PRELIMINARY DRAFT NOTICE: This Cross-cutting Roadmap, 2016 – 2019 is a preliminary draft. It has not been formally released by the U.S. Environmental Protection Agency (EPA) and should not at this stage be construed to represent Agency policy, nor the final research program.

Climate Change Research Roadmap

Cross-cutting Roadmap

Draft, October 30, 2015

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II. Introduction

In partnership with other federal agencies as part of the US Global Change Research Program, EPA plays a critical role in developing the nation's response to the far-reaching and complex challenges posed by global climate change. Assessing climate change impacts and understanding how to mitigate impacts of climate change through actionable science is a key role for the EPA in the area of global climate change research. As the science arm of the only federal agency with responsibilities to safeguard all aspects of the environment—air, water, natural ecosystems, and land—as well as to protect human health – EPA's Office of Research and Development (ORD) is tasked with informing the Agency about the impacts of climate change on air quality, water quality, and human and ecosystem health. While the formal climate research program, as reflected in EPA's appropriations, is relatively small, work in the National Research Programs touches on the role of climate to better understand, prepare for, and mitigate the complex impacts of climate change. As such ORD has designed a highly transdisciplinary, collaborative, and solution-oriented research program to deliver the information, data, models, and decision-support tools the Agency and its partners across the nation need to take action.

Climate Change, along with Environmental Justice, Nitrogen and Co-pollutants, and Children's Environmental Health, is one of four topics that cut across the six National Research Programs. ORD identified these cross-cutting topics as needing in-depth, formal roadmaps to enhance cross-program coordination and integration. This "Climate Change Research Roadmap" presents an overview of recent, ongoing, and planned science related to climate change across the six National Research Programs of ORD, and notes research gaps to inform the evolution of ORD's Strategic Research Action Plans (StRAPs). The roadmap highlights the unique role that EPA plays within the overall federal climate change research portfolio and illustrates how EPA's climate change research leverages national research expertise to advance the understanding of the impacts of climate change and approaches to address those impacts through preparation, adaptation, and mitigation. EPA's climate change research is an integral and visionary part of the Agency's overall efforts to protect air, water, and public health, and increase homeland security and community resiliency.

Background

"Addressing Climate Change and Improving Air Quality" is one of five strategic goals in its *Fiscal Year 2014-2018 EPA Strategic Plan*.[1] The EPA Strategic Plan specifically calls upon the Agency to address climate change in ways that promote sustainability, make a real difference in communities, and build partnerships at state, tribal, local, and international levels.

[1] http://www2.epa.gov/planandbudget/strategicplan

The President's Climate Action Plan (PCAP) calls for the nation to reduce carbon, or greenhouse gas (GHG), emissions and prepare for climate change across a wide range of sectors, from power generation to agriculture, forestry, and water.[2] The plan directs EPA to work closely with states, industry and other stakeholders to establish carbon pollution standards for new and existing power plants, and to help local communities across the nation take action on climate change. The Agency's climate change research program therefore is designed to inform Agency decisions and actions to implement PCAP.

Such a challenge requires working closely with partners and stakeholders both within the Agency and externally to identify and conduct the research needed to make real progress. ORD thus works closely with the Office of Air and Radiation (OAR), Office of Water (OW), Office of Solid Waste and Emergency Response (OSWER), Regional Offices, and others within EPA to understand their highest priority climate-related research needs. It is EPA's program and regional offices that have the responsibility to develop and implement federal environmental laws and regulations, many of which are now being, and will increasingly be, impacted by climate change. One example of how EPA actions are affected by climate change, and how ORD can provide information to help EPA respond, is the Climate Ready Estuaries program, a part of the National Estuary Program of the Office of Water. ORD provided technical guidance on the use of expert judgment to inform local decision makers about approaches to development of climate adaptation plans for estuaries.[3]

The President's Executive Order 13514[4] also required EPA to develop an Agency-wide Climate Change Adaptation Plan to ensure that EPA is able to achieve its mission in the face of a changing climate. This EPA Adaptation Plan and the 17 Office-specific Climate Adaptation Implementation Plans provide additional insights into the research needed by EPA to understand and respond to climate change. These plans include efforts to understand how ozone and particulate matter (PM) concentrations will change as temperatures increase, the potential for increased wildfires to affect air quality, how extreme precipitation events can result in floods that impact water quality and land use, and the impacts of climate change on aquatic ecosystems.[5,6]

Externally, EPA's Science Advisory Board (SAB) and the ORD Board of Scientific Counselors (BOSC) provide independent, expert guidance on the near-term and long-term climate-related science issues they perceive as critical to EPA. More broadly, EPA also connects to the diverse climate research efforts across the federal government role as a member of the U.S. Global Change Research Program (USGCRP).[7] The USGCRP provides a forum for the interactive, cross-

[2] http://www.whitehouse.gov/sites/default/files/image/president27sclimateactionplan.pdf.
[3] http://www2.epa.gov/cre/coastal-adaptation-toolkit#frameworks
[4] http://www.epa.gov/oaintrnt/practices/eo13514.htm
[5] http://www.epa.gov/climatechange/Downloads/EPA-climate-change-adaptation-plan.pdf
[6] http://www.epa.gov/climatechange/impacts-adaptation/fed-programs/Final-EPA-Adaptation-plans.html
[7] USGCRP coordinates climate change research across 13 federal agencies, emphasizing the foundational role of science in understanding global change and its impacts on the environment: "Research, along with an array of increasingly sophisticated tools for collecting and analyzing data, can provide essential knowledge to governments, businesses, and communities as they plan for and respond to the myriad manifestations of global change, including

agency discussions of the science of climate change and impacts across the nation to gain the most value from federal climate research investments. As EPA's representative to USGCRP, ORD actively engages with this community to communicate EPA's research needs, identify opportunities for interagency collaboration and coordination, and contribute research expertise and results to USGCRP's guidance and communication of the comprehensive federal research effort on climate change.

Purpose

The impacts of climate change on the environment affect the historical patterns of pollutant formation and their transport in all media and, not surprisingly, the responses of people and ecosystems to pollutant exposures. Experience with complex systems, on the other hand, warns us that these changes are not the only concern we must address. We must also factor in environmental effects related to implementation of those very practices and technologies used to mitigate the causes and respond to the impacts of climate change. The connectedness of natural and human systems and the potential impacts of interventions – even to mitigate – will undoubtedly impact how EPA achieves its mission to protect human health and the environment.

The climate science effort outlined below is designed *to provide EPA with the scientific and technical information it needs to better understand how climate change may affect its ability to protect human health and the environment, and at the same time, inform governmental bodies and communities as well as individuals about how to prepare for, adapt to, and mitigate those impacts*.

This Climate Change Research Roadmap will:

1. Describe the priority climate change related research needs of EPA Program and Regional Offices;
2. Describe the scope of current and planned research conducted by ORD that addresses the identified priority research needs of its partners (Agency Program and Regional Offices); and
3. Identify new research directions and gaps to better inform ORD's Strategic Research Action Plans (StRAPS) as these plans are implemented and as they evolve in the future.

This Research Roadmap draws from StRAPs developed for each of the six national research programs within ORD to shape and coordinate ongoing climate-related research efforts across its six National Research Programs. The roadmap is designed to emphasize and strengthen ORD's science leadership in climate change through its existing expertise and capabilities, while providing a map to leverage its partnerships with experts across and beyond the Agency, the greater scientific community, state and local governments, and industry. The roadmap illustrates how ORD applies its expertise in the research arenas of air and water quality, ecosystem behavior and services, and community and environmental health in the context of a changing climate. To that end, ORD's connections to EPA partner offices, such as the OAR, OW,

sea-level rise and ocean acidification, heat waves and drought, and the severe storms, floods, and forest fires that pose an ever-growing risk to life, property, and agriculture" (see USGCRP 2012-2021 Strategic Plan Executive Summary, http://downloads.globalchange.gov/strategic-plan/2012/usgcrp-strategic-plan-2012-executive-summary.pdf).

OSWER, and Regional Offices, help focus research on those issues of greatest importance to EPA decision making. The roadmap also illustrates the EPA's research relationships with other federal agencies, including the National Oceanic and Atmospheric Administration (NOAA), the Department of Energy (DOE), National Aeronautic and Space Administration (NASA) and others, as well as working with leading academic researchers and industry experts.

Figure 1 illustrates how the Roadmap coordinates input from ORD's research partners, external research organizations, and advisory groups to provide consolidated guidance on climate change research needs and priorities to the ORD research programs. The Roadmap also works across the ORD research programs and with the Laboratories and Centers to guide translation and delivery of the results of climate-related research to the research partners. The Roadmap does not replace or direct the ORD research programs, but acts to coordinate and consolidate that research in ways that help integrate across the programs to meet the needs of ORD's Program and Regional Office partners.

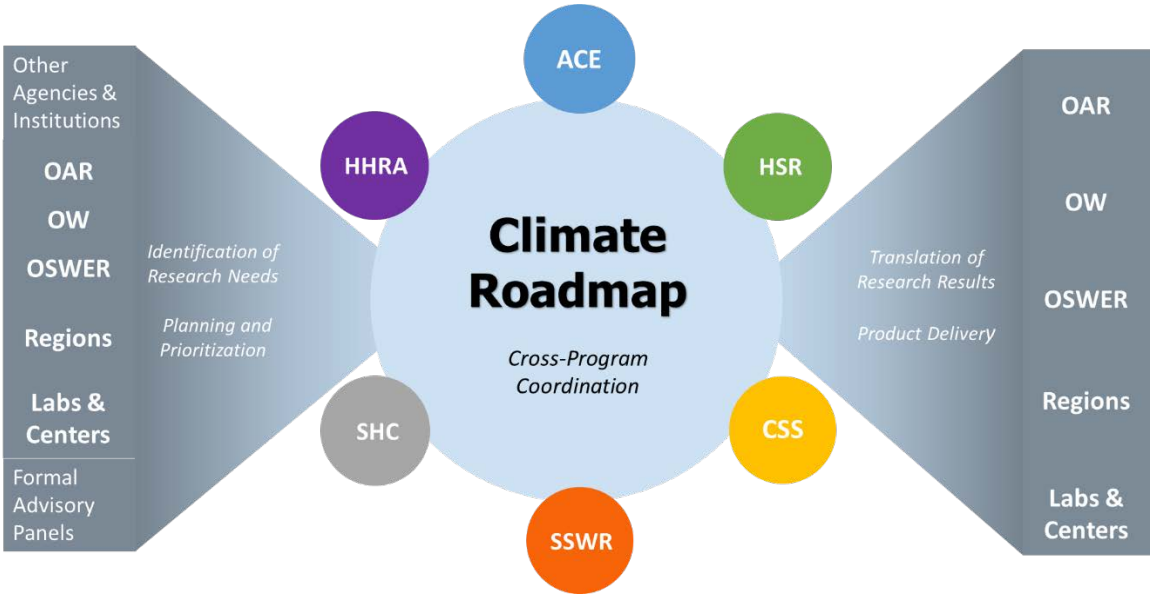

Figure 1. Schematic of the role of the climate research roadmap.

EPA's climate change science program addresses seven key research topics:

- Water quality and aquatic ecosystems
- Air quality
- Human health
- Ecosystems and land
- Mitigation and associated environmental impacts
- Social system influences
- Uncertainty

III. Research Scope

EPA provides scientific and technical information the Agency and its partners need to better understand, prepare for, adapt to, and mitigate the impacts of climate change. The scope of that work is focused to fulfill EPA's mission to protect human health and the environment, and to meet the Agency's statutory authorities and responsibilities.

