Recent contributions include the publications *Climate Change, Food Security, and the U.S. Food System; Effects of Drought on Forests and Rangeland in the United States;* and *Climate Change and Agriculture in the United States: Effects and Adaptation.* USDA scientists routinely contribute to the quadrennial United States' National Climate Assessment, which is mandated under the Global Change Research Act of 1990, and the Assessment Reports of the Intergovernmental Panel on Climate Change (IPCC). USDA scientists conduct numerous resource assessments, including the Resources Planning Assessment (RPA) as required by the Forest and Rangeland Renewable Resources Planning Act of 1974, the National Resources Inventory (NRI), the Resource Conservation Act (RCA) Appraisal, the Rapid Carbon Assessment (RaCA), and the Forest Inventory and Analysis (FIA), which are utilized by multiple scientific and programmatic efforts across the Department and the U.S. government to improve land management efforts. In addition to national-scale assessment efforts, many regional and subregional assessments have been conducted by USDA, such as the Regional Vulnerability Assessments conducted by the USDA Climate Hubs.

International Activities. As a U.S. government agency, USDA participates in and is beholden to a number of multilateral agreements, such as the United Nations Framework Convention on Climate Change (UNFCCC). In addition, USDA scientists participate in multiple international efforts (e.g., the Global Research Alliance on Agricultural Greenhouse Gases, the Climate and Clean Air Coalition, and the Global Alliance for Climate Smart Agriculture) aimed at better understanding the influences of climate variability and change in the food and agricultural sectors. USDA's international capacity building and development programs (e.g., the Cochran Fellowship Program, the Norman E. Borlaug International Agricultural Science and Technology Fellowship Program, and the Global Alliance for Climate-Smart Agriculture) help to link USDA and other U.S. scientists, educators, and agricultural professionals with their foreign counterparts in international cooperation, education, and technical assistance to promote climate-resilient agricultural systems, economic growth , and global food security. These agreements represent important uses of USDA information and tools, and foster market development for the Department's many stakeholders.

USDA's Building Blocks for Climate-Smart Agriculture and Forestry. The Building Blocks provide a framework for helping farmers, ranchers, and forestland owners understand their effect on climate change. Voluntary, incentive-based conservation, forestry, and energy programs help to reduce GHG

emissions, increase carbon sequestration, and expand renewable energy production in the agricultural and forestry sectors.

Food Systems and Integrated Modeling Assessments. Food security, both domestically and abroad, depends not only on efforts to improve agricultural productivity, but also on operations within the overall food system, including processing, packaging, storage, transport, trade, wholesaling, retailing, consumption, and waste. In addition, food security outcomes relate strongly to energy usage and the health of the underlying natural resource base. These relationships require building research capacity across traditional sectoral boundaries to include the biophysical and the socioeconomic sciences through integrated assessment modeling. One such effort is the Agricultural Model Intercomparison and Improvement Project (AgMIP), in which USDA researchers integrate models of human and environmental systems to better simulate the interactions between climate change and subsequent human responses, as well as to inform and optimize the effectiveness of adaptation and mitigation initiatives.

Global Change Task Force (GCTF). Representatives from 21 USDA agencies and offices comprise the GCTF, which meets monthly to share information regarding departmental activities and needs related to climate change. The GCTF seeks to anticipate necessary short- and medium-term coordination and ensure synchronization across USDA mission areas and approaches.

GHG Accounting and Inventories. USDA created a comprehensive methodology for estimating farm-scale and forest-management-scale GHG emissions to allow landowners and managers to voluntarily improve management of lands for GHG mitigation in the *Quantifying Greenhouse Gas Fluxes in Agriculture and Forestry: Methods for Entity-Scale Inventory* report. In addition, the Department publishes a Greenhouse Gas Inventory for Agriculture and Forestry for the United States that is consistent with the U.S. National Greenhouse Gas Inventory submitted annually in keeping with the nation's UNFCCC commitments. The USDA document provides an evaluation both geographically and by management practice and is designed to enhance understanding of contributions to GHG emissions and sequestration from these sectors. COMET-Farm is an entity-level tool that allows individual operations to estimate their carbon footprint and the GHG effects of changes in management.

Environmental Markets. GHG markets allow farmers and ranchers to monetize GHG emissions reductions and carbon sequestration on working lands by attracting nonfederal funding to support the goals of the USDA Building Blocks. Through the Environmental Markets Working Group, USDA facilitates the participation of landowners in environmental markets. This includes research into conservation practices and technologies that reduce GHG emissions on private lands, economic studies of environmental markets and the opportunities they represent, and improved science as it relates to the valuation of ecosystem services associated with the implementation of climate-smart agricultural practices.

Effects

Understand the Direct and Indirect Effects of Climate Change, Including Feedbacks to the Climate System

Effects, sometimes referred to as impacts, are the outcomes or consequences of the interaction of climate with natural, managed, and human systems over time. Effects in agricultural and other systems are related to the exposure to the climate event or change, the sensitivity of the system affected, and the capacity of the system to adjust to the exposure. Effects may be compounded by processes affected by the exposure ("indirect effects") as well as nonclimate stressors. In this Plan, the term "effects" rather than "impacts" is used because the outcomes of climate change will present opportunities as well as challenges.

Climate is important to natural and managed systems, and the human populations that rely on them, because it influences productivity, community structure and composition, ecosystem processes, and the goods and services that these ecosystems provide. Increases in temperature and changes in the amount and timing of precipitation can affect the cycling and availability of water and nutrients in forest and agricultural systems, as well as the growth, reproduction, and distribution of plants, animals, pests, pathogens, and microbes.

Climate change can increase the rate and intensity of disturbances in ecosystems and have substantial effects on human systems. Extreme events such as hurricanes, tornados, droughts, or floods can damage or destroy crops and forest stands, increase erosion, decrease water quality, and damage infrastructure. Warmer temperatures associated with climate change may present human health and safety concerns by affecting food security and increasing the incidence of disease, insects, invasive species, and fire. Climate change can also influence land and natural resources use, and decisions made on agricultural production and marketing. Rising temperatures can increase agriculture's demand for water resources in the absence of more efficient adaptation and mitigation practice adoption, while changing precipitation levels and patterns can alter hydrologic systems, resulting in reduced water supplies for irrigated agriculture in some regions. Effects on the economy may be felt at local, regional, national, and global levels, and cultural practices and artifacts may be threatened.

The effects of climate change may be amplified by feedbacks to the climate system. Fire and accelerated decomposition from disturbance can increase the release of GHGs to the atmosphere; conversion of natural or managed lands to developed uses can also increase the release of GHGs. Changes in cloud, land, snow, and sea ice cover can also alter the amount of solar radiation absorbed and reflected by the earth's surface.

