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.

Climate Change Research Roadmap

Cross-cutting Roadmap

Preliminary Draft - July 2, 2014

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I. Executive Summary

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II. Introduction

As 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, the U.S. EPA has a critical role to play in helping the nation meet the far-reaching and complex challenges related to the impacts of global climate change. To support that work, the Agency 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.

This "Climate Change Research Roadmap" presents an overview of recent, ongoing, and planned science across the six National Research Programs of EPA's Office of Research and Development (ORD), and identifies research gaps that can inform ORD's Strategic Research Action Plans (StRAPs). The roadmap highlights the unique role that EPA plays to support the overall federal climate change research portfolio, and illustrates how EPA's climate change research draws on expertise across the national research programs in ways that leverage research results to advance the understanding of the impacts of climate change, while simultaneously supporting overall efforts to protect air, water, and public health, and increase homeland security and community resiliency.

Because understanding the complex and dynamic nature of climate change and its far-reaching impacts requires a diversity of research disciplines and expertise, EPA climate change research is one of four highly coordinated research areas, along with Environmental Justice, Nitrogen and Co-pollutants, and Children's Environmental Health, that serve as exemplary models of how the Agency is designing integrated, transdisciplinary research that is ushering in a new paradigm for responsive, efficient, and impactful federal science.

Background

The EPA's mission to safeguard the environment and protect human health puts the Agency at the forefront of coordinating and leading federal efforts to help the nation mitigate and prepare for the impacts of climate change, particularly where they affect air, water, land, ecosystems, and human health.

Recognizing this responsibility, the Agency explicitly named "Addressing Climate Change and Improving Air Quality" as the first of five Agency-wide priorities to guide its *Fiscal Year 2014-2018 EPA Strategic Plan*.[1] More generally, the EPA Strategic Plan calls upon

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

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.

The President's Climate Action Plan (PCAP) calls for the nation to reduce 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 both new and existing power plants, as well as support other actions to help local communities across the nation take action on climate change. The Agency's climate change research program will support key Agency decisions and actions to support PCAP.

In addition, EPA is one of 13 departments and agencies that contribute to the U.S. Global Change Research Program (USGCRP), which coordinates federal climate change research. The Program emphasizes 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 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." EPA's research plays a leading role in contributing to solutions, particularly in the areas related to planning for and responding to the "manifestations of global change."

Supporting such efforts will require working closely with partners and stakeholders both within the Agency and out to identify their research needs. Within the Agency, the climate change research program works to support several different program offices, each with different environmental mandates to uphold, and with different research needs to be supported. For example, the Office of Air and Radiation (OAR) is responsible for taking action to address climate change under the authority and mandates of the Clean Air Act. OAR has identified both near- and long-term research needs that must be met for them to fulfill that work. The Office of Water's (OW) National Water Program Guidance includes areas of research that they need addressed to achieve their goals related to helping the nation and local communities prepare for climate change impacts related to water.[3]

Climate change also threatens EPA's ability to achieve its mission on a broader level. This recognition is the basis for the EPA Climate Change Adaptation Plan required under Executive Order 13514[4] and published (as draft) in February 2013[5] and the draft Office-specific Climate Adaptation Implementation Plans published in November 2013.[6] The lead ORD program for climate research is ACE. As such, the ACE budget includes

[2] http://www.whitehouse.gov/sites/default/files/image/president27sclimateactionplan.pdf.
[3] http://water.epa.gov/scitech/climatechange/upload/epa_2012_climate_water_strategy_full_report_final.pdf.
[4] http://www.epa.gov/oaintrnt/practices/eo13514.htm
[5] http://epa.gov/climatechange/pdfs/EPA-climate-change-adaptation-plan-final-for-public-comment-2-7-13.pdf
[6] http://epa.gov/climatechange/impacts-adaptation/fed-programs/EPA-impl-plans.html

resources for Global Change Research. In the FY 2015 President's Budget Request ORD requested $20.1 M under the Air, Climate and Energy research program for climate research. In addition, as the impacts of climate change have become increasingly apparent and in response to our Program and Regional partner needs, ORD has incorporated climate change as a stressor into many areas of our research portfolio.

The climate science effort outlined here is designed *to provide EPA with the scientific and technical information it needs to better understand the impacts of climate change, and inform governmental bodies, communities and individuals to prepare for, adapt to, and mitigate those impacts*.