Expanded Problem Statement

The impacts of climate change on air quality, water quality, communities and ecosystems threaten our health, our economy and our way of life. Climate change has been deemed a matter of national security[8] with impacts projected to increase in the future, and to intensify in many areas of the country. Our responses to climate change, whether to minimize greenhouse gas emissions or to prepare for and adapt to the impacts of climate change, will also impact the environment. The purpose of ORD's climate change research is to: understand the interactions between climate change and the environment; evaluate the resulting impacts on human health and welfare; inform regulatory actions and strategies to respond to these impacts; and ensure that such responses avoid further unintended, adverse impacts.

Science Challenges

The key research topics that align with five emphases of EPA's regulatory and other programmatic activities are: (1) water quality and aquatic ecosystems; (2) air quality; (3) human health; (4) ecosystems and land; and (5) mitigation and the subsequent environmental impacts of mitigation. The science challenges for these topics include:

- Water quality and aquatic ecosystems: understand how parameters critical to maintaining and enhancing water quality and aquatic ecosystems are affected by climate change such that historical records are no longer reliable guides for water management;
- Air quality: understand how climate change affects air quality and how air quality-related emissions and atmospheric processes affect climate change;
- Human health: understand the incremental impacts on human health due to climate-driven exacerbation of effects associated with exposure to existing environmental stressors, and to understand emerging health threats caused by climate change;
- Ecosystems and land: understand how and to what degree the impacts of climate change, such as flooding, sea level rise, and extreme events (storms, wildfire etc.), can disrupt communities, land use and ecosystem services.
- Mitigation: inform the development of effective mitigation strategies that avoid untoward or other, unacceptable environmental impacts.

In addition, it will be important to understand social system influences to effectively respond to climate change. As climate change will impact virtually all aspects of personal and community life, how communities contend with broad environmental change and better understand critical options will affect the means and likelihood of achieving sustainable and acceptable outcomes.

[8] https://www.whitehouse.gov/sites/default/files/docs/National_Security_Implications_of_Changing_Climate_Final_051915.pdf.

This understanding extends beyond the domain of technology alone, but requires an understanding of economic and social factors that are integral to broad-based community and governmental decision making. The complexity of climate change, its impacts on both natural and human systems and the many uncertainties inherent in the responses of complex systems require the development of transdisciplinary methods and approaches to inform decisions in the context of deep uncertainty.

Research Alignment and Coordination

Climate change research is of necessity scientifically broad and must be systems-based. ORD's unique research responsibilities focus on scientific topics that directly impact air quality, water quality, and waste management, and subsequently human health and the environment positions EPA to address impacts be they direct or indirect. The scope and magnitude of the science needs is such that EPA relies on external partners, primarily other federal agencies, to develop the fundamental scientific understanding (e.g., global atmospheric, oceanic and climate models) for those areas that fall outside the scope of EPA's legislated authorities or for which other agencies have been assigned the lead.

To meet the science challenges which fall to ORD, climate-related research is conducted as part of ORD's six programs, primarily within the Air, Climate, and Energy (ACE) and Safe and Sustainable Water Resources (SSWR) programs. While climate-related research is also embraced in the Sustainable and Healthy Communities (SHC), Homeland Security (HS), and Human Health Risk Assessment (HHRA) and Chemical Safety for Sustainability (CSS) research programs, it comprises a much smaller fraction of those programs and relies on highly leveraged activities. In general, work in ACE focuses on air quality-climate interactions, energy systems, climate change impacts on watersheds and ecosystems, development of land use and other climate-relevant scenarios, and decision support methods and tools. Complementing this work, SSWR investigates climate change impacts as one of several stressors on aquatic ecosystems, watersheds, and drinking water and wastewater infrastructure, with a focus on preparedness and adaptation, while SHC focuses on community-level information and decision tools that incorporate climate change as a multiplying stressor. Consistent with their missions, HS focuses on resilience of water systems to disasters including those caused by climate change, and HHRA incorporates climate change into evaluations of human health risks of exposure to pollutants. CSS research is responsible for considering climate impacts of new compounds that may be introduced into the environment as a consequence of climate change. The goal of this roadmap is to lay out this array of research systematically to better inform and guide ORD climate research plans consistent with EPA's overall climate vision.

Research coordination extends across the other cross-cutting roadmaps (nitrogen, children's health, and environmental justice). The need to consider the impacts of climate change on vulnerable populations and ecosystems highlights the connections between the Climate Change Roadmap and those for children's health and environmental justice. As noted in the Environmental Justice Roadmap, Tribal communities may be more vulnerable and disproportionately impacted by climate change, especially when it disrupts the ability to depend on surrounding ecosystems for food sources, cultural practices, and unique lifestyles. Other environmental justice communities are also expected to face disproportionate risks from the

impacts of climate change, as are children. Coordination of work across research programs therefore requires on-going efforts to ensure all these cross-cutting issues are effectively incorporated into research design and activities.

Communication of EPA's research needs and activities is critical to ensure coordinated research across ORD and that these efforts address the needs identified by our Partners (see Section V) as fully as possible. The development of the Strategic Research Action Plans (StRAPs) is at the core of these endeavors building upon annual, in-depth discussions between National Research Program teams and relevant Partner offices to plan upcoming research activities. There is regular discourse between ORD and our programmatic Partners across all organizational levels. Quarterly, monthly, and weekly discussions as appropriate allow for formal and informal exchanges of perspectives, results, and issues. Program teams provide guidance and input to the strategic and annual planning efforts of other research programs, and cross-cutting topic leads (climate change, nitrogen, children's health, and environmental justice) also review and contribute to the planning of each of the programs. Higher-level research priorities, such as those identified in the EPA Climate Change Adaptation Plan, are communicated to the six ORD research programs by the Associate Director for Climate.

EPA is one of 13 Federal agencies that perform climate change research coordinated at the federal level by USGCRP which serves as a forum to communicate EPA's research needs. Companion USGCRP agencies conduct research that addresses the fundamental science leading to changes to atmospheric and oceanic circulation, weather (including extreme events), fish and wildlife habitats, water supply risks, transportation, energy production and demands, and agriculture, among others (see Table 1 below). The focus of EPA research is to understand and synthesize the science of how climate change may affect human health and the environment to enable EPA to meet its legislated responsibilities.

To integrate the complex task of research to understand climate change, key needs are communicated through several interagency venues, including the USGCRP and other subcommittees of the Committee on Environment, Natural Resources, and Sustainability (CENRS), as well as through interactions between EPA and other agencies at working levels. At the working level, USGCRP coordinates the activities of 13 interagency working groups that foster informal cross-agency integration and collaboration (i.e., interactions that do not require formal interagency agreements) among research programs and investigators. ORD staff are active participants in nine of the Interagency Working Groups (IWGs), and EPA staff from other Offices are engaged with five of the same IWGs as well as two others (Appendix D). The ACE Associate Director for Climate

Table 1. Climate-related research conducted by other federal agencies of importance to EPA and ORD.

Agency	Climate-related research topics
USGCRP Agencies/Offices*	
Department of Agriculture	GHG inventories and climate-related impacts on natural and human systems associated with agricultural production; forest inventory; biofuel feedstock production and impacts

Department of Commerce (National Oceanic and Atmospheric Administration, National Institute of Standards and Technology)	Global climate modeling; climate and oceanic observations, including polar region observations; climate-related geophysical process understanding, including atmospheric transport and chemistry and aerosol science; ambient measurements of GHG concentrations; GHG measurement technologies and standards
Department of Energy (Office of Science, Office of Energy Policy and Systems Analysis, Office of Policy and International Affairs)	Global climate modeling; atmospheric system science, including aerosols, clouds, and radiative transfer; role of terrestrial ecosystems; carbon cycle observations; integrated assessment modeling; impacts to energy production and transmission
Department of Health & Human Services (National Institutes of Health, Centers for Disease Control and Prevention)	Health impacts of climate change due to heat, air quality, infectious diseases, and severe weather aftermath; health monitoring; public health adaptation strategies; potential health effects of GHG mitigation approaches
Department of the Interior (U.S. Geological Survey, Bureau of Reclamation)	Processes controlling Earth system responses to climate change; impacts on natural resources; water resource monitoring; remote sensing (Landsat); National Land Cover Database; biological carbon sequestration; GHG flux in ecosystems; regional impacts on fish, wildlife, and ecological processes
National Aeronautic and Space Administration	Satellite observations of atmosphere, ocean, land, sea ice, and ecosystems to understand carbon and water cycle dynamics, soil moisture, atmospheric composition, and radiative balance; global climate modeling
National Science Foundation	Atmospheric, oceanic, and ecosystem process understanding and modeling; human and human system response to climate change; impacts to ecosystems and ecosystem services; integrated model development
Other Agencies/Offices	
Department of Energy (Office of Fossil Energy, Office of Energy Efficiency and Renewable Energy)	Development, demonstration, deployment, and evaluation of low carbon energy generation and use technologies

* Relatively little research is provided by the other USGCRP member agencies (Department of Defense, Department of State, Department of Transportation, Smithsonian Institution, and U.S. Agency for International Development)

serves as the EPA representative to the CENRS Subcommittee on Global Change Research, further ensuring close coordination and integration with other federal agencies.

Additional interagency coordination occurs through collaborations such as the Climate Change and Water Working Group (CCAWWG), which is a working-level effort to coordinate water management activities that account for climate change. CCAWWG addresses research and implementation issues, and includes agencies outside the USGCRP umbrella, including the

Federal Emergency Management Agency and the Bureau of Reclamation.[9] Research needs and issues identified across the participating federal agencies are communicated to ORD primarily through OW.

Interagency research efforts are frequently coordinated using Memoranda of Understanding (MOUs) that define research activities and resource investments within each participating agency and how information will be shared across agencies. ORD's MOUs with other federal agencies define commitments toward achieving a common goal without transfer of resources Several MOUs related to climate research include those with the Army to evaluate "Net Zero" technologies, with NASA to promote collaboration on environmental and earth sciences, with NIEHS on children's health (including effects of climate), and with USGS to develop collaborative research on aquatic species habitat modeling. Additional informal interagency collaborations occur more frequently based on recognition of complementary expertise and resources, mutually beneficial outcomes, and availability of resources. More broadly, ORD and EPA frequently communicate with staff from other agencies, promoting good awareness of capabilities and needs across agency boundaries. These interactions are quite diverse in their constitutions and goals, EPA benefits substantially from strong interest on the part of other agencies to interact and conduct research that will be applied to EPA needs.

IV. Cross-cutting ORD Research

Current and Planned ORD Research

This section presents the climate change-related research currently being conducted across ORD as well as that planned in the StRAPs. The science needs of ORD's partners, developed through focused discussions with EPA Program and Regional Offices to determine their most important needs for scientific information, are presented, followed by brief descriptions of current and planned research designed to provide the needed information. Those identified needs that cannot be addressed by ORD are identified as gaps between what the Program and Regional Offices have identified as needs and what ORD is able to provide within the combined capacity of the National Research Programs.

The ORD research programs that have relevant expertise and program scope to address the key research topics discussed above are shown below in Figure 2. The figure reflects a subjective evaluation of program relevance.

The black cells indicate lead programs for the respective topics, based on the amount of climate-related research being done by each program. In the area of human health, ACE was identified as the lead program rather than HHRA, given the focus of HHRA on assessments and the Integrated Risk Information System (IRIS).

No lead program is identified for the social science topic because it fits within each program in different ways. The uncertainty topic is led by the ACE program, which broadly leads ORD's climate change research.

[9] http://www.ccawwg.us/index.php/home.