An understanding of current and predicted future effects allows USDA to target policy and management activities to expand economic opportunity, promote agricultural sustainability, and preserve and conserve natural resources in a changing climate. This effort is particularly important as current and future climate change may differ from the past in both the rate and intensity of change. As regional ecological, agricultural, and socioeconomic systems become exposed to a range of changing climate and nonclimate stressors, public and private decision makers need context-specific information on both climate effects over time and the basic processes driving these effects to be able to plan for desired

outcomes.

Scientists have made progress in understanding the effects of climate change since the release of the 2010 USDA Climate Change Science Plan. Improvements in climate models and wider availability of downscaled climate projections have increased information on local- to regional-scale exposure to climate stressors. Extensive research has advanced the knowledge of sensitivities to climate change and provided a foundation for projections on the effects of climate change on managed, natural, and human systems. USDA Climate Hubs' regional vulnerability assessments, agency assessments, and science syntheses provide new and refined information on the effects on forest and agricultural productivity, ecosystem services, and food security. Collectively, these documents begin to address the effects of climate extremes. They also identify and quantify nonclimate stressors and socioeconomic factors that influence agricultural and natural systems and their response to climate. These stressors and factors are now being incorporated into many predictive and process models. There is greater clarity on the degree of uncertainty associated with the magnitude and timing of climate-change effects even though uncertainty exists. Increasing clarity will inform model assumptions and sensitivities moving forward.

Improved understanding of the effects of climate change will rely on strategic work in the following priority areas:

- Ecosystem structure, processes, and services
- Weeds, pests, and pathogens
- Human dimensions
- Monitoring, data integration, and models

Specific science priorities for understanding the effects of climate change will likely vary by agency, by ecosystem, and by land use type and water source—across farmland, forest, grassland, and urban/suburban sectors—as well as by commodity and food system. Strategic implementation will be informed by research conducted within USDA research agencies, in partnership with academic institutions, private industries, national and global research alliances, and other agencies, including those affiliated with the USGCRP. Data collection may be enhanced by collaboration with other agencies and networks (see Introduction and Appendix A). Continued development of common standards for record linkage and metadata can also facilitate data integration and collaborative efforts to synthesize data.

Priority Areas

Science generated within the priority areas can inform the need for adaptation and activities, facilitate climate-informed decision making, and support development of indicators and metrics of climate change.

Ecosystem Structure, Processes, and Services

- Identify and quantify the effects of increasing temperatures, precipitation extremes, and atmospheric CO_2 concentration on ecosystem processes, disturbance regimes, water, food, feed, fuel, fiber, recreation, other goods, and ecosystem services, and identify critical tipping points or thresholds for change.

- Conduct research and develop improved tools to better understand the effects of climate change on long-term carbon storage and flux across the landscape and at the interface of terrestrial and aquatic ecosystems.
- Examine the effects of climate change on hydrologic systems and the availability of renewable surface and groundwater resources.
- Examine the effects of climate change on soil health, water infiltration, and rhizosphere processes, and the resulting effect on agricultural production.
- Examine the effects of climate change on the microbiomes of agricultural systems.
- Evaluate and catalogue the genetic basis of climate resilience in plants, animals, and microbes.
- Conduct interdisciplinary research and support experimental networks to examine the interactive effects of climate change stressors, natural disturbance regimes, land use, and management activities.

Weeds, Pests, and Pathogens

- Increase detection and monitoring of weeds, insects, pests, pathogens, and invasive species in forests, croplands, rangelands, animal production systems, aquaculture and food processing, and storage and transport systems, and increase the availability of real-time data.
- Identify the processes and climatic variables that affect the distribution and spread of pests and pathogens and the susceptibility of hosts or ecosystems to establishment.
- Improve understanding of the effects of climate on disease in humans, animals, and plants.

Human Dimensions

- Quantify effects of climate variability and change on crop, livestock, and aquaculture production; pricing; producer and consumer behaviors; and trade of goods and services from forests and agriculture.
- Examine the social, economic, and health effects of climate change on communities and agricultural producers, and the distribution of these effects.
- Conduct research on the effects of climate-induced water supply reductions on water conservation practices, water-pricing structures, and the use of irrigation systems, management strategies, and governance structures.
- Work with tribal communities to identify the effects of climate change on tribal lands, cultural resources, and indigenous first foods.

Monitoring, Data Integration, and Models

- Support interagency collaboration to improve projections of temperature, precipitation, and extreme events and their effect on land and water resources and associated biophysical variables, and support transdisciplinary research.
- Form partnerships with academic institutions, industry, other agencies, and NGOs, and provide infrastructure to enhance the collection and integration of big biophysical and sociocultural data

that can provide information on climate change and its effects.

- Support collaborative development of improved integrated models to assess vulnerabilities of forest, agricultural, and human systems across a variety of climate, socioeconomic, and management scenarios.
- Increase data sharing, access, and outreach on climate effects across and within agencies, nationally and regionally, and with international partners.
- Support long-term inventory and environmental monitoring programs and the development of low-cost data collection methods.

Implementation of adaptation and mitigation activities can create feedback on climate effects—adaptation by modifying system vulnerability and mitigation by modifying the factors driving climate change and lessening its degree. The science priorities associated with these activities are discussed in the following two chapters.

Adaptation

Develop Knowledge and Tools to Enable Adaptation to Climate Change and to Improve the Resilience of Natural and Managed Ecosystems

Adaptation is defined in the IPCC Fifth Assessment Report as "the process of adjustment to actual or expected climate and its effects." In human systems, including agriculture, adaptation seeks to moderate or avoid harm or exploit beneficial opportunities. In some natural systems, such as forestry or rangelands, human intervention may facilitate adjustment to projected climate changes. Climate change is ongoing and complex within an inherently dynamic system. Agricultural and forest systems dominated by human intervention are equally complex and dynamic, spanning from the natural resource base to production enterprises to the human dimensions of food security and rural community sustainability.

As discussed in the prior chapter, there are large potential economic, ecological, and social effects of sensitive agricultural, forestry, and natural ecosystems exposed to climate stressors. Therefore, it is essential to develop new knowledge and technologies for adaptation at multiple scales of agricultural and forest systems and strategies to improve resilience. As illustrated in Figure 1, adaptation may include characteristics or changes that allow the system to avoid exposure to the stressor or reduce the sensitivity of the system to the stressor. In addition, it is important to develop adaptive capacity to minimize damage caused by a stressor and to allow for rapid recovery from a stressor.

