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CUMULATIVE IMPACTS RESEARCH

Recommendations for EPA's Office of Research and Development

Office of Research and Development
Immediate Office of the Assistant Administrator

FINAL REPORT

Cumulative Impacts Research

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United States Environmental Protection Agency
Office of Research and Development

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Office of Research and Development Senior Leadership

H. Christopher Frey, Assistant Administrator for Research and Development and EPA Science Advisor

Maureen R. Gwinn, Principal Deputy Assistant Administrator for Science and Chief Scientist

Bruce Rodan, Associate Director for Science

Wayne Cascio, Director, Center for Public Health and Environmental Assessment

Report Authors

EPA Cumulative Impacts Scoping Workgroup Steering Committee

Susan Julius, Co-Chair and Project Lead, Assistant Center Director of the Center for Public Health and Environmental Assessment

Sarah Mazur, Co-Chair and Project Lead, Principal Associate National Program Director for the Sustainable and Healthy Communities Research Program

Nicolle Tulve, Co-Chair and Technical Lead, Research Physical Scientist, Center for Public Health and Environmental Assessment

Sean Paul, Special Assistant to the Assistant Administrator for Research and Development

Nick Loschin, ORISE Research Participant, Sustainable and Healthy Communities Research Program

EPA Cumulative Impacts Scoping Workgroup Members

Office of Research and Development

Tim Barzyk, Center for Public Health and Environmental Assessment

Kyle Buck, Center for Environmental Measurement and Modeling

Kathie Dionisio, Principal Associate National Program Director for the Chemical Safety for Sustainability Research Program

Andrew Geller, Senior Science Advisor for Environmental Justice

Joel Hoffman, Branch Chief, Center for Computational Toxicology and Exposure

Sang Don Lee, Principal Associate National Program Director for the Homeland Security Research Program

Beth Owens, Principal Associate National Program Director for the Health and Environmental Risk Assessment Research Program

Angie Shatas, Associate National Program Director for the Air, Climate, and Energy Research Program

Darcie Smith, Assistant Center Director of the Center for Environmental Solutions and Emergency Response

Joe Williams, Principal Associate National Program Director for the Safe and Sustainable Water Resources Research Programs

Office of Environmental Justice

Charles Lee, Senior Advisor

Onyemaechi Nweke, Physical Scientist

Regions

Carole Braverman, Regional Science Liaison (Region 5)

Matt Small, Regional Science Liaison (Region 9)

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And finally, we thank the EPA Science Advisory Board for giving their advice through a public meeting and written comments in early 2022, as well as the members of the public who took the time to provide written and oral comments through the Science Advisory Board's public comment period.

A Message from the ORD Assistant Administrator

William Ruckelshaus, the founding Administrator of the Environmental Protection Agency, set forth three foundational principles by which the EPA should conduct its work: follow the science, follow the law, and be transparent. Under the leadership of Administrator Regan, the EPA has adopted a fourth foundational principle: advance justice and equity. As stated in the Agency's FY2022-FY2026 Strategic Plan, "EPA will advance the promise of clean air, clean water, and safe land to the many communities across the country that have not received the full benefits from EPA's decades of progress."

As a science-based agency, we invest in the development of science to address administration priorities and inform decisions consistent with EPA's Strategic Plan. Ensuring scientific integrity and science-based decision-making is a cross-Agency strategy. The credibility of science-based decisions depends on the credibility of the science underlying those decisions. The mission of EPA's Office of Research and Development (ORD) is to conduct research that provides the foundation for decision-making in pursuit of the Agency's mission to protect human health and the environment. This must include leading in the development of science that informs decisions and actions to advance justice and equity.

Communities that have long been overburdened face cumulative impacts from chemical stressors in environmental media (air, water, land) and from non-chemical stressors, including social determinants of health. Changing climate is exacerbating many of these cumulative impacts. In ORD, we recognize that it is critical to bolster the scientific basis for identifying interventions — actions — that can improve community health and well-being, and for selecting, implementing, and evaluating such actions.

Over the past year, ORD developed FY2023-FY2026 Strategic Research Action Plans (StRAPs) for each of our National Research Programs. This report was developed concurrently to complement the development of StRAPs. It focuses on cumulative impact research recommendations that cut across the National Research Programs and offers recommendations for how ORD can provide management support for such complex research.

This report was prepared by an interdisciplinary group of scientists and experts from the Office of Research and Development, the Office of Environmental Justice, and Regional Offices. It is based on input from EPA programs and regions, states, tribes, and community representatives, the EPA Science Advisory Board, public comments, as well as previous recommendations from the National Environmental Justice Advisory Committee and the White House Environmental Justice Advisory Committee. The report was reviewed internally by ORD senior leadership as well as by staff across EPA programs and regions. The recommendations of this report are already informing actions within ORD to advance the state of the science, and we are prepared to do more as we implement cumulative impacts research in the years to come.

- H. Christopher Frey, Ph.D.