Purpose

The purpose of this Climate Change Research Roadmap is three-fold:

1. To describe the priority climate change related research needs of EPA Program and Regional Offices
2. To describe the scope of research to be conducted by EPA's Office of Research and Development in response to the priority research needs of its partners (Agency Program and Regional Offices);
3. To identify research directions and draw from different Agency Strategic Research Action Plans (StRAPS) to facilitate highly coordinated, efficient, and transdisciplinary research.

This Research Roadmap draws from StRAPs developed for each of the six national research programs within EPA's Office of Research and Development to identify and coordinate current climate-related research efforts, facilitating an efficient, collaborative research portfolio. It is also designed to identify priority climate-related research needs as they emerge across the Agency.

This roadmap is designed to emphasize and strengthen ORD's science leadership through its existing expertise and capabilities, and to take greatest advantage of its partnerships with experts across the Agency, the greater scientific community, state and local governments, and industry.

EPA's climate change science program is addressing 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 fulfil EPA's mission to protect human health and the environment, and to meet the statutory authorities and responsibilities of the Agency.

Expanded Problem Statement

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Science Challenges

The key research topics that align with five major areas of emphasis for 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 are:

- For water quality and aquatic ecosystems, to understand how climate change is altering conditions such that it is no longer possible to rely entirely on historical records for flows and other parameters critical to maintaining and enhancing water quality;
- For air quality, to understand how climate change affects air quality and how air quality-related emissions and atmospheric processes affect climate change;
- For human health, 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.
- For ecosystems and land, to understanding how the impacts of climate change can impact contaminated sites and terrestrial ecosystems; and
- For mitigation and subsequent environmental impacts, to develop the information needed to inform effective mitigation strategies that do not cause other, unacceptable environmental impacts.

In addition, two areas of research—social system influences, and uncertainty—that cut across the previous five are important for effectively addressing climate change. Research in the first of these areas will advance the understanding of how social systems, not just natural and technological systems, respond to a changing climate. Finally, because of the complexity of climate change and the inherent uncertainties associated with changes in the drivers of GHG emissions, it is critical to develop methods and approaches to inform decisions in the context of deep uncertainty.

Research Alignment and Coordination

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IV. Cross-cutting ORD Research

Current and Planned ORD Research

The ORD research programs that have relevant expertise and program scope to address the key research topics discussed above are shown below in Figure 1. The figure reflects subjective evaluation of program relevance.

The black cells indicate lead programs for the respective topics, based on the amount of 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 IRIS.

No lead program was identified for the social science cross-cutting topic, given that it is a truly cross-cutting issue that fits within each program in different ways. The emerging problems cross-cutting topic is identified as being led by the ACE program, primarily due to the fact that ACE has the lead for climate change research more broadly.

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

Figure 1. 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.

Water Quality and Aquatic Ecosystems

The basic science challenge related to water quality and aquatic ecosystems is to understand how climate change is altering temperatures, precipitation and ocean conditions such that it is no longer possible to rely entirely on historical records for flows and other characteristics of watersheds, wetlands, estuaries, and coastal environments. 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, pathogen viability, and wildfires. 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 and economic growth, and changing energy production technologies.

Research on the impacts of climate change on water quality and aquatic ecosystems is conducted in ACE, SSWR, and HSR, and covers several areas: vulnerabilities of regulatory programs to climate change; impacts to watersheds and aquatic ecosystems; impacts to water infrastructure; assessments of climate change impacts on water quality; evaluation of impacts to aquatic ecosystems; and development of sustainable energy-efficient water systems.

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 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 pollution potential
  - 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

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. This information has also been identified by OHS as a need, related to disaster response. Other water-related research identified by OHS as needed is information on changing water treatment systems. OAR has also identified the impacts to ecosystems, including aquatic ecosystems, caused by climate change as a research need.

Research is being conducted to understand the vulnerabilities of water quality regulatory programs to a changing climate, including vulnerabilities from direct impacts of climate change. This work includes specific application to develop guidance to incorporate changing temperatures into regulatory programs in collaboration with Region 10. Relevant projects: SSWR 3.1 and ACE MA-1, MA-2, MDST-3, and MDST-4.[7]

Work is underway to assess hydrologic and biogeochemical sensitivity to climate and land use change, and to develop indicators of watershed condition and attributes that

[7] See Appendix A for project titles.