Water Quality and Aquatic Ecosystems

The basic science challenge related to water quality and aquatic ecosystems is to understand how climate change is affecting watersheds, wetlands, estuaries, and coastal environments through alterations in temperatures, precipitation, runoff, flows, sea level, chemical and microbial dynamics and other variables. Changes in temperature and flow (including impacts on availability) are in themselves important to water quality and ecosystem and public health, and can lead to changes in other stressors such as nutrient processes, dissolved oxygen/biological oxygen demand, dissolved organic matter, chemical toxicity, and pathogen viability. More

	ACE	CSS	HHRA	HS	SHC	SSWR
Water Quality and Aquatic Ecosystems						
Air Quality						
Human Health						
Ecosystems and Land						
Mitigation and Associated Environmental Impacts						
Social Science						
Uncertainty						

Figure 2. ORD programs with relevant expertise and responsibilities for key research topics related to climate change. Black cells indicate lead responsibility, gray cells indicate relevant activities, and white cells indicate no significant activities.

frequent and severe wildfires can result in increased loads of nutrients, sediment, and organic matter downstream. Changes in coastal and ocean characteristics, such as acidification and sea level rise, create further issues of concern. Climate-driven changes are exacerbated by other major changes such as land use, population change, and evolving trends in energy production and agriculture.

Research on the impacts of climate change on water quality and aquatic ecosystems is conducted in ACE, SSWR, and HS, and covers several areas: impacts of climate change that pose threats to regulatory program effectiveness; impacts to watersheds and aquatic ecosystems; impacts to water infrastructure; assessments of climate change impacts on water quality; evaluation of impacts to aquatic ecosystems; development of monitoring methods and practices; and development of sustainable energy- and water-efficient infrastructure.

EPA SCIENCE NEEDS: Water Quality and Aquatic Ecosystems

Priority research needs related to climate change and water identified by OW and the Regions focus on four main topics:

- Changing, climate-driven demands on water treatment systems, including
  - Water reuse
  - Energy efficient nutrient removal
  - Impacts of source and influent water temperature changes

    - Potential need to treat increased or new pathogens
- Climate impacts on watersheds, including
    - Changes in flow and temperature, including methods to estimate low flows
    - Water supply shortfall
    - Watershed health and function
    - Monitoring and methods to identify tipping points and thresholds
- Impacts of climate change on harmful algal blooms
- Climate-driven changes in ocean and coastal environments, including
    - Indicators of changes in coastal water temperatures and acidification
    - Impacts of sea level rise and storm surge
    - Impacts of climate change on sea ice and subsequent impacts on Alaskan coastal communities

Water-related research is also of interest to OSWER. Information on the effects of climate change on extreme weather events, particularly the location, frequency, and magnitude of flooding events, is needed to inform guidance on siting and design of landfills. OAR has also identified the impacts to ecosystems, including aquatic ecosystems, caused by climate change as a research need.

ONGOING ORD RESEARCH: Water Quality and Aquatic Ecosystems

Research is being conducted by ORD to understand the vulnerabilities of water quality regulatory programs to a changing climate, including vulnerabilities from direct impacts of climate change.

ORD is conducting research to assess hydrologic and biogeochemical sensitivity to climate and land use change, and to develop indicators of watershed condition and attributes that promote watershed integrity. This research allows application of a range of future climate and land use conditions to examine how such changes may affect watershed and resource integrity and sustainability.

Research related to water infrastructure will provide information to OW, and ultimately water utilities, that will enable water utilities to plan for and respond to the challenges of climate change, reduce GHG emissions, and increase sustainability. Work in this area includes efforts to advance the use of green infrastructure for mitigating sewer overflows during high precipitation events, "net zero" utility operations and sustainability indicators, water reuse treatment technologies, technologies that reduce energy consumption in water treatment, and processes for energy production from water treatment wastes.

An assessment of the impacts of climate change on water quality is being developed by ORD to provide the scientific foundation for consolidating and synthesizing information needed by OW and others to develop effective responses. For example, this work includes specific applications to develop guidance to incorporate changing temperatures into regulatory programs in collaboration with Region 10.[10] Research on climate change and water quality includes not only assessments themselves, but the tools needed to support the development of assessments,

[10] See Appendix B for project titles.

such as land use scenarios. Our extramural program is studying climate and water quality, specifically how drought and related events, such as wildfires and changes in runoff, affect aquatic ecosystems, drinking water sources, and drinking water treatment.

ORD research is providing OW and others with information to understand the impacts of climate change on aquatic ecosystems and associated ecosystem services. This research includes development of indicators of ecological condition, studies to evaluate how climate (among other drivers) is related to nutrients and impacts on ecosystems, development of regional monitoring networks, and the vulnerability of estuarine and near-coastal species, habitats, and ecosystem services to climate change. ORD is also conducting research to examine the impacts of sea level rise on aquatic ecosystems and the interactions between sea level rise, hydrology, and storm surge. Research also includes efforts to evaluate the impacts of land use change associated with biofuel production, which may affect water quality and aquatic ecosystems.

Research in ORD is also providing guidance to OW and water utilities concerning the development of sustainable water systems, focusing on a systems perspective of water resources and water systems in the context of a changing climate. Much of this research is place-based, with the intent of evaluating real-world systems and developing system-based concepts that are broadly applicable to other communities. Taking a sustainability approach can provide information that guides resource managers toward the appropriate balance of active intervention (e.g. storm sewers) and reliance on natural adaptability (e.g. natural wetlands). This work includes development of a comprehensive, systems-based approach to management of Narragansett Bay and regionally-based case studies of water resource and treatment systems.

Research on climate change and nutrients seeks to understand how climate change influences nutrient flows and the impacts of both on critical environmental endpoints, including hypoxia in the Gulf of Mexico. From a broader perspective, this work is looking into the connections between the carbon and nutrient cycles at regional scales.

Research scheduled to begin in FY16 will evaluate the effects of increased water temperature on the frequency and characteristics of harmful algal blooms, such as bloom biomass increases and spatial distribution, and impacts on cyanotoxin production. Research is also planned to evaluate the capability of existing wastewater and drinking water treatment technologies to control and treat cyanobacterial and algal toxins associated with expected warmer water temperatures due to climate change.

ORD research will advance the identification and treatment of pathogens expected in warmer source waters and increased runoff in regions experiencing wetter climates. Research will also develop treatment processes, such as anaerobic ammonia oxidation for ammonia removal in wastewater, that have the potential to decrease energy consumption.

Air Quality

Within the air quality topic, the science challenge is to understand how climate change affects air quality and how emissions and atmospheric formation and transport of air pollutants can affect climate change.[11] Changing weather patterns alter pollutant formation and affect

[11] http://www.epa.gov/airquality/airtrends/2010/report/climatechange.pdf

anthropogenic, biogenic, and geogenic emissions. Concentrations of aerosols, ozone, and methane affect radiative forcing.

EPA SCIENCE NEEDS: Air Quality

Specific research needs identified by OAR and the Regions are:

- Quantification of the impacts of climate change on air quality
- Investigation of the linkages between air quality and climate change, including
    - Emissions and atmospheric transport of black carbon (BC)
    - Emissions and transport of other short-lived climate forcers
    - The role of BC as a climate forcer, with particular attention on Arctic impacts
- Laboratory testing of cookstove performance and emissions
- Consumer or producer behavior regarding energy-saving technologies (the "energy paradox")
- Other research to support OAR's emerging adaptation priorities, including
    - Fire emissions and their contribution to ozone, PM, GHGs, and regional haze
    - Ecosystem vulnerability via deposition
    - Impacts of climate change on stratospheric ozone
    - Community capacity to understand and take effective action to address climate-driven environmental impacts
- Advanced mechanical ventilation in residential and commercial buildings

ONGOING ORD RESEARCH: Air Quality

Expertise on measurement of particulate matter (PM) and development and application of remote sensing technologies is applied to climate-relevant emissions of black carbon (BC) and methane, two important short-lived climate forcers (SLCFs). Research in this area focuses on BC emissions from diesel and aircraft engines and biomass burning, and on methane emissions from oil and gas production and processing sources, in close coordination with OAR and interagency efforts. Regional Applied Research Effort (RARE) grants are in place with several EPA Regions to conduct research on both BC and methane emissions.

In the area of air quality modeling related to climate change, ORD's research is focused on applying the Weather Research and Forecasting (WRF) and Community Multiscale Air Quality (CMAQ) models to future climate and emission scenarios. This work involves development of techniques to downscale global climate model results to spatial scales at which CMAQ can be applied to incorporate regional-scale meteorology and emissions to understand how air quality may change under different possible climate conditions and emissions scenarios. Incorporation of atmospheric chemistry and evaluation of air pollutant concentrations is unique to EPA. This research effort leverages global-scale climate modeling results from other federal agencies, which are downscaled to apply CMAQ to evaluate potential future air quality, as well as for use in other regional-scale modeling efforts to understand watershed or other environmental responses. Additional efforts are being conducted to better understand possible changes in organic aerosol formation as the climate changes.

The third component of ORD's research into climate-air quality interactions involves tying together emissions, air quality modeling, and effects to better understand the impacts to air

quality and air quality-related health as a consequence of climate change and changing technologies. Considerable efforts in this area are addressed through Science to Achieve Results (STAR) grants on extreme weather events and how they can affect air quality, the role of black carbon in climate and air quality, the impacts of residential cookstoves, the impacts of climate change on particulate matter and indoor air quality. Additional work is evaluating the potential health impacts of increased biofuel use and examining different emissions control scenarios to identify more effective air quality management strategies that reduce climate forcing and health effects associated with exposure to air pollutants. This research involves coordination and collaboration in particular between ORD and OAR, as well as among several ORD Laboratories and Centers.

Planned work beyond the topics described above include incorporation of potential impacts of climate change and future energy technologies into the multidisciplinary ACE Centers supported by the STAR program. This represents an evolution of the prior Centers focus, which previously did not explicitly take climate change into account in the investigations of air quality and health. Evaluations of the impacts of climate change to indoor air quality and related potential changes to human health will also be supported by STAR funds.

ORD has also proposed research to better define the impacts of unconventional oil and gas production on air quality. This work would be conducted in collaboration with the Departments of Energy and Interior, and would include research to improve methods for measuring emissions of methane from unconventional oil and gas production. This will occur in close coordination with OAR, particularly in light of the existing U.S. Greenhouse Gas Inventory, Greenhouse Gas Reporting Program and the President's Methane Strategy.

Human Health

The science challenge related to climate change and human health is to understand the incremental impacts on human health due to climate-driven exacerbation of effects associated with exposure to environmental stressors already of concern, and to understand the effects caused by new, climate-caused environmental stressors and combined effects of existing and new stressors. Degraded air quality as a consequence of climate change is an example of a driver of health effects that is worsened by climate change. There are also possible health impacts associated with changing conditions at contaminated lands, such as environmental releases caused by flooding or higher temperatures. "New" health effects include those related to extreme heat, expanded range of invasive pathogens, and mental health issues related to disruptions caused by extreme weather events.

EPA SCIENCE NEEDS: Human Health

OAR and OSWER have identified research needs on the issue of the impacts of climate change on human health:

- Quantification of climate impacts on human health (OAR), including
  - Impacts of changes in air quality due to climate change, including co-benefits of reduced emissions as a consequence of mitigation approaches
  - Health impacts of exposure to extreme heat

  - Impacts associated with changes in vector-borne diseases
  - Impacts of combined stressors, such as extreme heat and air pollutant exposure
  - Scientific contributions to National Climate Assessment (NCA) Special Report on climate change/health and support for EPA-HHS collaboration
- Evaluation of the cumulative health effects of climate change, in particular the non-chemical stressors that people deal with after a weather event and how it impacts their susceptibility to chemical stressors (OSWER)

ONGOING ORD RESEARCH: Human Health

Considerable research is underway across ACE and other programs to evaluate the health impacts associated with exposure to air and water pollution, without explicitly focusing on climate as stressor. That work is not addressed here, although it forms the foundation for understanding the health impacts of climate change.