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Acronyms

ACE	Air, Climate, and Energy National Research Program
BOSC	Board of Scientific Counselors
CEQ	Council on Environmental Quality
CIA	Cumulative Impact Assessment
CRA	Cumulative Risk Assessment
CSS	Chemical Safety for Sustainability National Research Program
EJ	Environmental Justice
EO	Executive Order
EPA	Environmental Protection Agency
HABs	Harmful Algal Blooms
HERA	Health and Environmental Risk Assessment National Research Program
HIA	Health Impact Assessment
HS	Homeland Security National Research Program
NAAQS	National Ambient Air Quality Standards
NEJAC	National Environmental Justice Advisory Council
NEPA	National Environmental Policy Act
NRP	National Research Program
OEJ	Office of Environmental Justice
ORD	Office of Research and Development
RA	Research Area
RFA	Request for Applications
SAB	Science Advisory Board
SHC	Sustainable and Healthy Communities National Research Program
SSWR	Safe and Sustainable Water Resources National Research Program
STAR	Science to Achieve Results
STEM	Science, Technology, Engineering, and Mathematics
TEK	Traditional Ecological Knowledge
TSCA	Toxic Substances Control Act

Executive Summary

In January 2021, President Biden signed Executive Orders (EO) 13985 and 14008 to advance racial equity and support for underserved communities and to address the climate crisis. These EOs provide a framework for stimulating action across the federal government to address health inequities in the United States caused by disproportionate exposures to pollution and environmental degradation that are exacerbated by racial, economic, and geographic factors and climate change. In support of these Orders, EPA Administrator Regan issued an Agency-wide directive to take steps to better serve historically marginalized communities using cumulative impact assessment (EPA, 2021a, 2021b). In response to this directive, the Office of Research and Development (ORD) is resolved to strengthen the scientific foundation for assessing cumulative impacts. This report provides definitions, research gaps and barriers to implementing cumulative impact research at EPA, and recommendations for advancing cumulative impact research going forward within ORD's FY23-26 Strategic Research Action Plans.

To provide clarity and consistency to ORD's consideration of cumulative impacts across its research portfolio, this report offers definitions for "cumulative impacts" and "cumulative impact assessment" based on definitions developed by federal and state agencies. This is distinct from "cumulative risk assessment," which EPA is addressing through the Risk Assessment Forum's "Guidelines for Cumulative Risk Assessment: Planning and Problem Formulation," currently under review within EPA. The definitions developed for this report are as follows:

Cumulative Impacts *are defined as the totality of exposures to combinations of chemical and non-chemical stressors and their effects on health, well-being, and quality of life outcomes.*

Cumulative impacts include contemporary exposures to multiple stressors as well as exposures throughout a person's lifetime. They are influenced by the distribution of stressors and encompass both direct and indirect effects to people through impacts on resources and the environment. Cumulative impacts can be considered in the context of individuals, geographically defined communities, or definable population groups. Cumulative impacts characterize the potential state of vulnerability or resilience of a community.

Cumulative Impact Assessment *is defined as a process of evaluating both quantitative and qualitative data representing cumulative impacts to inform a decision.*

Cumulative impact assessment requires a systematic approach to characterize the combined effects from exposures to both chemical and non-chemical stressors over time across the affected population group or community. It evaluates how stressors from the built, natural, and social environments affect groups of people in both positive and negative ways. The posited elements of a cumulative impact assessment include community role throughout the assessment, such as identifying problems and potential intervention decision points to improve community health and well-being; combined impacts across multiple chemical and non-chemical stressors; multiple sources of stressors from the built, natural, and social environments; multiple exposure pathways across media; community vulnerability, sensitivity, adaptability, and resilience; exposures to stressors in the relevant past and future, especially during vulnerable lifestages; distribution of environmental burdens and benefits; individual variability and behaviors; health and well-being benefits/mitigating factors; uncertainty and variability associated with the data and information; and an approach for how to integrate data and information to assess cumulative impacts.

EPA's priority to promote the use of cumulative impact assessment across the Agency aligns with recommendations from the National Environmental Justice Advisory Council and the White House Environmental Justice Advisory Council that urge increased attention to the cumulative impacts of multiple chemical and non-chemical stressors on disadvantaged, underserved, and environmentally overburdened communities, including tribes (NEJAC, 2004, 2014; WHEJAC, 2021). Both Councils state the need to develop tools and methods to evaluate impacts to communities with environmental justice concerns, including characterizing risks before making environmental policy decisions. These recommendations also stress using a participatory approach in cumulative impact assessments by involving community members and other partners in all phases of the process. This requires cumulative impact assessments to be fit-for-purpose, conducted in the context of specific decisions at federal, state, and local levels.

The Cumulative Impacts Scoping Workgroup (Workgroup) was tasked to more fully understand how to grow ORD's existing cumulative impact research across the six National Research Programs to meet partners' needs in the context of ORD's FY23-FY26 research planning process. To that end, the Workgroup synthesized inputs from multiple engagement events with ORD partners both internal and external to the Agency. The engagements helped identify gaps and barriers to conducting and translating cumulative impacts research and formed the basis for the Workgroup's recommendations. Gaps relate to identification and characterization of both chemical and non-chemical stressors, methods to conduct analyses of cumulative impacts, and lack of high-resolution data. Barriers include missing skill sets and expertise in ORD; necessary partnerships with communities, tribes, and other governmental entities that require trust, resources, and/or agreements; and resource stability to plan and follow through on delivery of results. The resulting recommendations in this report fall into five broad categories:

1) **Establish the decision context and partner engagement –** Focuses on identifying partners, policies, and decisions that can be informed by cumulative impact assessment, establishing trust, and engaging with partners throughout the research process.
2) **Address scientific considerations for meeting partner needs –** Includes developing fit-for-purpose approaches to characterize assets, vulnerabilities, and overall cumulative impacts through holistic approaches that address exposures to the built, natural, and social environments (Total Environment Framework) and identifying potential intervention points.
3) **Empower local decisions and actions through science –** Calls on ORD to provide training and technical support on EPA methods and tools that support community solutions, and to develop best practices to use community-level and community-generated data in research and decision-making, consistent with EPA efforts.
4) **Support science translation and delivery –** To meet community needs, calls on ORD to translate approaches and results and increase usability and user-centered design for scientific tools and products.
5) **Provide research management support for cumulative impact assessment –** Recognizes that ORD needs to adapt to a new way of doing business by integrating cumulative impact research across National Research Programs through partnerships to advance the science to support decision-making, supporting data infrastructure and interoperability, developing the ORD workforce, and promoting a culture of community engagement.