Adaptation requires full understanding of climate effects, but also the capacity to resist damage or become more resilient to change or transition. At some level of stress, the existing agricultural, forestry, or rangeland system may become so maladapted to the prevailing conditions that transition to a different system is required. For annual crops, this may be reasonably straightforward. However, for forest and rangelands, long-lived perennial species cannot easily migrate to other regions, nor can new species be easily introduced. Many practices, technologies, and strategies will have both adaptation and mitigation elements and should be approached in an integrated manner, following climate-smart agricultural principles.

Because of the broad scope of USDA agencies' missions, a diverse scientific portfolio is needed to develop and deliver adaptation strategies, practices, and technologies to meet key societal goals for the agricultural, rangeland, and forest sectors. These goals include the following:

- Efficient production of crops, livestock, and forestry products
- Resilient air, water, and soil resources supporting sustained ecosystem function
- Secure food systems for vulnerable populations and efficiency along the entire food chain
- Resilient forest, grassland, and rangeland ecosystems that also provide recreational opportunities and wildlife habitat, while sustaining agricultural and ecosystem biodiversity
- Resilient rural communities

Education and extension are critical across all priority science areas, which are as follows:

- Basic research to improve understanding of genetic, genomic, and biogeochemical processes

- Applied science and technology development and delivery
- Integrated, landscape-scale or systems-level science
- Human dimensions
- Data to information to knowledge science

All agencies have opportunities to leverage their programs to incorporate science, technology, engineering, and mathematics (STEM) education internships and partnerships. The National Institute of Food and Agriculture (NIFA) has a strong partnership with land-grant universities and the State Agricultural Experiment Stations and funds competitive education and extension projects to address issues critical to agriculture and climate. There is an ongoing need to strengthen collaborative relationships with state extension programs, colleges, and universities to develop and deliver tools to adapt to climate change. Partnerships across USDA agencies and other federal, state, private sector, and nongovernmental (NGO) entities are essential. Because of the large contrasts in climate, agricultural and forestry systems, and vulnerabilities across the United States, USDA has established regional Climate Hubs to identify critical vulnerabilities and impacts and to foster effective communication and partnerships to promote adaptation and mitigation strategies, practices, and technologies. There is also an ongoing need to work toward accessible and coherent data systems across USDA agencies and other federal departments that address weather and climate, biological and physical land systems, agricultural economics, demographics, and health. The Economic Research Service (ERS) plays a critical role in assessing social and economic effects and evaluating adaptation and mitigation strategies to increase the adaptive capacity of communities and systems. In addition, increased investment in monitoring systems is needed to support the mission areas of the National Resources Conservation Service (NRCS), the Forest Service (FS), the Animal and Plant Health Inspection Services (APHIS), the Risk Management Agency (RMA), the Farm Services Agency (FSA), the Foreign Agricultural Service (FAS), and other agencies. Technical and financial assistance provided by numerous USDA agencies enhances the adaptive capacity of individuals, businesses, and rural communities.

Priority Areas

Basic Research to Improve Understanding of Genetic, Genomic, and Biogeochemical Processes

- Apply techniques spanning genomics through applied breeding to develop plant and animal germplasm, varieties, and breeds with heat, cold, drought, flooding, and pest tolerance, and enhanced nutritional value.
- Develop better understanding of the physiological and phenological tolerances of organisms, including crops, grasses, tree species, livestock, insects, pathogens, and other microorganisms, to climate.
- Develop better understanding of the relationship of soil health with infiltration and storage of water and of rhizosphere processes that can enhance the ability of plants to extract water and nutrients efficiently from the soil.
- Improve understanding of the role of the microbiome in the resilience of diverse ecosystems to

climate stressors.

Development and Delivery of Applied Science and Technology

- Assess how temperature, humidity, and flooding impact risks to human health from *E. coli*, *Enterococci,* mycotoxins, and other anti-health contaminants of commodity and food products, and develop and deliver new practices to protect health during climate-related disasters.
- Develop and deliver improved understanding of climate-driven range shifts of species and the impacts of encroaching species on existing ecosystems; land management measures to assist/deter species migration and vectors of zoonotic diseases; and technologies to support quarantine programs.
- Develop and deliver improved understanding of and management strategies for the interactive effects of insect, disease, and weed pressures under changing climate.
- Develop and deliver improved technologies and management regimes to allow managed aquifer recharge and efficient use of water of varying quality as an adaptation to drought and decreasing groundwater supplies.
- Develop integrated irrigation production systems, improving farm economic resilience and water-resource allocation flexibility in the face of declining water supplies and increased pressures for watershed-level water-management strategies that reallocate scarce water resources.
- Develop farm-level water-management strategies that enhance producer ability to respond to deficit irrigation options, cropping pattern shifts, short-term water trading, and/or contingent water markets.
- Develop and deliver improved technologies for urban agriculture, spanning from plant variety development to agronomic management to structures and watering systems to processing and marketing technologies that enhance resilience to high-temperature stress.
- Develop and evaluate regionally appropriate bioenergy feedstock production systems, bioenergy production technologies, and improved energy efficiency of agricultural systems that diversify cropping systems, reduce input costs, and enhance resilience to variable climate.
- Support engineering research to improve systems, processes, and measurement capacity, including realizing the potential of unmanned aerial vehicles (UAVs), remote sensing, and other high spatial-temporal data from multiple sources to support adaptive management of agricultural systems under variable climate; and monitoring of climate effects in remote, rugged, or hazardous areas.
- Develop and implement technological infrastructure and institutions to use big data from drones and remote sensing for adaptation research.

Integrated Landscape-Scale or Systems-Level Science

- Conduct research on sustainable intensification and improved understanding of the food-energy-water nexus.
- Conduct research that improves understanding of aggregate effects of water conservation

practices at the watershed scale.

- Evaluate the cost-benefits of integrating on-farm water conservation programs more readily with watershed-scale water-management practices, such as water markets, conserved water rights, drought-year water banks, reservoir management, groundwater management, and acreage retirement.
- Support landscape-scale and systems-level research to discern trade-offs and better optimize agroecosystems to changing climates, including developing knowledge to guide transformational change when existing systems cannot be sustained under new climate conditions.
- Improve understanding of how ecosystems respond to and recover from extreme events and provide education and outreach to enhance adaptive capacity of producers and resource managers.
- Develop methods for valuation of noncommodity ecosystem services.
- Evaluate interactive effects of nonclimate and climate stressors on ecosystem responses and develop efficient adaptation strategies to reduce risk and increase resilience.