Research that is explicitly designed to address climate change as a stressor is investigating the links between climate change and health through more "conventional" stressors such as air quality and weather events, changes in allergens, and waterborne and infectious disease. ORD is also currently participating in a multi-agency USGCRP effort involving EPA (OAR and ORD), CDC, NOAA, USDA, and other agencies to assess the state of understanding of climate change-related health effects.

Planned research includes a STAR support to investigate climate change and emerging diseases and health effects associated with air pollution in rural areas and that associated with goods movement, both of which will be affected by climate change.

Ecosystems and Land

Understanding the effects of climate-driven extreme events and sea level rise is the fundamental science challenge in the area of land and terrestrial ecosystems. Extreme weather events such as heavy precipitation and floods can result in contamination of waters by hazardous and other material. Higher temperatures, changes in precipitation, and sea level rise, may all adversely impact contaminated lands, potentially resulting in releases to the environment and will also affect ranges of wildlife and vegetation.

EPA SCIENCE NEEDS: Ecosystems and Land

Research on the effects of climate change on extreme weather events, particularly floods, can inform the siting and design of waste and chemical facilities, OSWER land revitalization efforts to create more resilient and sustainable communities, and sustainable materials management. Specific research needs identified by OSWER are:

- Information on the impacts of climate-driven extreme weather events and sea level rise on
  - Potential contaminant release from OSWER sites
  - Generation and management of storm debris
  - Potential revolatilization of hazardous materials from waste sites due to increased temperature

    - Ability to respond to weather-generated emergency conditions
- Investigation of the potential for wildfires at contaminated sites to promote the spread of contamination or impact remedies, including
    - Understanding how wildfires in the upland areas above contaminated sites could reduce vegetative cover, leading to increased surface water runoff and catastrophic flooding that spreads contamination or impacts remedies
    - Developing information to ensure new fuels are compatible with existing infrastructure and can be stored safely to prevent groundwater contamination by failed underground storage tanks
    - Understanding the assessment, cleanup, and area-wide planning impacts associated with green infrastructure and brownfields
    - Life cycle assessments related to materials management

In addition to the needs identified by OSWER, regional offices have identified needs related to the impacts of climate change on environmental justice and Tribal communities, including the need to understand how to incorporate traditional ecological knowledge into evaluation of impacts and development of adaptation strategies.

ONGOING ORD RESEARCH: Ecosystems and Land

Research on the environmental impacts of extreme weather events is addressed under a series of STAR grants under the solicitation, "Extreme Event Impacts on Air Quality and Water Quality with a Changing Global Climate."[12] This work explicitly addresses air quality and water quality, but can be applied to the OSWER needs, at least to the extent of better understanding extreme event frequency and magnitude.

Research on the potential leakage of biofuels into groundwater due to corrosion and leaks of underground fuel storage is being addressed by ORD. Work on monitoring and contaminant transport related to this leakage is being conducted in SHC.

ORD is also conducting work to understand how the behaviors of contaminants in sediments may change as environmental conditions are affected by climate change; this work is being conducted relative to remediation activities.

Additional research in this topic covers development of methods, tools, and indicators that can be applied in specific cases. This work includes development of scenarios and land use tools and datasets, climate indicators, and assessment methods and frameworks. The research in this area connects closely to interagency research on ecosystem impacts of climate change, particularly through standing USGCRP interagency working groups.

Understanding how climate change impacts Tribal communities is the focus of a series of STAR grants to understand ecological and human health for Tribal sustainability and well-being.

[12] See http://www.epa.gov/ncer/rfa/2011/2011_star_extremeevent.html.

Mitigation and Associated Environmental Impacts

The basic science challenge for mitigation is to develop the information needed to inform effective mitigation strategies that do not cause other, unacceptable environmental impacts. Although there will certainly be co-benefits associated with implementation of mitigation strategies,[13] the examples of increased production of biofuels and natural gas demonstrate that adoption of approaches to reduce CO_2 emissions could have adverse environmental impacts. Other approaches, such as smart growth communities, designed to improve community sustainability, also reduce CO_2 emissions. Understanding the potential for both co-benefits and adverse impacts provides important information for decision makers as they develop mitigation strategies.

This is, in some ways, the most forward-looking topic within the climate research portfolio given that explicit mitigation actions (e.g., the Clean Power Plan[14] and vehicle GHG standards[15]) are relatively recent at a national scale. Such actions, and any associated environmental consequences, are expected to expand substantially. As was the case with biofuels and natural gas, these consequences may not be explicitly perceived as associated with mitigation strategies.

EPA SCIENCE NEEDS: Mitigation and Associated Environmental Impacts

Research needs identified by OAR are:

- Laboratory testing of cookstove performance and emissions
- Residential and commercial buildings advanced mechanical ventilation
- Better data on applications of carbon capture technologies for gas-fired electric generating units
- Assessment of mitigation technologies to inform policy and regulation development
- Evaluation of the efficacy/permanence of non-geologic sequestration of carbon dioxide (e.g. carbon dioxide utilization in cement, industrial utilization of carbon dioxide) as well as recommendations for monitoring and accounting options
- Emissions from sources of non-CO_2 GHGs (e.g. landfills, coal mines, manure management, etc)
- Improved data on direct and indirect nitrous oxide emissions from agricultural soils, improving the ability to estimate (e.g., more in situ measurements, data inputs and process modeling) and identify opportunities to reduce emissions (in the context of other environmental benefits of improved N fertilizer use efficiency).

ONGOING ORD RESEARCH: Mitigation and Associated Environmental Impacts

[13] West et al., *Nature Climate Change* **3**, 885 (2013); http://www.nature.com/nclimate/journal/v3/n10/full/nclimate2009.html

[14] http://www2.epa.gov/cleanpowerplan/clean-power-plan-existing-power-plants

[15] http://www.epa.gov/otaq/climate/regs-light-duty.htm#new1

ORD's research is working with OAQPS to support growing interest on the part of partner offices to develop and understand future scenarios of energy production and use related to future air quality strategies. The use of energy system modeling provides OAR with insights into possible future conditions given the significant uncertainties associated with future technology advancement and policy directions. Interactions with both OAQPS and OAP within OAR and with the National Center for Environmental Economics in the Office of Policy (OP) provide guidance to ORD regarding scenarios of interest. Growing interactions with DOE in particular, as well as with industry and the academic community, will be an area of emphasis.

Research into possible scenarios of the US energy system and how such scenarios can impact emissions of key air pollutants and water demand is being done using the MARKAL model. Life cycle approaches are also being used to better understand the broader environmental implications of different energy technologies. Work is progressing to enable these two approaches to be combined, so that more complete understanding of future energy system configurations can be developed. At the community level, research on community sustainability and associated CO_2 emission reductions provides information that can be applied locally.

Complementing this work is research to evaluate performance of energy-related technologies. The greatest current effort in this area is evaluation of cookstoves (and including heating stoves) used primarily in developing nations, but with some application in the US. Efforts in this area are supported by internal testing and grants through the STAR program. Additional efforts are evaluating the potential environmental impacts, applicability, and retrofit potential of carbon capture technologies for power generation.

A STAR grant Request for Applications (RFA) is under development to solicit research related to environmental implications of a changing energy infrastructure. The RFA is evaluating options to consider the "energy paradox" noted in the needs above.

There are also opportunities to reduce GHG emissions through materials and land management practices. At each stage in material flow – as materials move through the economy from extraction or harvest to reuse or disposal – GHGs may be emitted. Additionally, how we manage and use land has a direct impact on GHG emissions and the fate of greenfields that serve as a carbon sink.

Cross-cutting Issues

The two cross-cutting issues identified above, social system influences and uncertainty, reflect two related science challenges: incorporating the influence and behavior of social systems into analyses of climate impacts and responses; and improving understanding and incorporation of deep uncertainties into evaluations of climate impacts and responses. These two are connected through the substantial uncertainties related to social system responses, such as changes in policies and economic and technological development.

EPA SCIENCE NEEDS: Cross-cutting Issues

Research needs on the cross-cutting issues were identified by ORD partners related to social systems:

- "Energy paradox" research that addresses consumer or producer behavior regarding energy-saving technologies
- Improve community's capacity to understand and take effective action to address harmful environmental impacts in their community (OAR)
- Understand interactions between social, behavior, environmental, and biological factors for EJ and Tribal communities who are disproportionately impacted (OAR)
- Identify and communicate best practices for communities to adapt and mitigate climate change (OSWER)

ONGOING ORD RESEARCH: Cross-cutting Issues

ORD has made progress in the area of incorporating social sciences into its climate-related research, but this area remains one in which additional progress is desirable. The scope of relevant social sciences expertise related to climate change is substantial, including economics, decision science, communications, community and institutional dynamics, planning, policy formulation, and cultural heritage. For areas such as economics and communication, ORD works with existing EPA expertise (the National Center for Environmental Economics and the EPA and ORD communications offices, respectively). In other areas, ORD works with other agencies, such as the Department of the Interior, as well as within cross-EPA structures such as the Tribal Science Council.

For other areas, such as decision science and community dynamics, efforts to incorporate social science expertise are being developed through several activities. Within ACE, research is underway to develop methods to apply robust decision making concepts to environmental decisions. Changes in population and demographics are incorporated into integrated climate and land use scenarios developed by ACE to support projections of climate impacts on environmental end points in the National Climate Assessment. ORD is expanding its efforts in the area of community support through additional climate-focused research within the SHC program, which will provide further resources for developing better understanding of what information is needed by communities to develop sustainable approaches to climate change adaptation and mitigation and how ORD can help provide that information. The SHC work began in FY15.

A significant and overarching research need is to develop perspectives and approaches to account and plan for the deep uncertainties associated with climate change. There are two aspects to this need. The first is to conduct research in ways that adequately evaluate the uncertainties in future conditions due to the inherent complexities of natural and human systems and their interactions. Such approaches may involve use of model ensembles and multiple scenarios of climate change drivers and impacts, and evaluation of model uncertainties. Closely related is the need to recognize the potential for "low probability-high consequence" impacts that are likely to result in impacts with

which we have little or no experience. These needs will not be addressed by ORD or EPA in isolation, but will require close interaction with other agencies and research organizations.

Equally important is the need to adequately communicate timing, magnitude, and uncertainties of climate change impacts. Such information is already incorporated into ORD's climate-related research products, and additional efforts to communicate the deep uncertainties related to climate change (e.g., those associated with policy and individual responses or responses of Earth systems) are being incorporated into Agency-wide training materials as part of the EPA Climate Change Adaptation Plan.

Examples of ORD Integration

Climate change provides opportunities for integration across multiple dimensions – discipline, Laboratory/Center, research program, regulatory office, and agency, to name the most apparent. From a strategic perspective, ORD seeks to integrate to the extent that it avoids unnecessary duplication, fills critical gaps, and provides results that reflect the multiplicity of impacts and needs associated with climate change.

There are numerous examples of ORD's collaborative research on the impacts and responses to climate change. With much of the fundamental research on climate-related processes conducted or supported by other federal agencies, work that involves interaction with other agencies is common. Such work includes development and application of land use and climate scenarios, evaluation of future energy scenarios (including impacts to water demand), downscaling of global climate to regional scales for use in air quality modeling (and development of improved representations of clouds and precipitation), and investigation of climate change's effects on coastal species.