This report is responsive to input from and reviews by partners both inside and outside the Agency. It represents ORD's commitment to develop an integrated cumulative impact research portfolio, in collaboration with others, to inform decision-making at all levels. Integrating cumulative impact assessment research into ORD's FY23-FY26 Strategic Research Action Plans will require ongoing support, coordination across National Research Programs, and collaboration with internal and external partners.

Introduction

On January 20, 2021, President Biden signed Executive Order (EO) 13985, titled "Advancing Racial Equity and Support for Underserved Communities Through the Federal Government" (EOP, 2021a). On January 27, 2021, President Biden signed EO 14008, titled "Tackling the Climate Crisis at Home and Abroad" (EOP, 2021b). These two EOs provide a framework for stimulating action across the federal government to address health disparities in the United States. The health disparities of particular interest to EPA are those caused or exacerbated by exposures to pollution and/or environmental degradation that are disproportionately borne by disadvantaged and overburdened individuals and communities. The EOs require federal action to reduce health inequities not just as single pollutant issues, but as systems challenges produced by the interaction of pollutants with economic, social, and policy drivers. President Biden's commitment to environmental justice was embraced by the Environmental Protection Agency (EPA) when Administrator Regan stated that "At EPA, we believe that every person in the United States has the right to clean air, clean water, and a healthier life — no matter how much money they have in their pockets, the color of their skin, or their zip code" (EPA, 2021a). The high priority given to advancing equity and environmental justice is evident in an Agency-wide directive to take steps to better serve historically marginalized individuals and communities (EPA, 2021c).

For EPA to fulfill its mission to protect human health and the environment, the Agency needs to address the cumulative impacts of exposure to multiple chemical[1] and non-chemical[2] stressors[3] using the best available science, as stated in EPA's 2022-2026 Strategic Plan (EPA, 2022b). The landmark environmental statutes EPA draws its authority from, including but not limited to the Clean Air Act, Comprehensive Environmental Response, Compensation, and Liability Act, Safe Drinking Water Act, and Toxic Substances Control Act (TSCA), have historically been implemented by evaluating the risks and effects associated with exposure to a single pollutant in a single exposure medium—or, in some cases, the risks associated with families of chemicals. Although in some instances the Agency has moved toward evaluating chemical mixtures, we recognize the need to expand beyond these initial efforts. The single

[1] Chemical stressors are defined as exogenous environmental compounds. Chemical stressors change or damage living organisms or ecosystems and are released into the environment by waste, emissions, pesticide use, or uses of formulated compounds like pharmaceuticals (Tulve et al., 2016).
[2] Non-chemical stressors are factors found in the built, natural, and social environments including physical factors such as noise, temperature, and humidity and psychosocial factors (e.g., poor diet, smoking, and illicit drug use) (Tulve et al., 2016).
[3] Stressors are defined as any physical, chemical, social, or biological entity that can induce a change (either positive or negative) in health, well-being, and quality of life (either now or into the future) (Tulve et al., 2016).

pollutant/single exposure paradigm is not well suited to the reality that individuals, communities, and tribes are exposed to numerous pollutants from a wide array of sources through multiple media and pathways over time. Additionally, these chemical stressors may interact with non-chemical stressors, including extreme weather events and climate change, to affect health and well-being. Chemical and non-chemical stressors aggregate and accumulate over time from one or more sources in the built, natural, and social environments, affecting individuals and communities in positive or negative ways. Solving longstanding, recalcitrant environmental health problems, including health disparities exacerbated by racial and social injustices, requires an accurate and realistic assessment of the effects from the combined exposures to chemical and non-chemical stressors (i.e., cumulative impacts) that inform decision-making at all levels. To support federal, state, tribal, and community decision-making, ORD must strengthen the scientific foundation for assessing cumulative exposures, impacts, and risks through existing and new methods, tools, data, and monitoring.

ORD's Cumulative Impacts Scoping Workgroup (Workgroup) was tasked with developing this report to provide ORD with a brief background on the history of cumulative impact assessment and gaps and barriers to conducting and translating cumulative impact research, and recommendations for developing science to advance the EPA Administrator's directive to incorporate cumulative impacts into Agency decisions. The Workgroup comprised EPA experts from ORD, the Office of Environmental Justice (OEJ), and regional office representatives for environmental justice and research. The Workgroup synthesized information from listening sessions and workshops that ORD held to gather input from across ORD, EPA program and regional offices, state and tribal governments, and community advocacy groups. A summary of the listening sessions and workshop can be found in Appendix A. The Workgroup used these inputs to identify research gaps and barriers to conducting research, as well as research recommendations for ORD to implement in its FY23-26 Strategic Research Action Plan, and beyond. This document incorporates revisions based on comments received from internal Agency review and consultation with the Science Advisory Board and the associated public comments.