Human Dimensions

- Quantify the nutrient requirements of different populations and micronutrient content of food products and how these are impacted by climate and health stressors, and communicate dietary guidance to consumers.
- Conduct research addressing the economics and factors influencing adoption of climate-resilient irrigation and cropping production systems, that is, the integration of more conserving on-farm water-management practices with high-efficiency irrigation application systems, and, for example, adoption of integrated cropping compared to specialized cropping systems.
- Improve understanding of and methods to increase adaptive capacity in the social, ecological, and economic realms and deliver programs to enhance adaptive capacity.
- Conduct cost-benefit analyses of adaptation and mitigation practices and develop improved tools for life cycle analyses of agricultural systems under contrasting management, economic, policy, and climate scenarios.
- Describe the effects of risk tolerance and barriers to adoption of practices, and develop education and outreach programs to overcome barriers.
- Use behavioral science approaches to understand climate effects on adoption of new practices and support stakeholder/community.

Data to Information to Knowledge Science

- Invest in data infrastructure and methodologies to cost-effectively analyze, archive, and provide big data that span the multiple disciplines and spatiotemporal scales essential to support adaptive management.
- Develop, evaluate, and apply rigorous and robust models of complex ecosystems and social

systems to evaluate alternative management and climate scenarios.

- Develop affordable monitoring technologies and strategies that support adaptive management of systems under variable climate.
- Develop new analytical and statistical methods to address big data and machine learning.

Mitigation

Moving Agriculture and Natural Resource Systems to Carbon Neutral and Beyond

Mitigating atmospheric GHG emissions is critical to minimizing weather extremes and slowing the rate of climate change, and therefore, is an important aspect of developing climate-resilient forest, crop, and livestock production systems. According to the IPCC Fifth Assessment Report, climate-change mitigation is "A human intervention to reduce the sources or enhance the sinks of greenhouse gases (GHGs)." It includes efforts to control the human sources of GHG emissions as well as efforts to enhance the removal of GHGs from the atmosphere (sinks). Mitigation involves every sector of the economy. Within agriculture and forestry, the main emphasis is on reducing CO_2, CH_4, and N_2O emissions from systems that produce food, feed, fuel, and fiber and increasing storage of carbon within soils, biomass, and biobased products. Across USDA, GHG mitigation research is closely linked with the Department's outreach, programs, and policies. The ultimate goal of mitigation research at USDA is to enable and equip farmers, ranchers, and forest and grassland managers to implement practices that mitigate GHGs while enhancing production and other environmental services, resulting in more sustainable and resilient production systems. Strategic coordination across the research agencies at USDA is required to accomplish this goal efficiently. An organized and efficient means for research to inform effective policy, technical and incentive programs, and outreach will be required.

Advanced technologies and improved management of forest, crop, and livestock production systems can play a significant role in slowing or reversing the buildup of GHGs and minimizing climate change. Within agricultural and forestry systems, the opportunities to mitigate GHGs are variable and diverse. Some involve changes in land use, such as shifting cropland into trees or permanent grasses to increase carbon storage. Others include adjusting existing land management systems, such as managing existing forests to store additional carbon, adopting no-till or reduced tillage systems on a long-term basis, eliminating fallow periods, planting cover crops, and implementing nitrogen fertilizer management practices (including source, rates, application method, timing, and use of inhibitors), resulting in increased carbon storage and reduced N_2O emissions. Adjustments to livestock production systems can also lead to GHG mitigation. Management considerations, such as altering livestock housing, feed mixes, or animal microbiome and changing manure collection, storage, processing, and land application practices, can reduce CH_4 and N_2O emissions. Agriculture and forestlands can also produce biomass energy feedstocks for liquid biofuels and renewable heat and power, displacing emissions of fossil-derived fuels and thereby reducing emissions such as CH_4 from lagoons and landfills. Many of these technologies and management practices have co-benefits, including soil conservation, enhanced soil health, improved wildlife and pollinator habitat, increased biodiversity, improved water quality, water conservation, odor control, improved nutrient-use efficiency, energy production, and/or the healthy function of ecosystems.

Because of the breadth of USDA activities, the priority scientific needs and gaps are diverse and can be categorized as follows:

- Basic research on mitigation and processes
- Applied data and tools for inventory, measurement, and modeling

- Management and technology development
- The human and socioeconomic dimensions
- The collaborative research environment

Priority Areas

Over the past decades, USDA's scientific efforts have made impressive gains in understanding many of the processes and interactions key to reducing GHG emissions and increasing carbon storage. Much of that increased understanding is valuable to the work of the recently established USDA Climate Hubs and central to many of the USDA conservation and stewardship initiatives. Through these and other efforts, land managers are becoming aware of opportunities to mitigate emissions, often with an associated positive effect on their production, resilience, or profit margin. Yet more resources and effort are needed. To achieve GHG-mitigation goals, USDA research and programs should aim to increase the integration of energy and climate goals across USDA, resulting in the following:

- Increased carbon storage in crop and grazing land soils
- Reduced losses of nitrogen and carbon to the atmosphere
- Reduced enteric CH_4 emissions from livestock
- Improved management and utilization of livestock waste
- Enhanced forest growth, health, and retention (including urban forests)
- Efficient use of biofuels and biomass for heat, power, and biobased products, reducing fossil fuel use and improving utilization of wood and related by-products
- Enhanced use of conservation practices and/or protection for sensitive or degraded lands to enhance GHG mitigation or carbon storage potential

To realize these outcomes, many specific and strategic research priorities require further development, coordination, and effort across USDA agencies.

Basic Research on Mitigation and Processes

- Conduct research into N_2O and CH_4 emissions and soil carbon–nitrogen interactions at multiple scales in agricultural and grazing lands under different management and environmental conditions, including aspects of soil biology, soil health, and nutrient-use efficiency.
- Develop and transfer agricultural and land management methods, livestock production practices, and related technologies that enhance USDA agencies' efforts to reduce GHG emissions while maintaining or increasing production.
- Develop information and technologies that enhance the adoption of appropriate renewable and/or bioenergy technologies, including quantifying their contribution to GHG mitigation.
- Improve quantification and understanding of prescribed fire as a management tool, including potential comparisons of risks and benefits (both short and long term) of prescribed burn versus suppression management.

- Analyze mitigation implications (including spatial and temporal aspects) of land use and land-cover change (including afforestation, conservation of sensitive lands, land restoration, crop rotation, biofuel feedstock production, etc.), including long-term and systematic considerations.
- Improve understanding of the CH_4 balance on managed lands, wetlands, and perennial forests and grasslands.