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. Relevant projects: SSWR 1.1, 1.2, and 3.1 and ACE MA-1 and MA-2.

ORD research related to water infrastructure is focused on providing information for use by 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 develop design principles for green infrastructure, "net zero" utility operations, and sustainability indicators. Relevant projects: SSWR 2.4, 4.2, 4.3, and 5.1, HSRP 4.01, and ACE MA-4.

Assessments of the impacts of climate change on water quality will provide the scientific foundation of consolidated, synthesized information needed by OW and others to develop effective responses. This effort includes not only assessments themselves, but the tools needed to support the development of assessments, such as land use scenarios. Relevant projects: SSWR 1.1 and 1.3 and ACE MA-2. There is also a new STAR grant focused on 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.

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, and the vulnerability of estuarine and near-coastal species, habitats, and ecosystem services to climate change. This work also includes efforts to evaluate the impacts of land use change associated with biofuel production, which may affect water quality and aquatic ecosystems. Relevant projects: SSWR 1.1 and 6.1, ACE MA-1, and SHC 2.1.4 and 3.3.1.

Research 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 understanding of more broadly applicable information. 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. Relevant projects: ACE MA-2 and MA-4, HSRP 4.01, and SSWR 6.1.

ORD's 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 Gulf of Mexico hypoxia. From a broader perspective, this work is looking into the connections between the carbon and nutrient cycles, although at regional rather than global scales. Relevant projects: ACE MA-1, MDST-3, and NMP-6, SSWR 2.3, and SHC 2.1.4 and 3.3.1.

Water Quality and Aquatic Ecosystems: Gaps

Considerable work is underway to understand how climate change will affect surface and groundwater availability, much of it outside of EPA. Similarly, research to understand thresholds and tipping points of importance to water quality is likely to require advances in research outside EPA.

Although there is some work related to understanding potential contamination by pathogens due to climate change, there is little work to evaluate the effectiveness of control technologies for them.

Methods to estimate the lowest 7-day flows over a ten-year period (7Q10) are not currently being developed. Considerable research external to EPA may be needed to develop the desired information.

Research is needed to monitor and predict changes in coastal and estuarine environments impacted by climate-driven changes including ocean acidification, sea level rise, and increasing temperatures. Some work is underway within ORD to investigate these environmental impacts. Considerable work is being done by NOAA and states to evaluate changes in ocean pH, sea level, and ocean water temperatures. Further efforts by ORD may be needed in this area, but would need to be done in the context of the recently released National Ocean Policy Implementation Plan.[8]

Research is not currently being conducted to evaluate the impact of climate change on harmful algal blooms.

Air Quality

Within the air quality topic, the science challenge is to understand how climate change affects air quality and how emissions and atmospheric processes affect climate change.[9] Changing weather patterns alter pollutant formation and affect anthropogenic, biogenic, and geogenic emissions. Concentrations of aerosols, ozone, and methane affect radiative forcing.

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

[8] http://www.whitehouse.gov//sites/default/files/national_ocean_policy_implementation_plan.pdf
[9] http://www.epa.gov/airquality/airtrends/2010/report/climatechange.pdf

    - 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

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. Relevant projects: ACE EM-1, EM-2, and SEE-2.

In the area of air quality modeling, research is focused on applying the Community Multiscale Air Quality (CMAQ) model to future emission and climate 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 emissions and meteorology 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, but the effort involves global-scale climate modeling results from other federal agencies, which are downscaled to allow application of CMAQ to evaluate potential future air quality, as well as for possible 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. Relevant projects: ACE MDST-4 and MA-3.

The third component of 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, and the impacts of residential cookstoves. 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. Relevant projects: ACE MA-2, MA-3, MA-4, SEE-1, and SEE-2.

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. 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 requested funding in the FY15 President's Budget to support 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 Greenhouse Gas Reporting Program and the President's Methane Strategy.

Air Quality: Gaps

Additional work is needed to better understand how climate change may impact PM levels in particular, 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.

No 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, monitoring and control systems, dedicated outdoor air systems, and automated HVAC systems are of interest.

Although some work is being conducted by ORD 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.

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 health effects that are 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, invasive pathogens, and mental health issues related to disruptions caused by extreme weather events.

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 storm and how it impacts their susceptibility to chemical stressors (OSWER)

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. Relevant projects: ACE MA-1, MA-2, and MA-3 and SEE-2.