Defining Cumulative Impacts and Cumulative Impact Assessment

The earliest known definition of cumulative impacts was published in the California Environmental Quality Act in 1970. Over the years, definitions of cumulative impacts and cumulative impact assessments have varied as they have been written into guidance documents and statutory authorities across state and federal agencies. In the interest of providing clarity and consistency to ORD's consideration of cumulative impacts across its research portfolio, the Workgroup reviewed several existing definitions. Below are the most relevant definitions that were considered:

- The California Environmental Quality Act of 1970 defines cumulative impacts as "two or more individual effects which, when considered together, are considerable or which compound or increase other environmental impacts...The cumulative impact from several projects is the change in the environment which results from the incremental impact of the project when added to other closely related past, present, and reasonably foreseeable probable future projects. Cumulative impacts can result from individually minor but collectively significant projects taking place over a period of time" (AEP, 2020; CALEPA, 2004).
- In 1978, the Council on Environmental Quality (CEQ) published implementing regulations for the 1969 National Environmental Policy Act (NEPA), which defined cumulative impacts as "the impact on the environment which results from the incremental impact of the action when added to other past, present, and reasonably foreseeable future actions regardless of what Agency (federal or non-federal) or person undertakes such other actions. Cumulative impacts can result from individually minor but collectively significant actions taking place over a period of time" (CEQ, 1978).[4]
- CEQ's definition of cumulative impacts was discussed in a 1999 guidance document titled "Consideration of Cumulative Impacts in EPA Review of NEPA Documents" (EPA, 1999). This guidance document states that "Cumulative impacts result when the effects of an action are added to or interact with other effects in a particular place and within a particular time. It is the combination of these effects, and any resulting environmental degradation, that should be the focus of cumulative impact analysis. While impacts can be differentiated by direct, indirect, and cumulative, the concept

[4] This definition is not currently in the 2020 regulations but is being considered by CEQ to reintroduce through a current Notice of Proposed Rule-making for the Phase I NEPA regulation revisions. federalregister.gov/documents/2021/10/07/2021-21867/national-environmental-policy-act-implementing-regulations-revisions

of cumulative impacts considers all disturbances since cumulative impacts result in the compounding of the effects of all actions over time."

- The California EPA developed the following definition in 2004: "Cumulative impacts means exposures, public health or environmental effects from the combined emissions and discharges in a geographic area, including environmental pollution from all sources, whether single or multi-media, routinely, accidentally, or otherwise released. Impacts will take into account sensitive populations and socio-economic factors, where applicable and to the extent data are available." (Cal/EPA, 2004).
- As a result of a 2017 workshop on environmental justice, the Minnesota Pollution Control Agency characterized cumulative impact analysis by describing each of the necessary elements of such an analysis. The posited elements of a cumulative impact analysis include sensitivity, additivity, multiple pathways, multiple sources, non-chemical stressors, and community vulnerability (MPCA, 2018).
- In its 2020 environmental justice law, the state of New Jersey defined cumulative impacts as "the environmental impact of the proposed new facility, or expansion of an existing facility, including any cumulative impacts on the burdened community, any adverse environmental effects that cannot be avoided should the permit be granted, and the public health impact on the burdened community of the proposed new facility or expansion of an existing facility" (NJ, 2020).
- Cumulative impacts are the total harm to human health that occurs from the combination of environmental burdens such as pollution and poor environmental conditions, pre-existing health conditions, and social factors such as access to quality healthcare (ATSDR, 2022).

EPA recognizes the linkage between the terms cumulative impact assessment and cumulative risk assessment. EPA's 2003 Framework for Cumulative Risk Assessment defines cumulative risk assessment as "An analysis, characterization, and possible quantification of the combined risks to human health or the environment from multiple agents or stressors" (EPA, 2003). A draft EPA Risk Assessment Forum document entitled "Guidelines for Cumulative Risk Assessment: Planning and Problem Formulation," updates the 1997 "Cumulative Risk Assessment Guidance on Planning and Scoping" and is undergoing review within EPA (EPA, 1997). We based our definitions of *cumulative impacts* and *cumulative impact assessment* on background research on these topics along with information learned through the workshops and listening sessions, internal discussions, and input from the Science Advisory Board. They incorporate the breadth of expertise that ORD can contribute, not just through human health research, but also through ecological and social sciences research to advance the science supporting cumulative impact assessment. These definitions are as follows:

Cumulative Impacts *are defined as the totality of exposures to combinations of chemical and non-chemical stressors and their effects on health*[5]*, well-being*[6]*, and quality of life*[7] *outcomes.*

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[5] The WHO defines health as "a state of complete physical, mental, and social well-being and not merely the absence of disease and infirmity."

[6] Human well-being can be described as the degree to which an individual, family or community can be characterized as being healthy, happy, and prosperous (Silva et al., 2018). The environment and ecosystem services are critical underpinnings of human well-being (MEA, 2005).

[7] Quality of life is defined by the WHO as "individuals' perception of their position in life in the context of the culture and value systems in which they live, and in relation to their goals, expectations, standards, and concerns." Quality of life is multidimensional, encompassing emotional, physical, material, and social well-being.

Cumulative impacts include contemporary exposures to multiple stressors as well as exposures throughout a person's lifetime. They are influenced by the distribution of stressors and encompass both direct and indirect effects to people through impacts on resources and the environment. Cumulative impacts can be considered in the context of individuals, geographically defined communities, or definable population groups. Cumulative impacts characterize the potential state of vulnerability or resilience of a community.

Cumulative Impact Assessment *is defined as a process of evaluating both quantitative and qualitative data representing cumulative impacts to inform a decision.*

Cumulative impact assessment requires a systematic approach to characterize the combined effects from exposures to both chemical and non-chemical stressors over time across the affected population group or community. It evaluates how stressors from the built, natural, and social environments affect groups of people in both positive and negative ways. The posited elements of a cumulative impact assessment include community role throughout the assessment, such as identifying problems and potential intervention decision points to improve community health and well-being; combined impacts across multiple chemical and non-chemical stressors; multiple sources of stressors from the built, natural, and social environments; multiple exposure pathways across media; community vulnerability, sensitivity, adaptability, and resilience; exposures to stressors in the relevant past and future, especially during vulnerable lifestages; distribution of environmental burdens and benefits; individual variability and behaviors; health and well-being benefits/mitigating factors; uncertainty and variability associated with the data and information; and approach for how to integrate data and information to assess cumulative impacts.