Applied Data and Tools for Inventory, Measurement, and Modeling

- Develop improved tools for inventory, estimation, measurement, and modeling of GHG emissions and carbon storage at local, regional, and national scales, improving capabilities for coordinated surveys, data management, and statistics for tracking progress; providing data to reduce uncertainties; and assessing the effectiveness of GHG emission and sequestration management.
- Improve coordination of data collection, integration, and use, including more standardized handling and delivery of data.
- Improve, integrate, and expand data networks, infrastructure, and analytical capacity for national- and regional-scale GHG inventory.
- Understand and quantify the trade-offs caused by—or co-benefits and additional environmental services provided by—mitigation practices and technologies, such as financial costs to farmers for implementation.
- Improve water quality, soil conservation, or habitat quality, considering potential negative impacts as well.
- Develop a standardized approach to life-cycle assessment and life-cycle cost analyses that more readily allows for intercomparison of alternative and traditional farming systems.
- Develop appropriate methodologies for measuring and estimating GHG emissions and sequestration for all production systems at a variety of scales, building upon existing methodologies, including metrics for tracking progress on mitigation-related activities.
- Improve application of emerging technologies, tools, models, standards, and protocols.
- Improve water conservation and resource allocation through collection of data useful for enhanced analysis of alternative water-pricing structures, water-management strategies, and governance principles for water supplies provided through irrigation districts.

Management and Technology Development

- Develop cropping systems, technologies, and management practices that will increase carbon sequestration, such as improved crop rotations, advances in cover cropping, crop management, crop genetics, and improved soil biology/microbiome.
- Assess the contribution of biomass feedstock production for biofuels and biomass heat and power-to-net reductions in GHG emissions, including the effect on global land use, in coordination with the Department's research on biomass energy.
- Identify new techniques and technologies that could spur future advances in biobased products

that enhance GHG mitigation efforts.

- Improve understanding of and ability to quantify the benefits of anaerobic digestion as a means of generating power, mitigating GHGs, and utilizing agricultural and food waste.
- Develop new or improved means of animal housing, feeding, manure storage and handling, and manure nutrient extraction to improve efficiencies and mitigate GHGs.
- Develop technologies and processes for increasing utilization of wood products in buildings.
- Develop technologies and information that reduce food waste and related emissions from production systems, post-harvest processing and distribution, and consumer behavior to reduce natural resource waste; and reduce related emissions during harvesting and processing of forest and woodland resources.

The Human and Socioeconomic Dimensions

- Analyze the environmental effectiveness, economic efficiency, human dimensions, and trade-offs of technologies, practices, and policy options that enable effective GHG management throughout agricultural and forestry production, processing, storage, and delivery systems.
- Improve understanding of social behavior and the levers, incentives, or motives of land managers to adopt GHG-mitigating practices, and develop methods to evaluate motivating factors and drivers of change.
- Analyze the trade-offs and costs related to policy implementation and practice or technology adoption.

The Collaborative Research Environment

- Engage USDA's international and domestic research partners to ensure the best possible science is underway to provide the broadest and most useful possible effect.
- Improve cross-agency coordination and interagency collaborations around research priorities to ensure a higher return on resources invested in mitigation efforts.
- Assess the ties between GHG mitigation and climate adaptation, food security, sustainability, and resilience to promote practices and technologies that have the broadest effect.
- Investigate potential trade-offs related to competing departmental conservation goals and assess possible interactions between climate policies, conservation programs, and practices using a standard set of methods, such as those in USDA Technical Bulletin 1939 and subsequent updates.
- Develop a plan to identify and systematically evaluate new technologies and practices for their GHG benefits and environmental co-benefits.
- Align USDA resources to increase communication and enhance the flow of research results to program and policy implementation.
- Harmonize programmatic and technical definitions across agencies wherever possible.

Decision Support

Support Climate-Informed Decision Making

Decision support is a core function of the USDA, in many ways reflecting the Department's responsiveness to stakeholder needs and perceptions. The rapidly changing climate is likely to alter ecological, agricultural, economic, and social systems, which in turn requires increased emphasis on science-based decision support that helps stakeholders minimize risk and take advantage of opportunities. Decision support seeks to generate and synthesize credible information relevant to stakeholder needs and deliver this information in ways that are accessible and meaningful to the stakeholder. This support involves listening to stakeholder issues, but also anticipating needs and providing education in cases where stakeholders are just beginning to grapple with the complexities of climate change.

This chapter describes strategic direction to identify and address stakeholder needs within several priority areas, which crosscut with other chapters in this Plan. These priority areas often have unique stakeholder groups, which, in turn, may be best supported in climate-informed decision making by a variety of information, tools, and delivery. The Climate Hubs network serves as a central source (a hub) of connections, communication, information, tools, and applied climate science experience, but is ultimately just an acceleration of a department-wide transformation to meet internal and external stakeholder climate support needs in all the priority areas listed below. These priority areas are divided into four broad categories:

- Science and assessment
- Planning and operations
- Programs and policy support
- Communication and education

USDA already engages in extensive in-person and programmatic interaction with stakeholders, providing decision support in diverse areas, such as agricultural production, natural resource conservation, and economics. A fundamental strategic approach to integrating climate considerations throughout USDA decision support and programs is to ensure that the USDA workforce is fully climate literate. This will ultimately harness the creativity and professionalism of the workforce and ensure that climate education, preparedness, and adaptation infuse USDA program implementation and science delivery. Given the pressing and complex nature of climate change, this requires near-term focused effort and investment to provide internal climate support services and education even as greater effort is devoted to external stakeholder climate-informed decision support. Development of these internal and external decision-support resources cannot be isolated in a single agency or office within USDA. Success depends on integrating knowledge from the many diverse fields and missions of the Department and making it available within needed timeframes in usable formats. Finally, strategic investment in applied research into the human dimensions of risk perception, management, and decision making in the context of climate change may aid the design of more effective decision support.

Priority Areas

Climate change should be made an explicit and functional component of the programmatic planning and implementation of all USDA mission areas through the timely development, delivery, and application of relevant science.

Science and Assessment

Transdisciplinary research programs should be created to achieve the following:

- Generate science and tools supporting climate-informed decisions in agriculture and forest management.
- Create and contribute to assessments that address the vulnerability of agricultural commodities, natural resources, and socioeconomic systems to climate change and weather variability.
- Evaluate the environmental effects (benefits/limitations) of conservation practices for climate-change adaptation or GHG mitigation on a regional basis for a spatially explicit analysis of cost-benefit from practice implementation.
- Assess the likely effects of climate change on regional and global food security, taking into account domestic and international trade.
- Develop deeper knowledge of the human dimensions of climate change, including perceptions and effective framing of risk, adaptation and mitigation incentivization, successful models of adopting change, and decision drivers and thresholds.

Planning and Operations

- Integrate climate factors into alert systems that predict the spread of agricultural pests and animal diseases domestically and globally.
- Foster the creation and maintenance of climate-adaptation demonstration projects in agriculture and forestry that exemplify coping with local climate challenges and taking advantage of new opportunities.
- Review and adjust existing practices and programs for the potential to include and support climate-informed decision making.
- Develop, test, and deliver decision-support models and tools suited for direct use by extension educators, service providers, producers, and others.