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.

Human Health: Gaps

Research is needed to evaluate health impacts in a cost-benefit context, although this topic has been more fully (but not completely) addressed by previous work related to environmental regulatory evaluation. Further, there is a need for 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 health implications of extreme weather events, including exposures to materials released from contaminated sites due to heat

or floods. 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.

From OAR's perspective, the cross-agency climate-health assessment would benefit significantly from ORD scientific contributions, including work on air quality-climate-health linkages and 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 RFP coordination/integration.

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.

Research on the effects of climate change on extreme weather events, particularly floods, can inform the siting and design of existing 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 could 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

Research on the environmental impacts of extreme weather events is addressed under a STAR grant. 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. Relevant project: MA-2.

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 is being conducted in SHC. Relevant project: SHC 3.1.4.

Some work is being conducted to understand behaviors of contaminants in sediments, although it is being conducted relative to remediation activities. Relevant project: SHC 3.1.1.

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. Relevant projects: MA-1 and MA-2.

Land and Terrestrial Ecosystems: Gaps

Research is needed in several areas: contaminated site behavior under extreme weather conditions related to climate change; debris generation and disposal; and green infrastructure brownfield impacts.

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,[10] 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.

This is, in some ways, the most forward-looking topic within the climate research portfolio given that explicit mitigation actions are relatively recent at a national scale. Such actions, and the 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.

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

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

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 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 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. Relevant projects: ACE SEE-1 and MA-4.

ORD is conducting limited work to understand the environmental implications of biofuels. Although work in this area has been scaled back following publication of the final Renewable Fuels Standard, work is continuing to understand how increased use of biofuels may impact vehicle emissions and subsequently, air quality and health. Relevant project: ACE SEE-2.

Complementing these two areas of 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. Relevant projects: ACE SEE-1 and MA-4.

A STAR grant Request for Assistance (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.

Mitigation and Associated Environmental Impacts: Gaps

No work is currently being done 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.

The rapidly changing regulatory context for CO_2 highlights the research need to understand the capabilities and consequences of changing 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 and needs to be expanded.

Substantial efforts in technology development are underway in DOE and to some extent in DOT, as well as within industry, and interactions with these groups are crucial to provide EPA partners with necessary information.

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.

Research needs related to the cross-cutting issues were identified by ORD partners relate 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)

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 ACE program has brought on board a post-doctoral researcher with a background in community decision processes to develop a better understanding of the ability of communities to develop adaptation strategies and implementation plans. 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 how ORD can help provide that information. The SHC work is expected to begin 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 develop information in ways that adequately

convey the substantial uncertainties in future conditions due to the inherent complexities of natural and human systems and their interactions. 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.

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, for which the lead US agency is the Department of State. Input from DOS and DOE provide guidance to NRMRL 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.
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 ACE's work 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 issues where climate change is 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. Provided with an opportunity to measure methane, the investigators found emissions to be considerably higher than expected. After discussion with ACE staff and the ADC, the investigators developed an approach that would bring in 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[11] provided strong scientific basis for ozone in the 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 now underway in collaboration with HHS and USDA, and a planned Climate Change-Water Quality Assessment within ORD.

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 program is working to make such synthesis products a common component of all projects, but that goal has not yet been realized. Further efforts are needed to plan and develop syntheses that cut across research programs.

[11] 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

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.

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

Synthesis of Existing Gaps

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

The needs identified by ORD's partners included several that are not currently being addressed by ORD's research programs:

- Evaluate the capability of existing wastewater and drinking water treatment technologies to control and treat the types and populations of pathogens associated with expected warmer water temperatures due to climate change
- Identification of watersheds for which community water systems may be at risk of long-term water supply shortfalls