Cumulative impact assessments may use information supported by relationships among stressors, exposures, effects, and/or health, well-being, and quality of life outcomes for which cause-and-effect linkages may not be well understood. Fit-for-purpose assessments consider the extent to which specific types of uncertainty in causality between stressors and receptors can be tolerated. Unknown effects of co-exposures to non-chemical stressors are treated as risks, even if causal mechanisms are not fully understood, to protect against these unknowns.

Figure 1, adapted from Tulve et al., 2016, represents the complex interrelationships among components describing cumulative impacts. The linked and overlapping circles suggest that all components are multidirectional and interactive within the total environment. Health, well-being, and quality of life at each lifestage throughout the lifecourse are influenced by all other components (Silva et al., 2018; Tulve et al., 2016; WHO, 1948). Chemical and non-chemical stressors can come from the built[8], natural[9], and social environments[10], collectively referred to as the total environment. Additionally, activities and behaviors and lifestyle considerations, as well as systems biology (inherent characteristics to include genetic and epigenetic considerations), interact with the stressors to influence health, well-being, and quality of life. Figure 1 also shows that both factors we control *and* don't control should be considered

[8] The built environment refers to the manmade surroundings that provide the setting for human activity (Tulve et al., 2016).

[9] The natural environment encompasses all living and non-living things naturally occurring on Earth (Tulve et al., 2016).

[10] The social environment includes not only social interactions but factors such as the economy, community, home, school/daycare, demographics, safety, and welfare (Tulve et al., 2016).

in understanding how cumulative impacts influence health, well-being, and quality of life at the individual, geographically defined community, or definable population group levels.

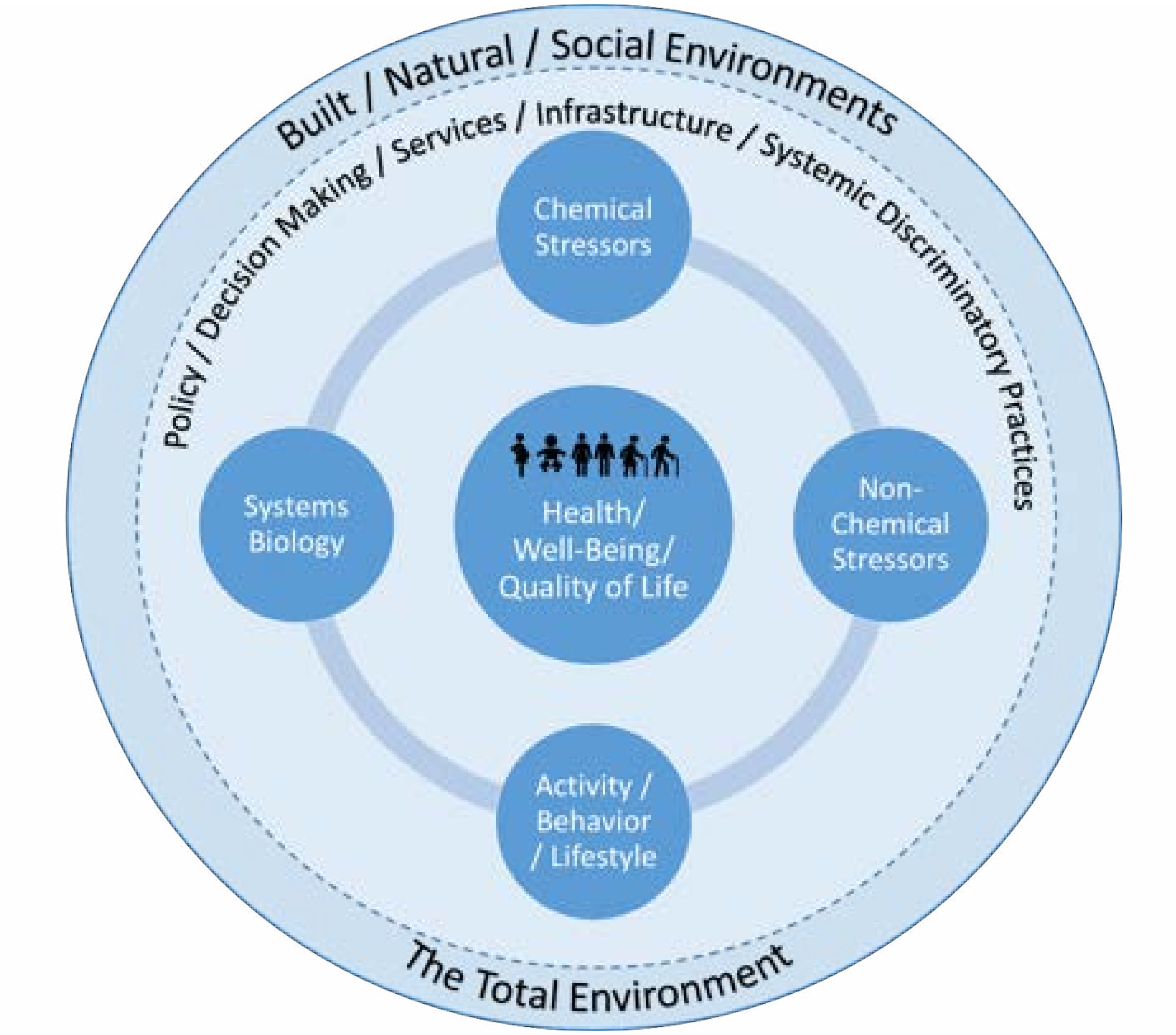


Figure 1. Combined influences on the total (built, natural, social) environment for individuals, geographically defined communities, or definable population groups.