Specific examples of integrated research include:

1. *Evaluation of cookstove performance and test protocol development.* This work is focused in the ACE program, combining internal work conducted by ORD researchers and external research supported by the STAR program. Research is conducted in close collaboration with the Global Alliance for Clean Cookstoves[16] (GACC), for which the lead US agency is the Department of State. Input from DOS and DOE provide guidance to ORD in the development and implementation of the testing program, and the STAR solicitation was developed with input from GACC, DOS, DOE, HHS, and within EPA, OAR. ORD focuses on development of cookstove testing approaches, evaluating life cycle impacts of biomass-based cookstove use, and understanding the ambient and indoor health impacts of exposure to cookstove emissions. DOE's focus is on development of new cookstove technologies, HHS is evaluating population-level health impacts, and DOS works with GACC to coordinate efforts with other countries and provide guidance to the broader issues related to financing, cookstove adoption, and development of international program support.

[16] See http://cleancookstoves.org/.

2. *Adaptation to climate-driven changes in water quality.* There are multiple research tasks across SSWR and ACE that are relevant to this relatively broad topic. Research supported under the STAR program is evaluating the impacts of extreme weather events on water quality, and is jointly funded by ACE and SSWR. ACE efforts to evaluate the responses of watersheds to climate change connects with SSWR work on watershed integrity, as well as with the cross-cutting nutrient research conducted by SSWR and ACE. Research to evaluate sustainable water systems involves SSWR's green infrastructure research and work by SSWR and ACE on the energy-water nexus. In general, research within ACE focuses on problems in which climate change is the major stressor, while SSWR has responsibility for water resource issues for which climate change is just one of several stressors. This is not the sole or a static determination, but is developed dynamically as partner needs are evaluated in the context of Program capabilities.
3. *Evaluation of methane emissions from lakes.* An example of how emerging issues are addressed to improve cross-program integration is a recent SSWR study initially designed to evaluate water quality management strategies for reservoirs located in agriculture-dominated regions. Preliminary results indicated methane emissions from lakes may be a more significant source of GHGs than previously known. Plans for further research will include methane measurement expertise from ACE to validate their preliminary results. SSWR will continue to provide the expertise to understand reservoir and aqueous nitrogen dynamics, and ACE will provide additional expertise related to methane emission measurement.

In each of these examples, research was conducted by the Program that had the appropriate expertise and facilities to address the specific research question(s). Working with the National Research Program staff to coordinate research planning and with individual investigators to identify opportunities as research evolved has resulted in climate-related research that is more comprehensive and informative compared to efforts conducted in the absence of such coordination and integration.

Integration is more than cross-organizational or multidisciplinary research. Research syntheses can provide greater understanding of the implications of the detailed research results for EPA. OAR relies on quantitative assessments of climate change impacts on air quality, human health, and ecosystems to inform climate change policy, rulemaking, and communication. For example, the ORD 2009 climate and ozone assessment[17] provided the strong scientific basis for including the health impacts of ozone in the 2009 Endangerment Finding. ORD is moving toward development of such synthesis products, both internally and with external partners. Examples include the interagency Climate Change-Human Health Assessment in collaboration with HHS and USDA, and the Climate Change-Water Quality Assessment in collaboration with OW.

[17] U.S. EPA. Assessment of the Impacts of Global Change on Regional U.S. Air Quality: A Synthesis of Climate Change Impacts on Ground-Level Ozone (An Interim Report of the U.S. EPA Global Change Research Program). U.S. Environmental Protection Agency, Washington, DC, EPA/600/R-07/094F, 2009 http://ofmpub.epa.gov/eims/eimscomm.getfile?p_download_id=491176

The STAR program is placing increased emphasis on development of synthesis documents that summarize and place into context the research conducted across each RFA, and the ACE and SSWR programs are working to make such synthesis products a common component of all projects. Further efforts are needed to plan and develop syntheses that cut across research programs.

Opportunities for Further Integration

There has been substantial improvement in integrating and coordinating climate-related research across ORD's NRPs over the past several years, and the formation of national-, and EPA-, and partner Office-level policies and guidance has played an important role in facilitating that improvement. This is due to the increasingly consistent messages about the importance of climate change to EPA and, in more detail, the partner offices.

The past several years have seen substantial increases in interactions across EPA on the issue of climate change, with particular emphasis on increasing the communications between ORD and our EPA partners. These communications have made it clear that there are numerous opportunities for connecting with Regions and states, in particular. Efforts such as the development of parameters needed to incorporate stream temperatures into implementation of water quality regulations is a good example of moving ORD's research into practice. This effort brought together stakeholders from the state, a local tribe, and an EPA region to help design the research to ensure that the parameters and analytical method could be incorporated into the regulatory process.

Additional efforts for further cross-organizational integration have included in-depth discussions with OAR regarding use of scenarios in development of air quality standards and collaborations with the National Center for Environmental Economics and OAR to develop STAR grant solicitations. ORD consistently seeks opportunities to work with other agencies on co-funded or coordinated requests for research grant proposals.

ORD's national research programs each recognize the critical need for continued communication across EPA and with external partners to ensure that we are taking advantage of opportunities for collaboration, integration, and understanding. The research portfolios that are developed throughout the ORD planning process are the result of on-going informal and formal negotiations concerning research priorities that occur throughout the year.

V. Research Gaps & Priority Research Needs

This section summarizes the research gaps and illustrates how priorities for research topics are determined. In short, the gaps reflect research that has been identified during the extensive efforts by the EPA Program and Regional Offices to identify their climate-related science needs but that is not being conducted by ORD. The research activities described above are those that address the highest priority needs identified by ORD's partners and are within the scope of EPA (in the context of federal, cross-agency

research activities). The gaps are those needs that have been identified, but are not among the highest priorities or within EPA's scope.

Synthesis of Existing Gaps

The research needs represent a synthesis of needs identified by OAR, OW, OSWER, and Regional Offices. Appendix C presents a table of identified research needs and relevant ORD research underway to address those needs.

The research needs presented in Appendix C are the result of focused discussions between EPA Program and Regional Offices to determine their most important needs for scientific information. The needs identified by the Program and Regional Offices reflect the issues those Offices are currently facing, or expect to be facing in the near future, and for which additional scientific information is needed to inform decisions on those issues.

The EPA Climate Change Adaptation Plan and the Adaptation Implementation Plans developed by each EPA office provide context for the research needs. The intra- and inter-Office discussions that occurred, and continue to occur, regarding the vulnerabilities of EPA activities to climate change inform the research needs developed by ORD's internal partners. Factors such as relative states of understanding, expected timing of impacts, and other factors in addition to the vulnerabilities are incorporated into the development of the research needs.

Similarly, the portfolio of research conducted by ORD at any specific time is dependent upon several factors, including the availability of resources, including facilities and personnel. Development of the annual research portfolio also incorporates input from the partner offices regarding their priorities, guidance from external advisory groups such as the SAB and BOSC, and status of on-going research. Those needs that are not addressed in a given year are considered gaps between what the partners have identified and the current-year research portfolio. The portfolio is adjusted annually to address as many partner needs as possible. The needs identified by ORD's partners included several that are to be addressed in future years:

Gaps: Water quality and aquatic ecosystems

The effects of climate change on water availability and flow is a gap within EPA, given the importance of availability and flow to water quality. The U.S. Geological Survey (USGS) has primary responsibility for information and data on water availability, and ORD works closely with USGS to ensure the appropriate data is used in projections of water quality that are affected by availability. A specific gap is the identification of watersheds for which community water systems may be at risk of long-term water supply shortfalls.

Another gap is the need for methods to estimate projected future flows, such as the lowest 7-day flows over a ten-year period (7Q10). Although OW is working with the USGS to improve methods to estimate flow extremes, additional research within EPA may be needed to develop the information to the extent needed to inform decision making.

Additionally, research to understand other thresholds and tipping points of importance to water quality, such as changes in sea level or precipitation patterns, is likely to require advances in research outside EPA. Collaboration with USGS, NOAA, and other agencies will continue to play an important role in ensuring ORD has the knowledge and data needed to develop information about future water quality in a changing climate.

Research is needed to understand the consequences of warmer surface water temperatures on the cost, complexity, and performance of water treatment required to comply with National Drinking Water Standards and to optimize performance of wastewater treatment systems.

More research is needed to understand the impacts of thawing permafrost on Alaskan water infrastructure and approaches to adapt and prepare water systems.

More generally, research is needed to monitor and predict changes in the Nation's waters (lakes, streams, wetlands, and coastal and estuarine environments) impacted by climate-driven changes including ocean acidification, sea level rise, and increasing temperatures, and changing precipitation patterns. Some work is underway within ORD to investigate these environmental impacts. NOAA and states are doing substantial work to evaluate changes in ocean pH, sea level, and ocean water temperatures. Similarly, NOAA and other agencies are addressing issues related to loss of sea ice and associated environmental impacts. Further efforts by ORD may be needed in these areas, within the context of the National Ocean Policy Implementation Plan[18] and the coordination of federal activities by the Interagency Arctic Research Policy Committee (IARPC).[19]

Gaps: Air Quality

Additional work is needed to better understand how climate change may impact PM levels, as well as levels of hazardous air pollutants. Other air quality related needs include a more complete understanding of the impacts of biogenic emissions, dust, and wildfires on air quality. There is a need to continue and expand research related to human health impacts of changes in air quality due to climate change, assessing increased vulnerability to air quality impacts under future climate conditions, and air quality and health co-benefits of climate mitigation and adaptation strategies.

Limited ORD research is being conducted to evaluate the impacts of climate change on stratospheric ozone. Additional work by other agencies (particularly NOAA) is likely to be needed to fully evaluate these impacts.

There is also no work within ORD to develop or evaluate advanced residential or commercial ventilation technologies. There is a need for research to determine new or improved ways to enhance ventilation and health that are cost effective, energy efficient and practical to implement. Approaches such as vertical displacement,

[18] http://www.whitehouse.gov//sites/default/files/national_ocean_policy_implementation_plan.pdf

[19] https://www.whitehouse.gov/administration/eop/ostp/nstc/committees/cenrs/iarpc

monitoring and control systems, dedicated outdoor air systems, and automated HVAC systems are of interest.

Although ORD is conducting some work to understand measurements and emissions of black carbon, it is not focused on the contributions of tropospheric ozone and black carbon to Arctic climate change. The capabilities of other agencies (especially NASA and NOAA) are needed to effectively address this topic.

Gaps: Human health

Research is needed to evaluate and quantify health impacts in a cost-benefit context to inform cost-benefit analyses, although this topic has been partially addressed by previous work related to environmental regulatory evaluation. There is a further need to evaluate and project changes in the overall public health burden of air pollution due to changes in baseline health as well as the effect of changes in ozone and PM concentrations and the occurrence of extreme air quality events on cardiovascular and respiratory health.

Additional efforts are needed to understand the cumulative health implications of extreme weather events, including exposures to materials released from contaminated sites due to heat or floods and non-chemical stressors on health and potential subsequent effects on chemical stressor susceptibility. Research in the area of vector-borne diseases and expanded pathogen range is also needed, although such work may be more appropriately conducted by other agencies such as NIEHS or CDC.

Additional topics of OAR interest include syntheses of STAR grants on extreme weather and emerging diseases, and vulnerable populations. ORD could also play a role in the HHS-EPA collaboration on health indicators, data sharing on heat mortality, and coordination and integration of research grant topics and solicitations.

Gaps: Ecosystems and land

Research is needed to better understand how extreme weather events and wildfires associated with climate change can impact contaminated sites, affect contamination spread, and impact the ability to respond to emergency situations such as spills. Although there is research related to extreme weather events, there is a need to extend that work to include the effects on municipal and hazardous waste disposal sites. The anticipated effects include direct impacts due to floods (including sea level rise and storm surge) and wildfires as well as secondary impacts associated with increased risk of flooding or landslides as a consequence of wildfire destruction of stabilizing vegetation. In addition, extreme weather events need to be evaluated in terms of their potential to generate storm debris and the ensuing need for debris collection and disposal.