- Evaluation of increased water temperature on incidence and characteristics of harmful algal blooms (volume/unit time; change in efficiency to produce cyanotoxins; human toxicity of cyanotoxins)
- Understanding of the consequences of warmer surface water temperatures on the cost, complexity, and performance of water treatment required to comply with National Drinking Water Standards
- Developing approaches to improve 7Q10 streamflow estimation (7-day low flow over a 10-year period) with modeled projections of streamflow to reflect low flow conditions
- Development and evaluation of advanced mechanical ventilation systems for residential and commercial buildings
- Understanding the impacts of climate change on stratospheric ozone protection
- Investigation into how wildfires at contaminated sites may affect the spread of contamination or impact remedies
- Evaluation of how wildfires in areas above contaminated sites could reduce vegetative cover, leading to increased surface water runoff and resulting in catastrophic flooding that spreads contamination or impacts to remedies
- Evaluation of the assessment, cleanup, and area-wide planning impacts associated with green infrastructure and brownfields
- Evaluation of the cumulative health effects of climate change, including non-chemical stressors on health following extreme weather events and subsequent impact to chemical stressor susceptibility
- Improve a community's capacity to understand and take effective action to address harmful environmental impacts in their community
- Understand interactions between social, behavioral, environmental, and biological factors for environmental justice and Tribal communities who are disproportionately impacted
- Identification of best practices for communities to adapt to and mitigate climate change

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, below are additional issues that need to be incorporated into ORD's climate research.

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 adapt to climate change and understanding the factors related

to disproportionate impacts of climate change to EJ communities. 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 focus on future conditions. This focus emphasizes the importance of uncertainty in the planning, conduct, and communication of research. Although most of the other environmental issues have addressed looked to future improvements, they did not for the most part need to address significant changes in environmental conditions or changes in populations, technologies, or policies. The deep uncertainties associated with such changes requires research approaches that account for a range of possible, perhaps even unlikely, future conditions to adequately inform our partners.

Such approaches involve the development and application of scenarios and ensembles. Common sets of scenarios for climate forcing, such as the IPCC Reference Concentration Pathways (RCPs),[12] can enable comparison of results across programs and with external research. Consistent scenarios for socioeconomic variables or sensitivities of environmental end points 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.

Decision-relevant Scale

Although not always explicitly stated, there is a common need for information at "decision-relevant scales" – i.e., the regional or local scales at which decisions are often made or implemented. Global-scale models indicate changes in temperature and precipitation patterns are likely to differ across regions, and the health and environmental responses to those changes will also differ. Risk management decisions are also made at regional or smaller (state, tribal, local) scales. It should be recognized that many of the above research topics will entail regional variations that need to be more fully understood.

Syntheses

The value of synthesizing information has been noted above, although in the context of significant assessment development efforts. More broadly, there is considerable value in developing syntheses of research results that communicate the understanding gained over a body of work, in the context of what has been done elsewhere, and with an evaluation of what the findings imply for future research and decision making. Given the volume of research conducted on climate change and its impacts and responses,

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

syntheses that consolidate and evaluate a body of research from an EPA perspective can have substantial influence toward increased understanding of climate change.

Prioritized Research Needs for ORD

Researchers within EPA's Office of Research and Development have established a number of 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.

The list of research needs in Appendix B includes OW's priority ranking. The needs identified by OAR and OSWER represent their priority list, with all stated topics considered to be important.

Informing 2016 – 2019 ORD Research Planning

ORD is continually working on a process to prioritize research needs and develop our climate research strategy. Over the next year, through this Roadmap, we will lay out our research strategy along these key areas at the core of EPA's mission. We will work with Agency partners to collectively consider the individual research needs from the different Program and Regional offices, and develop an Agency-wide set of science needs for climate adaptation. It will be important to balance meeting near-term partner needs and long-term more fundamental climate-related research to inform EPA's future decisions. The final Roadmap will articulate how our priority research areas are distinct from, yet related to, research going on across the federal government and other bodies and why these are the most important science challenges related to climate for EPA to address.

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 quality
- Climate-driven impacts to human health
- Impacts of climate change on contaminated sites and materials management
- Climate change impacts to ecosystems, including aquatic ecosystems and ecosystems goods and services
- Environmental impacts of changing 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. These approaches were noted above, but warrant further emphasis here:

- 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. Expanded understanding of approaches to evaluate, incorporate, and communicate uncertainty is needed for all climate-related research.

- 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 a synthesis 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 discussions 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. 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

TO BE COMPLETED IN FINAL CROSS-CUTTING ROADMAP

Appendix A. Abbreviations and Acronyms

ACE	Air, Climate, and Energy Research Program (within ORD)
AQRS	Air Quality Research Subcommittee (within CENRS)
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
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
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
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	Reference Concentration Pathways
RFA	Request for Assistance
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

Appendix B. Climate-Related Research Projects

The projects are current as of FY2014. Programmatic changes may have resulted in project realignment, mergers, or splits that are not reflected in this table.