Programs and Policy Support

- Support the land-grant colleges and universities to ensure that extension specialists and agents have the climate training and tools needed to foster broader public understanding of climate-change issues and solutions.
- Develop standards and protocols for climate change and carbon information to help align existing USDA information collection programs, and then provide coherent reports on carbon and climate metrics to USDA agencies.
- Assess opportunities to identify actions that capture and store carbon, mitigate GHGs, and

foster adaptation.

- Facilitate climate-informed decision making by stakeholders through inclusion of climate adaptation and mitigation considerations in support programs.
- Coordinate climate initiatives and education with federal, state, academic, extension service, nongovernmental, and local community partners.
- Incentivize or require grant recipients to produce plain-language summaries of their research findings for the general public and policy makers.

Communication and Education

- Increase climate literacy within the USDA workforce through focused training and education programs.
- Assist USDA employees in framing climate-related discussions with clients.
- Increase public awareness of climate change, its likely effects on agriculture and forestry, and adaptation and mitigation solutions through in-person interaction with climate-literate USDA professionals and partners, as well as through all forms of print and electronic media.
- Establish inclusive "communities of practice" to encourage peer-to-peer learning and discussion, and more adaptive feedback loops between research and implementation (Figure 2).
- Collect and actively curate applied climate, climate effects, and adaptation information relevant to regional agriculture and forestry, with delivery via modern web architecture and best practices.

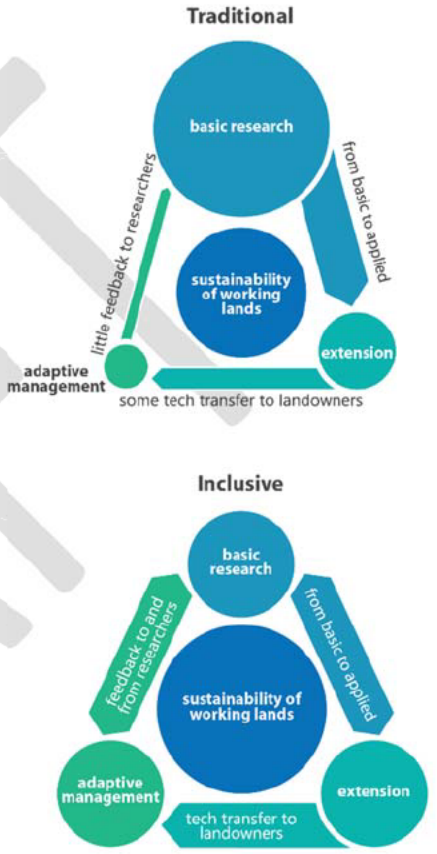

Figure 2. Traditional and inclusive approaches to supporting sustainability on working lands

Indicators and Metrics

Guide Science to Develop and Support Indicators and Metrics of Climate Change

Within climate-change research and policy, indicators are observations or calculations that can be used to track conditions and trends. They are commonly accepted and provide meaningful, authoritative, climate-relevant measures about the status and trends of key physical, ecological, and societal variables and values. Indicators can inform decisions on management, research, and education at regional to national scales. They identify climate-related conditions and impacts to help in the development of effective mitigation and adaptation measures. Indicators are the basis of many climate-change monitoring and response plans. Two well established sets of national indicators are compiled by the USGCRP and the Environmental Protection Agency (EPA).

Metrics of climate change combine individual measurements that can be used to gauge system performance. Metrics may provide a tool for developing and implementing response strategies, measuring progress, and improving performance. USDA science should support the development of metrics that not only determine how adaptation and mitigation efforts have avoided adverse climate effects, but also whether mitigation efforts are effective. To be useful, metrics should be relevant to stakeholders, measurable, and comparable. Measurement can be difficult due to uncertainty. While many of the current metrics address GHG emissions and land and water use, there is less focus on the relationship between the environmental, social, and economic effects of climate change.

Beyond the commonly accepted indicators, there may be additional observations or calculations that assess agricultural risk under climate change, can measure mitigation, and can improve adaptation planning. For example, the EPA lists drought conditions of U.S. lands as an indicator, but a more helpful metric for agriculture and forests may be agricultural and forest droughts as opposed to the alternative, hydrological drought. Together, indicators that cover broad geographic areas and trends and metrics that provide more specific and fine-scale data can help the agricultural and forest communities respond to climate change.

This chapter will focus on addressing the following questions:

- What science is needed to develop and support reliable indicators and metrics?
- What science is needed by USDA to support the indicators and metrics for the agricultural sectors?
- What metrics are needed to understand the effects of climate change and progress toward observing and predicting these effects?
- What support can USDA provide to increase the availability of existing indicators and metrics?

This chapter focuses on indicators and metrics for climate change as a means to support and inform the National Climate Assessment (NCA), not on developing metrics to measure the success of USDA programs. The goal of this chapter is not to measure the success of USDA programs or national policies, to identify science needs for performance metrics, or to develop an assessment plan to measure how USDA agencies are addressing the goals of this Science Plan.

The priority science areas for this chapter are as follows:

- Indicators
- Metrics
- Data to support indicators and metrics
- Informing policies and programs

USDA climate science efforts can be successful in supporting robust indicators. USDA long-term investments in data collection, inventories, observational networks, and surveys provide critical data used in climate science. The data generated from these inventories and surveys are necessary for use in research by scientists within and outside USDA. USDA not only generates data, but also relies on data from other sources, such as federal agencies, university partners, and even citizen science, in its programs and models. Maintaining these networks is essential to provide key data for indicators of climate change.

One of the greatest challenges to informing climate-change indicators for USDA is the availability and quality of data. An additional challenge is examining data to identify and extract information about trends in a manner that allows the data to be useful in conveying information about system behavior and how systems are responding to management/mitigation efforts. The observational data collected by USDA scientists and networks are particularly valuable, as observations taken at a point in time can never be taken again. These data are essential to track climate change and variability and to maintain a historical record of conditions. These data are needed to conduct research, develop models, and develop decision-support tools. A cohesive departmental metadata structure would improve accessibility and utilization of data. A key issue is improving the Department's ability to support indicators by identifying gaps in USDA science and observational networks in which missing data prevents USDA from measuring indicators. Developing department-wide policies and infrastructure will greatly improve data accessibility and subsequent research efforts.

Priority Areas

Indicators

- Evaluate interactions between social and economic indicators and the effects of climate change on agricultural production and the supply chain.
- Evaluate how other global-change processes, such as land-use change and disturbance regimes, influence climate-change indicators.
- Develop indicators from urban systems, such as urban forestry.
- Develop indicators for the northern boreal lands.
- Develop indicators for the terrestrial–aquatic interface in partnership with other federal agencies.
- Support research for developing new tools and technologies to improve reporting of indicators.
- Develop indicators of climate-change effects on regional water-supply scarcity in partnership with other federal agencies.