There is substantial empirical evidence that elucidates how pollution, climate, and other environmental stressors, socioeconomic disadvantage, lack of environmental assets, and health vulnerability tend to be clustered spatially in patterns which are described as recurrent, persistent, and systematic in nature (Bullard et al., 2008; Chakraborty, 2001; Chakraborty et al., 2011; Lerner, 2012; Morello-Frosch & Jesdale, 2006; Morello-Frosch et al., 2011; O'Neill et al., 2003; UCC, 1987). This literature speaks to the connections between spatial concentrations of environmental burdens and benefits, their distribution in society, and the resultant health disparities which continue over generations. This literature is supplemented by emerging evidence about how structural drivers of inequity are associated with current environmental conditions and health disparities (Hoffman et al., 2020; Lane et al., 2022;

Richardson et al., 2020). Examples that underscore these observations are studies that demonstrate the association between the 1930's practice of redlining and the current location of urban heat islands, air pollution levels, and health disparities. Better understanding these relationships is important for informing approaches toward community engagement, collaborations among affected communities, government agencies and other stakeholders, and ultimately, health interventions and policy choices.

While the content of this report is largely focused on research to support cumulative impact assessment for the Agency's equity and environmental justice goals, the study and assessment of cumulative impacts is not necessarily bound to the identification and alleviation of environmental health disparities. A parallel framework that could be used to consider cumulative impacts is the exposome, which "encompasses life-course environmental exposures (including lifestyle factors), from the prenatal period onwards" (Wild, 2005). This term seeks to frame the connection between environmental exposures and genetics and has gained traction in recent years as a way of taking a more holistic view of the causes of one's health. In fact, some definitions of the exposome concept, such as Miller and Jones' 2014 definition as "the cumulative measure of environmental influences and associated biological responses throughout the lifespan, including exposures from the environment, diet, behavior, and endogenous processes," are quite similar to the definition of cumulative impacts laid out earlier in this section (Miller & Jones, 2014).

The exposome has historically been oriented toward understanding cumulative exposures to chemical and non-chemical stressors for precision medicine as is now being considered for public health (Martin-Sanchez et al., 2020). The terminology developed and applied in this report is responsive to the need to identify cumulative health and well-being effects from combinations of chemical and non-chemical stressors and potential interventions to support Agency actions needed to alleviate these effects.

Background and Context

EPA has identified cumulative impact assessment as one means to address environmental injustice. As such, ORD has committed to develop scientific approaches, data, methods, tools, and analyses to support regulatory, permitting, equitable development, compliance monitoring and enforcement activities, and other decisions and actions. This science must be translated to facilitate the explicit inclusion of cumulative impacts in decision-making to achieve EPA's priority of equitable outcomes across communities.

Applying a cumulative impact assessment approach to risk-based decision-making is a natural evolution of existing EPA risk assessment methods that have been developed and expanded over time. As more data on chemical interactions, multiple modes of action, and adverse outcome pathways have become available, EPA has started to move beyond single chemical risk assessments to conduct multi-chemical and cumulative risk assessments (EPA, 2003). For example, EPA has done cumulative risk assessments on pesticides under the 1996 Food Quality Protection Act and disinfection byproducts under the Safe Drinking Water Act (Sexton, 2012). This expansion now includes co-exposures to social determinants of health, making cumulative impact assessment a logical evolution toward a more holistic approach for evaluating risks associated with exposures to chemical and non-chemical stressors from the built, natural, and social environments (Alves et al*.*, 2012; Gallagher et al*.*, 2015; PAHO, 2013).

Cumulative impacts can be experienced by individuals, geographically defined communities, or definable population groups. EPA's focus under the current Administration is on those who experience disproportionate environmental burdens resulting from persistent and systematic recurrence of chemical and non-chemical stressors. EPA's priority to promote cumulative impact assessment across the Agency aligns with recommendations from the National Environmental Justice Advisory Council and the White House Environmental Justice Advisory Council (NEJAC, 2004, 2014; WHEJAC, 2021). These recommendations focus on considering disadvantaged communities, tribes, and their members, with increased attention to the cumulative impacts of multiple chemical and non-chemical stressors. They also emphasize the participatory nature of cumulative impact assessments by engaging the communities in all phases of the process including planning, performance, interpretation, and implementation of the assessment findings. The recommendations also discuss the need for developing tools and methods to better evaluate impacts to communities with environmental justice concerns. The Workgroup considered the NEJAC and WHEJAC recommendations when developing the recommendations found in this report. Relevant NEJAC and WHEJAC recommendations can be found in Appendix B.

Input from EPA program, regional, state, tribal, and community partners has consistently emphasized that cumulative impact assessments should be conducted in the context of specific decisions. EPA, for example, has reviewed and identified several of its legal authorities where environmental justice can be considered[11] (EPA, 2011, 2022a) and several states and municipalities have either adopted or are in the process of adopting policies where cumulative impact assessment is required (see for example the CA 2015 Senate Bill 673, the MA 2022 Draft Cumulative Impact Analysis (CIA) Framework for Air Permits, NJ's 2020 Environmental Justice Law and 2022 Proposed Rule, and Chicago's 2022 Cumulative Impact Ordinance) (Coleman, 2021; DTSC, 2021; MassDEP, 2021; NJDEP, 2021b). Cumulative impact assessment can be, and has been, used to inform decisions across multiple scales. Decision contexts span from local land-use and zoning decisions to national regulatory, permitting and enforcement actions, and can be used for different purposes from awareness and education to regulation and policy, likely requiring differing levels of rigor and complexity. Figure 2 provides examples of decisions across local, state, federal, and tribal scales and demonstrates the interrelationships that exist between them. In some cases, these relationships may be direct and specific in that federal decisions (e.g., setting a NAAQS standard) influence state decisions (e.g., air permits), and both in turn influence local decisions (e.g., energy efficiency programs). In other cases, these relationships are more complex.