Research is also needed to understand how climate change may affect assessment, cleanup, and area-wide planning impacts associated with green infrastructure and brownfields.

Although work is underway to provide communities with information needed to effectively respond to climate change through preparation, adaptation, and mitigation,

the need for such information is growing rapidly. Of particular concern are Alaskan native communities facing loss of cultural and natural resources due to permafrost thawing. Additional efforts are needed to address the range of community-specific issues, with a particular need for environmental justice communities.

Gaps: Mitigation and Associated Environmental Impacts

The rapidly changing regulatory context for CO_2 highlights the research need to understand the capabilities and consequences of changing to low-carbon technologies for CO_2 mitigation. Life cycle and systems approaches are needed to understand the environmental consequences (positive and negative) of application of these technologies, and immediate cost and performance data need to be evaluated and synthesized. Current ORD work in this area is minimal.

Research is needed to better understand the environmental impacts of proposed mitigation strategies, which, for renewable energy, tend to place a greater emphasis on ecosystem changes due to land use for renewable energy production as opposed to a focus on emissions from fossil-fired energy production. More information is also needed regarding the effects on social systems (including institutions such as EPA) to understand and, where possible, anticipate the pressures these changes can bring to help ease the social transitions as well as the technological transitions.

There is also a need for work to evaluate applications of carbon capture systems for gas-fired electric generating plants or to investigate advanced ventilation systems. Work conducted by others, especially DOE, may be the more appropriate source of information in these areas, depending upon the specific scope.

There are several research needs related to filling gaps in the U.S. Greenhouse Gas Inventory and Greenhouse Gas Reporting Program. These include: evaluation of the efficacy/permanence of non-geologic sequestration of carbon dioxide (e.g. carbon dioxide utilization in cement, industrial utilization of carbon dioxide) as well as recommendations for monitoring and accounting options; non-CO_2 sources for the U.S. GHG Inventory (e.g. landfills, coal mines, manure management, etc); and, for direct and indirect nitrous oxide emissions from agricultural soils, improving the ability to estimate (e.g., more in situ measurements, data inputs and process modeling) and identify opportunities to reduce emissions (in the context of other environmental benefits of improved N fertilizer use efficiency).

The substantial efforts in technology development in DOE, DOT, and industry provide opportunities for interactions that can provide EPA partners with the necessary information.

It is clear from this list that the scope of work to address climate-related research needs goes beyond the scope of any single media-focused research program. This highlights both the cross-cutting nature of climate change and the need to address climate impacts across ORD's programs. While the current process in which ORD's partners communicate needed research does identify specific work related to climate change,

the process also ensures that all needs, whether or not they are climate related, are communicated to the appropriate ORD research programs.

In addition to the above gaps between needs identified by partners and current ORD research, there are additional issues that were not identified by partners and need to be considered in a longer-term research context, as well as issues that are more cross-cutting and need to be incorporated into ORD's climate research.

Emerging Issues

The priority needs identified by ORD's partners focus on addressing relatively near-term environmental impacts of climate change, such as increases in ozone or changes in precipitation due to heavy downpours or drought. All of the identified needs address the known possible impacts of climate change, but do not consider relatively understudied, or even unknown, impacts, some of which might be quite severe. For example, sea level rise that is higher and occurs more rapidly than indicated by the central modeled projections. Abrupt climate change such as accelerated sea level rise, more rapid change of Arctic ice cover, or more severe drought are all within the range of possibilities, and may have significant environmental impacts. Similarly, complex, interconnected systems may be subject to cascading failures that emerge from previously unknown vulnerabilities. For example, energy system failures during heat waves could increase heat-related mortality beyond what would be expected due to lack of air conditioning. Similarly, insufficient water supplies for electric power generation could contribute to heat-related mortality. The current research effort does not incorporate efforts to prepare for such surprises, which will become more likely in the absence of substantial, global scale mitigation efforts; and is just beginning to develop more holistic approaches to understanding complex, integrated systems such as urban areas.

The impacts of climate change and our responses to minimize those impacts are also likely to result in unexpected or unprecedented environmental problems. The growing interest in geoengineering, as an example, will require working with other agencies and institutions to understand how these approaches might impact water availability and quality.

Social Sciences

There are several research needs explicitly identified by ORD's partners that require incorporation of social sciences into the ORD research portfolio, in particular improving community capacity to identify and apply best practices to adapt to climate change and understanding the factors related to disproportionate impacts of climate change to environmental justice and Tribal communities. Although the term "social sciences" covers a broad range of disciplines, EPA's needs center on the complex interactions of the social, behavioral, environmental, and biological factors that influence how individuals, communities, and organizations perceive and respond to climate-related risks. EPA's efforts to address environmental justice and the Agency's responsibilities to Tribal communities further highlight the need to apply social sciences to more effectively respond to the needs of these populations. For instance, topics such as

incorporating traditional ecological knowledge have the potential to improve the resilience of communities affected by climate change. Such research is expected to compose a small fraction of the overall ORD portfolio, but has the potential to significantly improve the effectiveness and applicability of research results through more effective communication of those results in ways that are tailored by the ultimate users to meet their specific needs. While ORD's focus on sustainable solutions has strengthened its capabilities in economics and decision science, additional expertise in areas such as organizational dynamics and sociocultural anthropology may also provide important insights into the impacts of, and responses to, climate change.

Uncertainty

A common thread through all of the identified research needs, whether they are currently being addressed by ORD or represent gaps in the research being conducted, is the uncertainties associated with climate change. Although uncertainty is inherent in most environmental issues, the substantially longer time periods associated with climate change force us to consider significant changes in environmental conditions or changes in populations, technologies, and policies. The deep uncertainties associated with such long-term and complex changes requires research approaches that account for a range of possible, perhaps even unlikely, future conditions to adequately inform our partners.

One approach to improve understanding of possible futures is the use of scenarios. Common sets of scenarios for climate forcing, such as the IPCC Representative Concentration Pathways (RCPs),[20] can enable comparison of results across programs and with external research. Consistent scenarios for socioeconomic variables or sensitivities of environmental endpoints to climate change may need to be developed in collaboration with partners and other agencies for ORD's work to be as useful as possible.

Yet while scenario-based approaches are needed, they are not adequate to understand the critical decision points and uncertainties. New approaches and methods are needed to inform decisions that are robust to potential changes in technologies, policies, and climate impacts. Non-probabilistic approaches are needed, such as identifying potential tipping points or critical conditions and then working backward to identify and evaluate unknowns, uncertainties, and decision points. The method of robust decision making is one approach to address deep uncertainties, and needs further development for application to issues of relevance to EPA.

Decision-relevant Scale

There is a substantial demand for information at "decision-relevant scales" – i.e., the regional or local scales at which decisions are often made or implemented. Regional- or local-scale results derived from global-scale models often indicate substantial differences in projected changes in annual precipitation, for instance. Furthermore, regulatory decisions often need highly time-resolved projection data that varies

[20] http://sedac.ipcc-data.org/ddc/ar5_scenario_process/RCPs.html

significantly across models, even for a given climate change scenario. ORD should further develop approaches to downscale global climate data, continue interaction with federal partners such as NASA and NOAA, and work with their EPA partners to provide guidance regarding suitability and applicability of available data to EPA decisions.

Syntheses

There is considerable value in developing synthetic insights through an examination of a body of work and communicating those findings to decision makers and the research community. Given the volume of research conducted on climate change and its impacts and responses, peer-reviewed syntheses that consolidate and evaluate a body of research from an EPA perspective can support effective actions with respect to climate change.

Prioritized Research Needs for ORD

ORD has established avenues and vehicles to identify priority research needs and to deliver research results in ways that also solicit feedback to inform further research into the Roadmap and Strategic Research Action Plans. These avenues and communications methods are tailored to meet the needs of each specific partner who relies on ORD research results to take action on climate change.

In addition to the partner-specific research needs, an effort to identify a limited number (1-3) of Agency-level priority science needs was conducted as part of the EPA Climate Adaptation Plan. This effort, led by OP and ORD, convened a cross-EPA work group to identify Agency-level priorities with a focus on issues that address needs of multiple Offices, taking into account the Office-specific priority needs identified above. Although final decisions on those priorities were not available for inclusion here, priorities recommended by the work group were:

- Projected impacts on children's health from climate-change-related increases in extreme precipitation and flooding
- Guidance on suitability and applicability of climate data and tools
- Development of an annotated reference guide on key climate datasets and tools for use by EPA staff
- A synthesis report that provides quantitative information on the costs to communities of extreme weather events

Appendix C presents the climate-related research needs identified by OW, OAR, and OSWER. The list for OW is in priority order.

Research Directions to Inform 2016 – 2019 ORD Research Planning

ORD is continually making efforts to work with Agency partners to ensure priority research needs are being met in ways that further our climate research strategy. We will continue to work with Agency partners to collectively consider the individual research needs from the different Program and Regional offices, as well as Agency-wide science needs for climate adaptation. These discussions are important to the

development of a research portfolio that balances meeting near-term partner needs and longer-term climate-related research to inform EPA's future decisions.

Although specific issues may evolve over time, EPA's unique niche is likely to remain focused on those topics that are at the core of EPA's strategic directions:

- Air quality impacts of climate change
- Impacts of climate change on water quality, including drinking water and surface water quality
- Climate-driven impacts to human health
- Impacts of climate change on contaminated and waste disposal sites
- Climate change impacts to ecosystems, including aquatic ecosystems and ecosystems goods and services
- Environmental impacts of changing energy technologies

As mentioned above, ORD's future climate research needs to develop and apply approaches that account for the long-term, system-wide nature of climate change impacts, preparation, and responses. For example:

- Uncertainty and scenarios – approaches to address the deep uncertainty associated with future conditions impacted by climate change, technological and economic development, policy responses, and changing demographics. Future efforts are needed to evaluate and, where appropriate, adopt common scenarios consistent with other EPA efforts. Scenarios developed by working backward from possible future conditions to examine critical decision points may be of particular value. Expanded understanding of approaches to evaluate, incorporate, and communicate climate-related uncertainty is needed for all climate-related research. Focused efforts to develop guidance regarding suitability and applicability of data describing projected climate impacts associated with different scenarios are increasingly important.
- Syntheses – greater emphasis is needed to develop syntheses of research results. While some synthesis efforts are underway, all climate research efforts should work toward developing syntheses of results in ways that can be used by decision makers at all levels.
- Regional- and local-scale information – continued emphasis is needed on research results that can be used at decision-relevant scales (regional, local, watershed). The growing emphasis on supporting community decisions requires approaches to develop data and information at those same scales. While much of the current climate research does focus on these scales, there is a need to translate results into information that helps decision makers understand the magnitude, timing, and uncertainties of expected changes.

Two additional topics key to achieving EPA's mission need greater emphasis: social sciences and technologies. These two topics are, in some ways, more focused than the above discussion of approaches:

- Social sciences – a greater understanding is needed regarding how individuals, institutions, and other social systems respond to climate change, impacts, and responses. Much of the discussion regarding incorporation of social sciences has been focused on economics and behavioral and decision science. Although these areas of expertise are important to climate change, it is equally important to engage a wider range of social science disciplines. Questions concerning impacts to cultural resources; understanding of organizational structure and dynamics, particularly under conditions of significant change; and evaluations of community networks and relationships are some of the social science issues that are appropriate for including in climate-related research. Given the scarcity of social science expertise within ORD, it will be necessary to rely upon external expertise to provide guidance on best approaches to building social science capacity.
- Technologies – EPA's expanding efforts to reduce GHG emissions have not been matched by similar increases in research to understand the environmental impacts of mitigation approaches. Expanded use of natural gas and biofuels represent two examples of changes in technology that have considerable potential for reducing GHG emissions but also have resulted in significant concerns (at a minimum) regarding their environmental impacts, for example, impairments to water quality and quantity, increased nutrient and pesticide use, and reduced biodiversity. Similarly, some types of green energy technologies require a variety of metals, including rare earth elements used for wind turbines, solar panels, batteries and other products, that require consideration of mining impacts. As energy production and use technologies change, ORD needs to expand its ability to understand what changes are likely to occur and how those changes will affect human health and the environment.