Table A1. ORD projects with climate-relevant research.

Program Number	Title
ACE MA-1	Vulnerable People and Ecosystems
ACE MA-2	Climate Change Impacts, Adaptation, and Managing Uncertainty, at National, Regional, and Local Scales
ACE MA-3	Characterization of Relationships between Air Quality, Climate Change, and Adverse Health Effects
ACE MA-4	Sustainability, Interactions, and Co-benefits
ACE MDST-3	Integrated Multimedia Systems Modeling for Sustainability
ACE MDST-4	Hemispheric- to Global-Scale Multipollutant Air Quality and Climate Modeling and Decision Support
ACE NMP-6	Atmospheric Deposition Tools to Inform Secondary NAAQS
ACE SEE-1	Energy and the Environment: Improving Human and Ecosystem Health in an Evolving Energy Landscape
ACE SEE-2	Energy from Biomass: Managing the Impacts of Emerging Bioenergy Pathways
HSR 4.01	Innovative Design and Management of Drinking Water Systems of the Future
SHC 2.1.4	Place-based and Thematic EGS [Ecosystem Goods & Services] Research
SHC 3.1.1	Contaminated Sediments
SHC 3.1.4	Environmental Releases
SHC 3.3.1	Sustainable Management of Nitrogen
SSWR 1.1	Watershed Integrity and Sustainability
SSWR 1.2	Economic Mechanisms, Integrated Management Approaches and Ecological Thresholds for Watershed Integrity
SSWR 1.3	Interoperability of Data and Models Supporting Watershed Integrity and Sustainability
SSWR 2.3	Optimized Solutions for Sustainable Nutrient Management
SSWR 2.4	Mitigating Environmental Impacts of Subsurface Land Use Practices
SSWR 3.1	Impacts and Mitigation of Climate Variability and Changing Human Demographics on Water Quality and Availability
SSWR 4.2	Green Infrastructure BMP Performance and Metrics
SSWR 4.3	Green Infrastructure Modeling Tools and Data Inventories
SSWR 5.1	Development and Application of Tools and Metrics for the Next Generation of Water Systems
SSWR 6.1	Narragansett Bay and Watershed Sustainability: Demonstration Project

Appendix C. Research Needs

The table beginning on the following page shows the climate-related research needs identified by OAR, OSWER, and OW. The needs identified by OAR and OW were developed with input from Regional Offices.

Table B1. 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 5.2d: Development and optimization of biological treatment for drinking water facilities SSWR 5.4a: Technology development for water reuse, nutrient extraction, and energy recovery SSWR 5.4b: Integrated assessment of water reuse, nutrient extraction, and energy recovery at demonstration sites
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?	Not currently addressed
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 056: Developing approaches for coupling atmospheric and hydrology models ACE 206: Regulatory vulnerabilities to climate change: water quality programs ACE 204: Regional coordination and implementation of climate change mitigation and adaption; Region 10 pilot ACE 249: Vulnerability of Pacific Northwest (PNW) hydrologic landscapes and streamflow to climate change
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.	Not currently addressed

Partner	Need	Response
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 wetlands are at risk of damage, what ecosystem services do they provide, at what rate are the services expected to degrade?	ACE STAR 15: Impact of extreme events on air quality and water quality in the US from global change
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 5.4a: Technology development for water reuse, nutrient extraction, and energy recovery SSWR 5.4b: Integrated assessment of water reuse, nutrient extraction, and energy recovery at demonstration sites
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?	Not currently addressed
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.	Not currently addressed

Partner	Need	Response
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 018: Assessing the vulnerability of near-coastal species and habitats to individual and multiple climate drivers at regional scales
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 252: Watershed modeling to assess hydrologic and biogeochemical sensitivity to climate and land use change ACE 057: Developing approaches for linking atmospheric, hydrology, watershed, and ecosystem models
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 3.1b/ACE 206: Developing monitoring networks to detect climate change effects in streams SSWR 1.1a: Indicators of watershed condition and watershed attributes that promote integrity
OAR	Quantification of climate impacts (human health, air quality, ecosystems in the U.S.)	ORD participation in interagency climate-health assessment ACE 041: Climate change scenarios based on first-principles modeling approaches ACE 114: Health effects of climate changes on human responses to air pollutants ACE 121: Impact of climate change on disease risk - How do climate associated changes in air quality and weather events impact allergic, chronic, waterborne and infectious disease risk among specific populations? ACE 250: Vulnerable populations and climate change
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