Several approaches exist for considering cumulative impacts and incorporating stakeholder priorities into decision-making. For example, Health Impact Assessment (HIA) is one approach to engage stakeholders affected by a decision and to assess the environmental health consequences of decision alternatives on the community (EPA, 2021a). Building on this and other decision-making approaches like the traditional risk assessment paradigm, we developed a broad categorical approach for how to support cumulative impact assessment. This approach includes establishing the decision context, addressing the scientific considerations for meeting partners' needs (e.g., selecting the appropriate methods, tools, and associated data), and engaging and involving the community in each phase of the process to incorporate their knowledge and translate scientific results in a way that empowers them to take action. We used these categories to organize the research recommendations at the end of this report.

[11] In addition, OGC is finalizing a Cumulative Impacts Addendum to "EPA Legal Tools to Advance Environmental Justice" that will be published at epa.gov/ogc/epa-legal-tools-advance-environmental-justice.

Federal Rulemaking and Enforcement

EPA sets primary National Ambient Air Quality Standards to protect public health with an adequate margin of safety. As part of the rulemaking process, EPA develops an integrated science assessment (ISA) to synthesize the scientific evidence to inform the decision. The recent PM2.5 SA examines the influence of non-chemical stressors (e.g., race, income) on exposure and health and finds that minorities, particularly Black populations, are at increased risk for PM2.5-related health effects, in part due to disparities in exposure (EPA, 2019b, 2022c).

State Permitting

The state of New Jersey's Environmental Justice Law mandates denial of permits for eight types of sources if "an environmental justice (EJ) analysis determines a new facility will have a disproportionately negative impact on overburdened communities." The EJ analysis would consider several environmental and public health stressors from existing and potential future conditions and compare them to a reference geography (NJDEP, 2021b).

Local Planning and Land Use Decisions

Combined sewer overflows degraded water quality in the Proctor Creek neighborhood of Atlanta. The city proposed green infrastructure to address the issues and needed to determine the design and scope of the project. The community had several concerns (including social vulnerability, water quality, flooding and property damage, and heat islands), that were considered in the final decision (EPA, 2015).

Tribal

The sustainable flow of natural resources and ecological services is required to meet nutritional, cultural, societal, and economic needs of Tribal communities. For the Colorado River Indian Tribes and the Chemehuevi Indian Tribe, staple fish were at risk from poor water quality and harmful algal blooms (HABs). Tribes, working with EPA, implemented floating vegetation islands (FVIs; platforms that hold plants so roots can grow into the water) and evaluated their effectiveness to remove nutrients in the water. They used Tribal Traditional Ecological Knowledge (TEK) to identify culturally relevant and native species known to absorb more nutrients to help develop and serve as leading indicators of ecosystem function. These indicators can help track effectiveness of management practices for reducing HABs, improving water quality, and preserving fish populations vital for health, wellbeing, and quality of life (Hall et al., 2020).

Figure 2. Example Decision Contexts for Cumulative Impact Assessment

Because cumulative impacts will be used as the starting point or as a critical factor in a broad range of decisions, cumulative impact assessments will require different methods and approaches targeted to the specific decisions. Lee (2021) posited a fit-for-purpose continuum of approaches to integrate disproportionate impact analyses into decision-making, in which the type, scale, and quantification of analyses are driven by the decision context itself. It is also important to recognize that there may be multiple decisions or authorities needed to address impacts that have accumulated over time from a multitude of decisions. The decision landscape and associated authorities may influence the desired scope of the cumulative impact assessment. This highlights the importance of working closely with partners to understand the decision context(s) and develop and apply fit-for-purpose approaches and potential solutions. Some questions to consider in the development of a cumulative impact assessment can include the following:

- *What is the baseline condition for the identified population/community? This should include socioeconomic, environmental, and health data as available, including information on pre-existing vulnerabilities and historical exposures.*
- *What are racial/ethnic and income gaps in the baseline environmental/health condition (e.g., concentration, exposures, or incidence) that need to be addressed?*
- *What are the responsible stressors, their sources, and exposures?*
- *How are baseline conditions and stressors projected to change in the future?*

Additionally, cumulative impact assessments can address other questions such as the following:

- *What are the impacts (positive or negative) of the decision?*
- *Does the decision increase or decrease identified racial/ethnic and income gaps in health and environmental impacts/risks? If so, how much?*
- *Who was or is engaged in developing this intervention(s)?*
- *Does the intervention address the highest priority needs of the community(ies) within the decisionmaker's purview?*
- *What important sources, exposures, stressors, or impacts cannot be addressed through this intervention(s)? Are there opportunities to partner with others to address these additional concerns?*
- *How do we evaluate progress of the intervention(s) toward improving health conditions in disproportionately affected populations?*

Other factors in conducting a cumulative impact assessment include the need to consider changing baseline conditions and uncertainty analysis. Changing environmental conditions, such as climate change, affect the totality of exposures and their effects, either directly or indirectly, and must be considered as part of a cumulative impact assessment. Characterizing and conducting uncertainty analyses to the extent possible is also critical because failure to do so could hinder the correct interpretation of results that feed into decision-making processes. There are quantitative and qualitative methods and approaches to incorporate uncertainty and variability throughout analyses. See for example, Chapter 8 in the EPA Guidelines for Human Exposure Assessment (EPA, 2019a).