VI. Summary

ORD's research that addresses climate change, its impacts, and approaches to respond through preparation, adaptation, and mitigation have evolved into a more cohesive and coherent whole since the restructuring of ORD's research programs in FY2012. This evolution has involved substantial and on-going interactions between ORD and the Regional and Program Offices who apply the research results to achieve the Agency's mission. The development of the Climate Change Research Roadmap has incorporated the information gained from these interactions to produce an ORD-wide view of climate research needed by EPA's regulatory and implementation efforts.

Climate change has become a more visible and ubiquitous component of the research needs identified by ORD's partners across the six national research programs. The activities to revise the Strategic Research Action Plans have informed, and been informed by, the development of the current Climate Change Research Roadmap. Combined with the understanding of the climate-related research needs, the Roadmap

provides a cross-ORD view of research needs and activities that allows research to be identified, prioritized, planned, conducted, and communicated in an increasingly coherent way. Despite the diverse research needs of ORD's partners, there are growing opportunities for integration across the national research programs. The roadmap has identified a few of the existing integration activities, and provides the framework for integrating future climate research within and across program boundaries.

The interactions between ORD and its EPA partners, with direct guidance from advisory bodies such as the BOSC and SAB and indirect guidance from the NRC and other expert groups, have identified several research issues that extend the potential scope of ORD's climate research portfolio. Social sciences, alternative approaches to describing possible future conditions, translation of research results to facilitate their application, and a greater emphasis on technological systems pose a range of challenges to, and provide opportunities for ORD and its EPA partners. Addressing these emerging issues will require investment of scarce resources needed to address the substantial and growing array of near-term needs, and also holds the potential to enable proactive response to mid- to long-term problems. Finding the appropriate balance between immediate and longer term issues has always been, and will continue to be, a challenge for ORD and its EPA partners.

These, and other challenges that will arise in the coming years, can only be effectively addressed if the interactions across EPA continue to expand and mature. The value of this roadmap is less in the descriptions of issues, lists of needs, and outlines of research activities than in the discussions, improving understanding, and deepening relationships behind the text. To the extent these interactions remain active, the roadmap as a guide will be dynamic and responsive even as the text remains static.

Appendix A. Abbreviations and Acronyms

ACE	Air, Climate, and Energy Research Program (within ORD)
AQRS	Air Quality Research Subcommittee (within CENRS)
BOSC	Board of Scientific Counselors
CENRS	Committee on Environment, Natural Resources, and Sustainability
CMAQ	Community Multiscale Air Quality model
CO_2	carbon dioxide
CSS	Chemical Safety for Sustainability (ORD)
DOE	Department of Energy
DOI	Department of the Interior
DOS	Department of State
EJ	Environmental Justice
EPA	Environmental Protection Agency
GACC	Global Alliance for Clean Cookstoves
GHG	Greenhouse gas
GWP	Global warming potential
HHRA	Human Health Risk Assessment (ORD)
HSR	Homeland Security Research Program (ORD)
IPCC	Intergovernmental Panel on Climate Change
IWG	Interagency working group
MSA	Multipollutant Science Assessment
NAAQS	National Ambient Air Quality Standards
NASA	National Aeronautics and Space Administration
NOAA	National Oceanic and Atmospheric Administration
NRP	National Research Program
NRC	National Research Council
NSF	National Science Foundation
NOx	nitrogen oxides
NWP	National Water Program
OCSPP	Office of Chemical Safety and Pollution Prevention (within EPA)
OAP	Office of Atmospheric Programs (OAR)
OAR	Office of Air and Radiation (EPA)
OHS	Office of Homeland Security (EPA)
ORD	Office of Research and Development (EPA)
OSC	Office of Sustainable Communities (EPA)
OSWER	Office of Solid Waste and Emergency Response (EPA)
OW	Office of Water (EPA)
PCAP	President's Climate Action Plan
PM	particulate matter
RARE	Regional Applied Research Effort
RCP	Representative Concentration Pathways
RFA	Request for Assistance
SAB	Science Advisory Board

SDR	Subcommittee on Disaster Reduction (CENRS)
SHC	Sustainable and Healthy Communities Research Program (ORD)
SO_2	sulfur dioxide
SSWR	Safe and Sustainable Water Resources Research Program (ORD)
STAR	Science to Achieve Results (ORD)
StRAP	Strategic Research Action Plan
SWAQ	Subcommittee on Water Availability and Quality (CENRS)
USDA	U.S. Department of Agriculture
USGCRP	U.S. Global Change Research Program
USGS	U.S. Geological Survey

Appendix B. Climate-Related Research Projects

Table B1. ORD projects with climate-relevant research.

Project Number	Title
ACE 4.01	Climate Change Impacts, Vulnerability and Adaptation: Climate Impacts on Human Health, Air Quality, and Ecosystems
ACE 4.02	Climate Change Impacts, Vulnerability and Adaptation--Watersheds, Water Quality and Ecosystems
ACE 4.03	Climate Change Impacts, Vulnerability and Adaptation: Systems-based Approaches for Sustainable Solutions
ACE 5.01	Emissions and Measurements for Informing Policy Decisions
ACE 5.02	Improving Emissions Inventories Using Measurements and Models
ACE 5.03	Changing the Paradigm for Air Pollution Monitoring
ACE 6.01	Atmospheric and Integrated Modeling Systems: Multiscale, Multipollutant Air Quality Modeling
ACE 6.02	Atmospheric and Integrated Modeling Systems: Integrated Multimedia, Multi-stressor Systems Model Development
ACE 7.01	Local and Regional Characteristics Influencing Public Health Impacts of Air Pollution in Healthy and At-Risk Populations
ACE 7.03	Protecting Environmental Public Health and Well-being: Air Pollution and its Impacts on Ecosystems and Wellbeing
ACE 8.01	Sustainable Energy and Mitigation: Systems, Scenarios, and Life Cycles
ACE 8.02	Sustainable Energy and Mitigation: Energy Extraction, Production, and Delivery
ACE 8.03	Sustainable Energy and Mitigation: End-Use Impacts
HSR 4.01	Innovative Design and Management of Drinking Water Systems of the Future
SHC 1.62	EnviroAtlas
SHC 1.63	Environmental Workforce and Innovation (EWI)
SHC 2.61	Community-Based Final Ecosystem Goods and Services
SHC 2.62	Community Public Health & Well-being
SHC 2.63	Assessing Environmental Health Disparities in Vulnerable Groups
SHC 2.64	Indicators, Indices and the Report on the Environment
SHC 3.61	Contaminated Sites
SHC 3.62	Environmental Releases of Oils and Fuels
SHC 3.63	Sustainable Materials Management
SHC 4.61	Integrated Solutions for Sustainable Communities
SSWR 3.01	Watershed Sustainability: Assess, map, and predict the integrity, resilience, and recovery potential of the Nation's water resources
SSWR 3.03	Watershed Sustainability: Protecting water while developing energy and mineral resources
SSWR 4.01	Nutrients: Reducing Impacts of Harmful Algal Blooms
SSWR 4.02	Nutrients: Science to Inform the Development of Nutrient Thresholds and Targeting Actions
SSWR 4.03	Nutrients: Science to Improve Nutrient Management Practices, Metrics of Benefits, Accountability and Communication

SSWR 5.01	Green Infrastructure: Models and Tools
SSWR 5.02	Green Infrastructure: Information and Guidance through Community Partnerships
SSWR 6.01	Current Systems and Regulatory Support
SSWR 6.02	Next Step: Technology Advances
SSWR 6.03	Transformative approaches and technologies for water systems

Appendix C. Research Needs

The table below shows the climate-related research needs identified by OAR, OSWER, OW, and Regional Offices. Regional Offices also contributed to development of the needs identified by OAR and OW.

Table C1. Research needs identified by partners and how those needs are being addressed in the ORD programs.

Partner	Need	Response
OW	(Priority 1) Energy Efficient Nutrient Removal: Affordable and effective technologies to retrofit existing types of municipal wastewater treatment systems for nutrient removal to achieve ecoregion-based reference criteria.	SSWR 6.02: Next Step: Technology Advances
OW	(Priority 2) Pathogens: What is the capability of existing treatment technologies in wastewater and drinking water treatment facilities to control and treat the types and populations of pathogens associated with the warmer water temperatures expected to result from a changing climate?	SSWR 6.01: Current Systems and Regulatory Support
OW	(Priorities 3 and 4) Temperature and Flow: Revise flow, temperature and precipitation interpretive statistics for use in CWA programs. Evaluate vulnerability of designated uses to warmer waters and low streamflows due to a changing climate.	ACE 6.02: Atmospheric and Integrated Modeling Systems: Integrated Multimedia, Multi-stressor Systems Model Development ACE 4.02: Climate Change Impacts, Vulnerability and Adaptation--Watersheds, Water Quality and Ecosystems
OW	(Priority 5) Decision Support: OW Climate Workgroup Priority #4: Options to improve 7Q10 streamflow estimation with modeled projections of streamflow to reflect low flow conditions expected during terms of and NPDES permit or TMDL.	Addressed by OW and USGS
OW	(Priority 6) Water Supply Management: Identify watersheds where community water systems may be at risk of long-term shortfalls in supply as a result of climate change and other factors.	Not currently addressed
OW	(Priority 7) Sea level rise and storm surge: Projected impact of changes in sea levels and storm surges on coastal wetland area and function across the country. Which coastal and estuarine	ACE 4.01: Climate Change Impacts, Vulnerability and Adaptation: Climate Impacts on Human Health, Air Quality, and Ecosystems

	wetlands are at risk of damage, what ecosystem services do they provide, at what rate are the services expected to degrade?	SSWR 3.01: Watershed Sustainability: Assess, map, and predict the integrity, resilience, and recovery potential of the Nation's water resources
OW	(Priority 8) Water Reuse: Guidelines for "acceptable" drinking water treatment plant source water quality to serve as a target for alternative sources such as reclaimed wastewater effluents, harvested stormwater, produced water, etc.	SSWR 6.03: Transformative approaches and technologies for water systems
OW	(Priority 8) Drinking Water: Consequences of warmer water temperatures for compliance with National Drinking Water Standards. To what extent will expected changes to the condition of surface waters from warming water temperatures make treatment needed to comply with drinking water standards more complex and costly or result in lower compliance rates?	SSWR 6.01: Current Systems and Regulatory Support
OW	(Priorities 8 and 9) Harmful Algal Blooms (HABs): relationship of increased air temperature to water temperature, and effects of increased water temperature on incidence of HABs (volume/unit time; change in efficiency to produce cyanotoxins; human toxicity of cyanotoxins) Identify expected changes in HABs under warmer water temperatures expected as a result of climate change.	SSWR 4.01: Nutrients: Reducing Impacts of Harmful Algal Blooms
OW	(Priority 10) Indicators of Changes in Water Temp and Estuarine & Coastal Acidification: Metrics for establishing a baseline for measurement of long-term trends in estuarine and coastal water temperature and other parameters (pH, total alkalinity, PCO2, dissolved inorganic carbon, DOC, and DO)	ACE 4.02: Climate Change Impacts, Vulnerability and Adaptation--Watersheds, Water Quality and Ecosystems SSWR 4.02: Nutrients: Science to Inform the Development of Nutrient Thresholds and Targeting Actions
OW	(Priority 11) Watersheds at Risk: Identify watersheds with greatest risk of increased pollution loading as a result of climate and other stressors. Models that integrate hydrology, land cover, air quality, and economics for assessment and comparison of climate change mitigation and adaptation policies for decision makers; Tools to prioritize response actions for wetland protection and restoration.	ACE 4.02: Climate Change Impacts, Vulnerability and Adaptation--Watersheds, Water Quality and Ecosystems ACE 4.01: Climate Change Impacts, Vulnerability and Adaptation: Climate Impacts on Human Health, Air Quality, and Ecosystems ACE 6.02: Atmospheric and Integrated Modeling Systems: Integrated Multimedia, Multi-stressor Systems Model Development