Partner	Need	Response
OAR	Investigation of the linkages between air quality and climate change	ACE 041: Climate change scenarios based on first-principles modeling approaches ACE 073: Development of modeling approaches to represent and quantify impacts of global pollution on regional air quality and climate ACE 100: Evaluation, sensitivity, and uncertainty of hemispheric/global models ACE 110: GLIMPSE: An integrated tool for simultaneously improving air quality and taking action on climate change ACE 155: Linkage with global climate models: Downscaling techniques ACE 212: Role of heterogeneous chemistry of atmospheric aerosols on aerosol optical thickness: laboratory and field studies ACE STAR 12: Adaptation for future air quality analysis and decision support tools in light of global change impacts and mitigation
OAR	Research/modeling atmospheric transport of black carbon, other SLCFs and the role of BC as a climate forcer	ACE 110: GLIMPSE: An integrated tool for simultaneously improving air quality and taking action on climate change ACE STAR 14: Investigation of black carbon's role in global to local scale climate and air quality
OAR	Laboratory testing of cookstove performance and emissions	ACE 094: Evaluation of cookstoves for developing countries
OAR	"Energy paradox" research that addresses consumer or producer behavior regarding energy-saving technologies	STAR: Alternative energy infrastructures

Partner	Need	Response
OAR	Research to support OAR's emerging adaptation priorities: Air quality modeling that incorporates climate impacts Climate change influence on ecosystem vulnerability Effects of climate change on stratospheric ozone	Air quality modeling addressed under: ACE 041: Climate change scenarios based on first-principles modeling approaches ACE 073: Development of modeling approaches to represent and quantify impacts of global pollution on regional air quality and climate ACE 100: Evaluation, sensitivity, and uncertainty of hemispheric/global models ACE 155: Linkage with global climate models: Downscaling techniques Climate change influence on ecosystem addressed under: ACE 018: Assessing the vulnerability of near-coastal species and habitats to individual and multiple climate drivers at regional scales ACE 056: Developing approaches for coupling atmospheric and hydrology models ACE 137: Integrated climate and land use tools and datasets for impacts, vulnerability, and adaptation assessments ACE 145: Interactive impacts of climate change and nitrogen deposition on ecosystems and ecosystem services ACE 177: National vulnerability assessment methods applied to wetlands ACE 249: Vulnerability of Pacific Northwest (PNW) hydrologic landscapes and streamflow to climate change SSWR 6.1: Determine how the drivers of change and disturbance (including climate), and improvements, related to nutrients affect ecosystem structure and function. Impacts on stratospheric ozone not currently addressed

Partner	Need	Response
OAR	Residential and commercial buildings advanced mechanical ventilation	Not currently addressed
Region	Fire emissions contribution to O3, PM2.5, GHGs, and Haze (Regions 8 and 10)	ACE STAR 14: Investigation of black carbon's role in global to local scale climate and air quality
OAR	Improve community's capacity to understand and take effective action to address harmful environmental impacts in their community	
OAR	Understand interactions between social, behavioral, environmental, and biological factors for EJ and Tribal communities who are disproportionately impacted.	
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 STAR 15: Impact of extreme events on air quality and water quality in the US from global change
OSWER	How will more powerful storms resulting from climate change affect storm debris that will need to be appropriately managed?	ACE STAR 15: Impact of extreme events on air quality and water quality in the US from global change
OSWER	What are the impacts of increased temperature on revolatilization of hazardous materials?	SHC 3.1.1.2: Passive sampling techniques for assessing the bioavailability, fluxes, and biotic uptake of contaminants and sediments as related to remediation activities
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 STAR 15: Impact of extreme events on air quality and water quality in the US from global change
OSWER	Life cycle assessments related to materials management	

Partner	Need	Response
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 3.1.4.3: Biodegradability and toxicity of biodiesel blends SHC 3.1.4.5: Research supporting LUST sites
OSWER	What are the assessment, cleanup, and area-wide planning impacts associated with green infrastructure and brownfields?	Not currently addressed
OSWER	Models are needed that can downscale the effects of climate change to a local or community level	ACE 041: Climate change scenarios based on first-principles modeling approaches ACE 155: Linkage with global climate models: Downscaling techniques
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?	