- Develop indicators that distinguish hydrological drought from agricultural and forest droughts.

Metrics

- Develop soil-health metrics, with a focus not only on land for crop and animal production, but also forests, grasslands, and shrublands.
- Develop metrics from earth observations for identifying, measuring, and monitoring the effects of climate change.
- Identify gaps in USDA observational networks in which USDA is missing data, and identify opportunities to utilize existing USGCRP agency data and data from other partners to fill these gaps.
- Develop metrics for the northern boreal lands.
- Continue to support and further develop metrics that assess changes in behaviors and/or practices.

Data to Support Indicators and Metrics

- Determine how USDA can use its existing database and inventories to better determine the drivers of land-use change in the United States and how climate change alters the effect of these drivers; evaluate and utilize data from other USGCRP member agencies to support the indicators and metrics.
- Work to develop a USDA metadata structure and data policies that will improve accessibility of USDA data for research programs.
- Identify gaps in USDA research and science delivery to provide missing data, increase accessibility of data, and collaborate amongst the agencies to provide better tools and technologies.
- Improve interagency coordination and data collection sharing by developing a multipurpose sampling method.
- Develop modern systems for storing, linking, and serving big data in cooperation with other governmental agencies.

Informing Policies and Programs

- Determine how existing monitoring systems can be optimized for detecting the effects of climate change on ecosystems, developing early-warning indicators, and improving forecasts of potential future changes.
- Utilize existing socioeconomic and environmental data to guide decisions and program implementation leading to successful adaptive behaviors.
- Integrate policy evaluation into policy impact assessment, using econometric program evaluation methods.
- Identify the types of policy interventions that lead to adaptation to and mitigation of climate variability and change.

- Determine the effect of conservation practices on adaptation and mitigation, which can then be used to determine whether programs are improving climate resilience.
- Increase emphasis on satellite-based research and development (R&D) in USDA programs to provide data on GHG emissions associated with agriculture at local levels.
- Explore novel methods to gather stakeholder inputs to help agencies better target programming to advance GHG mitigation.

Coordination and Implementation

Share Progress Across Agencies to Ensure Research Gets Used and Applied

Climate change science is a collaborative effort across USDA. Twenty-one USDA agencies, program offices, and mission areas are involved. Each entity has a different focus and plays a distinct role in the Department's climate-change program. Notably, science and research agencies must work together with program and service agencies. With so many participants, there is a risk that data and results may not be fully utilized or available across agency lines. Central to the success of this Science Plan is the coordination and implementation of ideas developed across agencies.

To achieve the most progress, it is important to facilitate coordination across USDA and other federal agencies. Coordination can help avoid duplicating efforts and reduce obstacles to adoption of available research. Efforts toward central coordination exist within USDA, through the Climate Change Program Office (CCPO), and at the federal level, with the USGCRP, but there remains a need for each USDA agency to connect to the research, development, and application pipeline. To address this, it would be beneficial to improve communication and awareness at all levels. Priorities for coordinating such efforts are as follows:

- Centralize data, making it available and accessible through the National Agricultural Library (e.g., PubAg), climate.data.gov, or other open-data outlets. Include appropriate documentation for ease of data access.
- Analyze current working groups, reviews, and data products, and streamline where possible.
- Develop cross-agency opportunities for focused discussion and collaboration, such as topical workshops. Include agencies across USDA and, where appropriate, outside stakeholder participants.
- Provide communication channels for regular updates of involved USDA agencies. Existing groups, such as the GCTF, may be able to use their infrastructure to facilitate this effort.
- Elevate climate-change collaboration to a department-wide priority. This may drive greater consciousness about the need for adoption of results from different agencies.

The goal of this coordination is to ensure that programs and services needing research information know it is available for their use and that they can collaborate with researchers to develop needed science and technology. While awareness is the first step toward ensuring that research, development, and application intersect, implementation remains an important aspect. The crosscutting activities described in the Introduction can help to foster interaction between specific agencies and areas, but broader participation is needed. It is incumbent upon each climate science participant in every USDA agency and program office to think about his or her work not in a vacuum, but as part of the greater ecosystem, as encapsulated in Figure 1.

No single pathway to implementation is proposed here. Instead, there is an emphasis on ensuring that the full cycle of research, development, and application is consistently considered. This Science Plan highlights the need to provide the community with the necessary tools and funding to support this cycle. It is a priority for all involved agencies and offices to continually explore ways to implement and

incorporate the available scientific and programmatic options to make the most sound climate-change actions.

Appendix A: Selected USDA Agency and Office Roles and Responsibilities

USDA provides leadership to the nation and the world on food, feed, fuel, fiber, agriculture, natural resources, rural development, nutrition, and related issues based on sound public policy, the best available science, and efficient management. Climate-change activities are central to achieving these goals and are supported by the following agencies.

The ***Agricultural Marketing Service (AMS)*** administers programs that create domestic and international marketing opportunities for U.S. producers of food, feed, fuel, fiber, and specialty crops. AMS biofuels market reports and market intelligence reports apprise stakeholders of prices and volumes of select feedstocks, fuels, and transport metrics.

The ***Agricultural Research Service (ARS)*** is the largest intramural research agency of USDA. ARS has a workforce of approximately 8,000 employees, including nearly 2,000 life and physical scientists, engineers, and veterinarians who represent a wide range of disciplines and work at more than 90 locations across the country and at four overseas laboratories. The ARS research agenda is broad, with about 750 research projects organized under four major program areas: Nutrition, Food Safety, and Quality; Animal Production and Protection; Natural Resources and Sustainable Agricultural Systems; and Crop Production and Protection. ARS is also home to the National Agricultural Library (NAL), which offers a wealth of information on all agricultural subjects and serves as the physical and digital library of USDA.

USDA's ***Animal and Plant Health Inspection Services (APHIS)*** provides leadership in ensuring the health and care of animals and plants. The agency improves agricultural productivity and competitiveness, and contributes to the national economy and public health.

The ***Climate Change Program Office (CCPO)*** coordinates departmental efforts on climate change, including organizing the USDA Global Change Task Force, GHG accounting methods and inventories, assessments, life-cycle analysis of biofuels, and building block efforts.

Departmental Management (DM) develops policy and implements programs and projects for USDA sustainable practices, environmental response and restoration, and biobased product market transformation. USDA's BioPreferred program increases the development, purchase, and use of biobased products through two initiatives: mandatory biobased product purchasing requirements for federal government agencies and voluntary bioproduct certification and labeling.