		SSWR 3.01: Watershed Sustainability: Assess, map, and predict the integrity, resilience, and recovery potential of the Nation's water resources
OW	(Priority 12) Monitoring: identify parameters and methods to monitor as indicators of impacts due to climate change; methods to identify tipping points and thresholds.	SSWR 3.01: Watershed Sustainability: Assess, map, and predict the integrity, resilience, and recovery potential of the Nation's water resources ACE 4.02: Climate Change Impacts, Vulnerability and Adaptation--Watersheds, Water Quality and Ecosystems
OAR	Quantification of climate impacts (human health, air quality, ecosystems in the U.S.)	ORD participation in interagency climate-health assessment ACE 4.01: Climate Change Impacts, Vulnerability and Adaptation: Climate Impacts on Human Health, Air Quality, and Ecosystems ACE 7.01: Local and Regional Characteristics Influencing Public Health Impacts of Air Pollution in Healthy and At-Risk Populations
OAR	Scientific contributions to National Climate Assessment (NCA) Special Report on climate change/health and support for EPA-HHS collaboration	ORD participation in interagency climate-health assessment
OAR	Investigation of the linkages between air quality and climate change	ACE 4.01: Climate Change Impacts, Vulnerability and Adaptation: Climate Impacts on Human Health, Air Quality, and Ecosystems ACE 6.01: Atmospheric and Integrated Modeling Systems: Multiscale, Multipollutant Air Quality Modeling ACE 6.02: Atmospheric and Integrated Modeling Systems: Integrated Multimedia, Multi-stressor Systems Model Development
OAR	Research/modeling atmospheric transport of black carbon, other SLCFs and the role of BC as a climate forcer	ACE 4.03: Climate Change Impacts, Vulnerability and Adaptation: Systems-based Approaches for Sustainable Solutions ACE 4.01: Climate Change Impacts, Vulnerability and Adaptation: Climate Impacts on Human Health, Air Quality, and Ecosystems
OAR	Laboratory testing of cookstove performance and emissions	ACE 8.03: Sustainable Energy and Mitigation: End-Use Impacts
OAR	"Energy paradox" research that addresses consumer or producer behavior regarding energy-saving technologies	ACE 8.01: Sustainable Energy and Mitigation: Systems, Scenarios, and Life Cycles

OAR	Research to support OAR's emerging adaptation priorities: Air quality modeling that incorporates climate impacts Improved understanding of interactions between climate change and atmospheric deposition and resulting impacts on ecosystems and ecosystem services Effects of climate change on stratospheric ozone	Air quality modeling addressed under: ACE 6.01: Atmospheric and Integrated Modeling Systems: Multiscale, Multipollutant Air Quality Modeling ACE 6.02: Atmospheric and Integrated Modeling Systems: Integrated Multimedia, Multi-stressor Systems Model Development Climate change impacts on ecosystems addressed under: ACE 4.02: Climate Change Impacts, Vulnerability and Adaptation--Watersheds, Water Quality and Ecosystems ACE 4.03: Climate Change Impacts, Vulnerability and Adaptation: Systems-based Approaches for Sustainable Solutions ACE 6.02: Atmospheric and Integrated Modeling Systems: Integrated Multimedia, Multi-stressor Systems Model Development SSWR 4.03: Nutrients: Science to Improve Nutrient Management Practices, Metrics of Benefits, Accountability and Communication Impacts on stratospheric ozone not currently addressed
OAR	Residential and commercial buildings advanced mechanical ventilation	Not currently addressed
Regions	Fire emissions contribution to O3, PM2.5, GHGs, and Haze (Regions 8 and 10)	ACE 4.01: Climate Change Impacts, Vulnerability and Adaptation: Climate Impacts on Human Health, Air Quality, and Ecosystems ACE 5.02: Improving Emissions Inventories Using Measurements and Models ACE 5.03: Changing the Paradigm for Air Pollution Monitoring
OAR	Climate change impacts on particulate matter (e.g. wildfire, dust)	ACE 4.01: Climate Change Impacts, Vulnerability and Adaptation: Climate Impacts on Human Health, Air Quality, and Ecosystems
OAR	Mitigation technology synthesis papers and/or assessments	ACE 8.02: Sustainable Energy and Mitigation: Energy Extraction, Production, and Delivery
OAR	Understanding the impacts of climate change on health effects from exposure to air pollution	ACE 4.01: Climate Change Impacts, Vulnerability and Adaptation: Climate Impacts on Human Health, Air Quality, and Ecosystems

OAR	Evaluation of the efficacy/permanence of non-geologic sequestration of carbon dioxide (e.g. carbon dioxide utilization in cement, industrial utilization of carbon dioxide) as well as recommendations for monitoring and accounting options.	Not currently addressed.
OAR	Non-CO_2 sources for the U.S. GHG Inventory (e.g. landfills, coal mines, manure management, etc)	Landfill emissions addressed under ACE 5.01: Emissions and Measurements for Informing Policy Decisions Other topics not currently addressed.
OAR	For direct and indirect nitrous oxide emissions from agricultural soils, improving the ability to estimate (e.g., more in situ measurements, data inputs and process modeling) and identify opportunities to reduce emissions (in the context of other environmental benefits of improved N fertilizer use efficiency).	ACE7.03: Air Pollution and its Impacts on Ecosystems and Wellbeing
OAR	Improve community's capacity to understand and take effective action to address harmful environmental impacts in their community	SHC 2.62: Community Public Health & Well-being
OAR	Understand interactions between social, behavioral, environmental, and biological factors for EJ and Tribal communities who are disproportionately impacted.	SHC 2.63: Assessing Environmental Health Disparities in Vulnerable Groups
OSWER	To what extent will rising sea levels and flooding and inundation from more intense and frequent storms lead to contaminant releases through surface soils, groundwater, surface waters, sediments, and/or coastal waters at OSWER sites?	ACE 4.01: Climate Change Impacts, Vulnerability and Adaptation: Climate Impacts on Human Health, Air Quality, and Ecosystems ACE 4.03: Climate Change Impacts, Vulnerability and Adaptation: Systems-based Approaches for Sustainable Solutions SSWR 3.01: Watershed Sustainability: Assess, map, and predict the integrity, resilience, and recovery potential of the Nation's water resources
OSWER	How will more powerful storms resulting from climate change affect storm debris that will need to be appropriately managed?	ACE 4.01: Climate Change Impacts, Vulnerability and Adaptation: Climate Impacts on Human Health, Air Quality, and Ecosystems ACE 4.03: Climate Change Impacts, Vulnerability and Adaptation: Systems-based Approaches for Sustainable Solutions SSWR 3.01: Watershed Sustainability: Assess, map, and predict the integrity, resilience, and recovery potential of the Nation's water resources
OSWER	What are the impacts of increased temperature on revolatilization of hazardous materials?	SHC 3.61: Contaminated Sites

OSWER	How could wildfires at contaminated sites promote the spread of contamination or impact remedies? How could wildfires in the upland areas above contaminated sites reduce vegetative cover, thereby increasing surface water runoff and resulting in catastrophic flooding that spreads contamination or impacts remedies?	Not currently addressed
OSWER	How will the frequency and magnitude of natural disasters affect the ability of emergency response efforts directed out of OSWER?	ACE 4.01: Climate Change Impacts, Vulnerability and Adaptation: Climate Impacts on Human Health, Air Quality, and Ecosystems SSWR 3.01: Watershed Sustainability: Assess, map, and predict the integrity, resilience, and recovery potential of the Nation's water resources
OSWER	Life cycle assessments related to materials management	SHC 3.63: Sustainable Materials Management
OSWER	Emerging biofuels need to be evaluated with respect to their compatibility with and impacts on the existing fuel storage and dispensing equipment. Ensuring new fuels being developed are compatible with existing infrastructure and can be stored safely will help protect groundwater supplies from contamination by failed underground storage tanks	SHC 3.62: Environmental Releases of Oils and Fuels
OSWER	What are the assessment, cleanup, and area-wide planning impacts associated with green infrastructure and brownfields?	ACE 4.03: Climate Change Impacts, Vulnerability and Adaptation: Systems-based Approaches for Sustainable Solutions
OSWER	Models are needed that can downscale the effects of climate change to a local or community level	ACE 4.01: Climate Change Impacts, Vulnerability and Adaptation: Climate Impacts on Human Health, Air Quality, and Ecosystems ACE 4.03: Climate Change Impacts, Vulnerability and Adaptation: Systems-based Approaches for Sustainable Solutions SSWR 3.01: Watershed Sustainability: Assess, map, and predict the integrity, resilience, and recovery potential of the Nation's water resources
OSWER	Need to evaluate the cumulative health effects of climate change (e.g. the non-chemical stressors that people deal with after a storm and how it impacts their susceptibility to chemical stressors)	Not currently addressed
OSWER	What are best practices for communities to adapt and mitigate climate change?	SHC 4.61: Integrated Solutions for Sustainable Communities

Region 4	Need improved understanding of the impacts of sea level rise, including impacts to coastal ecosystems and effects on storm surge and saltwater intrusion.	ACE 4.02: Climate Change Impacts, Vulnerability and Adaptation--Watersheds, Water Quality and Ecosystems ACE 4.03: Climate Change Impacts, Vulnerability and Adaptation: Systems-based Approaches for Sustainable Solutions Saltwater intrusion is not addressed.
Region 10	Better understand the extent of the problems and impacts associated with coastal erosion from melting sea ice, and strategies for communities to adapt to the melting sea ice	Not currently addressed
Region 10	Better understand the extent of permafrost thawing and impacts on tribal cultural and natural resources, and impacts on, and strategies to adapt, water infrastructure due to permafrost thawing	Not currently addressed
Region 10	Need to understand the impacts of climate change on environmental justice and Tribal communities, including the need to understand how to incorporate traditional ecological knowledge into evaluation of impacts and development of adaptation strategies	SHC 2.63: Assessing Environmental Health Disparities in Vulnerable Groups

Appendix D. EPA Participation in USGCRP Working Groups

The table below shows the number of ORD and other EPA staff participating in interagency working groups (IWGs) of the U.S. Global Change Research Program. In addition to IWG participation, EPA also has one staff member on detail as the Deputy Director of USGCRP and one staff member serving as the EPA Principal to the Subcommittee on Global Change Research.

USGCRP Working Group	ORD Staff	Other EPA Staff
Adaptation Science Interagency Working Group	1	4
Carbon Cycle Interagency Working Group	1	0
Coordinating Group on Scenarios and Interpretive Science	1	1
Education Interagency Working Group	0	0
Global Change Information System Interagency Coordination	0	0
Indicators Working Group	1	0
Integrated Observations Interagency Working Group	1	0
Interagency Crosscutting Group on Climate Change and Human Health	2	3
Interagency Group on Integrative Modeling	1	1
Interagency National Climate Assessment Working Group	1	1
International Research and Cooperation Interagency Working Group	0	1
Process Research Coordinating Committee	1	0
Social Sciences Coordinating Committee	0	1