The ***Economic Research Service (ERS)*** is USDA's primary source of economic information and analysis, and economic and social science research. The mission of ERS is to inform and enhance public and private decision making on economic and policy issues related to agriculture, food, feed, fuel, fiber, the environment, and rural development.

The ***Farm Services Agency (FSA)*** manages the Conservation Reserve Program, which provides in excess of 40 Tg GHG mitigation benefits, and the Biomass Crop Assistance Program (BCAP), which provides financial assistance to owners and operators of agricultural and private forestland who wish to establish, produce, and deliver biomass feedstocks.

The ***Food Safety and Inspection Service (FSIS)*** is the public health regulatory agency in USDA responsible for ensuring that meat, poultry, and processed egg products are safe, wholesome, and accurately labeled. FSIS enforces the Federal Meat Inspection Act (FMIA), the Poultry Products Inspection Act (PPIA), and the Egg Products Inspection Act (EPIA), which require federal inspection and regulation of meat, poultry, and processed egg products prepared for distribution in commerce for use as human food. FSIS also enforces the Humane Methods of Slaughter Act (HMSA), ensuring that humane methods of handling and slaughter are employed by the establishments that it regulates.

The ***Foreign Agricultural Service (FAS)*** links U.S. agriculture to the world to enhance export opportunities and global food security. FAS delivers programs and services in trade policy, data analysis, market development and export assistance, and food security. In addition to its Washington, DC, staff, FAS has a global network of 93 offices covering 171 countries. These offices are staffed by agricultural attachés and locally hired agricultural experts who are the eyes, ears, and voice for U.S. agriculture around the world. FAS staff identifies problems, provides practical solutions, and works to advance opportunities for U.S. agriculture and support U.S. foreign policy around the globe.

The ***National Agricultural Statistics Service (NASS)*** is USDA's statistical agency. NASS conducts hundreds of surveys every year and prepares reports covering virtually every aspect of U.S. agriculture. The statistical data provided by NASS is essential to the public and private sectors for making effective policy, production, and marketing decisions on a wide range of agricultural commodities. NASS also conducts statistical science research on survey design, sampling, and other methodological issue areas. NASS works closely with the states in determining their agricultural profiles.

The ***National Institute of Food and Agriculture (NIFA)*** is the primary extramural research, education, and extension funding agency of USDA. Its mission is to invest in and advance agricultural research, education, and extension to solve societal challenges. Some funding opportunities are specific to the land-grant university system, and others are open to participation by other academic institutions, government agencies, NGOs, and even private sector entities.

USDA's ***Natural Resources Conservation Service (NRCS)*** is the Department's principal agency for providing conservation technical assistance to private landowners, conservation districts, tribes, and other organizations through voluntary conservation. NRCS delivers technical and financial assistance to landowners and agricultural producers to help plan and implement conservation practices that address natural resource concerns or opportunities to help save energy and improve soil, water, plant, air, animal and related resources on agricultural lands and nonindustrial private forestland. NRCS programs that help clients put conservation plans into action include the Environmental Quality Incentives Program (EQIP), the Conservation Stewardship Program (CSP), the Agricultural Conservation Easement Program (ACEP), the Regional Conservation Partnership Program (RCPP), the Agricultural Management Assistance (AMA) Program, and Conservation Technical Assistance (CTA). The development of sound conservation practice standards and other tools used at the field level are key to NRCS conservation assistance and voluntary conservation implementation.

The USDA ***Office of the Chief Scientist (OCS)*** was established in accordance with the Food, Conservation, and Energy Act of 2008 to provide strategic coordination of the science that informs the Department's and the federal government's decisions, policies, and regulations that affect all aspects of U.S. food and agriculture and related landscapes and communities.

The ***Risk Management Agency (RMA)*** administers the federal crop insurance program and assists growers to manage losses due to insured causes of loss, including natural disasters, drought, or flooding. RMA managed over $102.4 billion in liability in 2015 and paid over $6.2 billion in losses from natural disasters to producers on over 296 million acres.

Rural Development (RD) offers technical and financial assistance to help agricultural producers, cooperatives, and other businesses improve the effectiveness of their operations, produce energy as a new cash crop, and process raw agricultural and forestry materials into value-added, biobased products.

The ***United States Forest Service (USDA FS)*** supports the management of 193 million acres of national forests and grasslands in the United States and provides stewardship assistance for more than 500 million acres of state and private forestland. The Forest Service works at the forefront of science to improve the health and use of the nation's forests and grasslands, a role of the agency since its inception in 1905. The Forest Service Research and Development Deputy Area (FS R&D) includes seven research stations and 81 experimental forests and ranges. FS R&D provides the scientific and technical knowledge necessary to promote sustainable management of the nation's diverse forests and rangelands, making the information and technology produced through basic and applied science programs available to the public for its benefit and use. Its research complements, and is coordinated with, that of the REE agencies.

Appendix B: List of Acronyms and Abbreviations

AgMIP	Agricultural Model Intercomparison and Improvement Project
AMS	Agricultural Marketing Service
APHIS	Animal and Plant Health Inspection Services
ARS	Agricultural Research Service
CCPO	Climate Change Program Office
CH_4	Methane
CO_2	Carbon Dioxide
DM	Departmental Management
DOI	Department of the Interior
EPA	Environmental Protection Agency
ERS	Economic Research Service
FAS	Foreign Agricultural Service
FIA	Forest Inventory and Analysis
FS	Forest Service
FSA	Farm Services Agency
FSIS	Food Safety and Inspection Service
GCTF	Global Change Task Force
GHG	Greenhouse Gas
IPCC	Intergovernmental Panel on Climate Change
LTAR	Long-Term Agroecosystem Research
LTER	Long Term Ecological Research
N_20	Nitrous Oxide
NASS	National Agricultural Statistics Service
NCA	National Climate Assessment
NEON	National Ecological Observatory Network

NGO	Nongovernmental Organization
NIFA	National Institute of Food and Agriculture
NOAA	National Oceanic and Atmospheric Administration
NRCS	Natural Resources Conservation Service
NRI	National Resources Inventory
OCS	USDA Office of the Chief Scientist
PubAg	U.S. Department of Agriculture (USDA), National Agricultural Library's (NAL) search system for agricultural information
R&D	Research and Development
RaCA	Rapid Carbon Assessment
RCA	Resource Conservation Act
RD	Rural Development
RMA	Risk Management Agency
RPA	Resources Planning Assessment
STEM	Science, Technology, Engineering, and Mathematics
UAV	Unmanned Aerial Vehicle
UNFCCC	United Nations Framework Convention on Climate Change
USDA	United States Department of Agriculture
USDA FS	United States Forest Service
USGCRP	United States Global Change Research Program

1