Current ORD Research

This section provides an overview of past and ongoing research related to cumulative impact assessments across ORD's six National Research Programs (NRPs). While not all research described below explicitly uses the terminology in this report, it represents a cross-section of work done on topics including multi-pollutant mixtures, social determinants of health, and development of assessment methods. This section also provides a high-level overview of the directions each research program is taking over the next four years (FY23-26). These research directions have been informed by this report.

Air, Climate, and Energy

One objective of the Air, Climate, and Energy (ACE) NRP is to assess human and ecosystem exposures and the effects associated with air pollutants at different scales, from individual to regional to global. This objective is underpinned by one of EPA's primary responsibilities under the Clean Air Act, which is to set, periodically review, and, when appropriate, revise the National Ambient Air Quality Standards (NAAQS) for a set of six pollutants (ozone, carbon monoxide, nitrogen dioxide, sulfur dioxide, particulate matter, and lead) commonly found in outdoor air and considered harmful to public health and the environment.

While the air pollutants controlled through the NAAQS are generally regional in scale, ACE also assesses the effects of air toxics—those designated as hazardous air pollutants because they are known or suspected to cause cancer or other serious health effects, as well as other pollutants of emerging concern—that are more likely to be felt on a local scale. Emissions of these pollutants tend to be linked to nearby sources and often these sources, such as ports, railyards, industrial facilities, and agricultural operations, are proximate to communities. Under the Clean Air Act, another EPA responsibility is to regulate emissions from large industrial sources through both technology-based and risk-based reviews, which must consider whether the level of emissions is sufficient to protect public health with an ample margin of safety, as well as through the operating permits program, which sets emissions limits. However, while each individual source may be operating according to set limits, communities may be exposed to smaller amounts of pollution from multiple sources simultaneously and with varying durations of exposure. This is a complex exposure environment that often has other complicating factors (e.g., socioeconomic) that can affect the impacts of the exposures.

Recognizing that exposures can be complex, ACE research evaluates the health and ecological effects of exposures to individual pollutants and multi-pollutant mixtures, including both regional criteria pollutants and local air toxics, as well as how the impacts of these exposures can be modified by co-exposures to other pollutants or non-chemical stressors (e.g., extreme temperatures, noise, social factors). In addition, ACE research investigates exposure durations, including the possible cumulative effects of multiple short-term exposures.

ACE recognizes that factors (e.g., lifestage, diet, pre-existing disease, genetics/epigenetics, and socioeconomics) that put people or ecosystems at risk from exposure to air pollution must be considered to fully assess impacts, inform air quality management decisions, and target risk communication strategies to reduce exposures to and risks from air pollution. Past ACE research has studied potential confounding and exposure measurement error in air pollution epidemiological studies to clarify the effects of selected pollutants within a mixture of air pollutants and has aimed for integrated approaches—incorporating evidence from epidemiological, human clinical, and toxicological studies—to improve our understanding of the biological mechanisms that impact susceptibility and key exposure factors (Ward-Caviness, Pu*,* et al*.*, 2020; Weitekamp et al*.*, 2020).

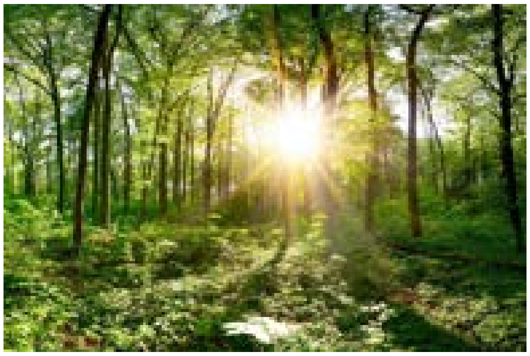
Some populations and lifestages are at greater risk for health effects from air pollution due to combinations with climate change and other environmental exposures, as well as socioeconomic characteristics (e.g., neighborhood characteristics, education, and income) that contribute to health disparities. An ACE Output "Climate change, air pollution, and cumulative impacts on human health" will evaluate the cumulative effects and impacts of air pollution in combinations with other stressors (e.g., climate change-related, psychosocial) over acute, intermittent, and chronic exposure durations. Another ACE Output "Longer-term impacts of climate change on human health at local, regional, national, and international scales" will consider the impacts of ongoing housing inequalities on health disparities and cumulative stressors.

ACE supports more temporally- and spatially-resolved estimates of individual and population exposures, including for at-risk groups and communities with environmental justice concerns, and accounting for time spent indoors in its Output "Modeling exposure to air pollution." Another ACE Output "Methods to measure personal and community level exposures to air pollution" will characterize the relationships between non-chemical stressors (i.e., social, cultural, and economic factors) and individual or community exposures to air pollution, and climate change related factors (e.g., temperature, humidity) that modify the relationship between ambient concentrations and individual or community exposures.

Providing information and evaluating strategies that can help reduce exposures to stressors (e.g., pollution, heat) is also a research focus. Using a systems approach, ACE research assesses interventions and interactions that can improve public health, benefit the climate, and promote equity. An ACE Output "Quantifying benefits of reducing air pollution and emissions of climate forcers" will examine the potential impacts of urban green infrastructure on local-scale air quality, heat islands, carbon capture, stormwater management, and other ecosystem services.

Chemical Safety for Sustainability

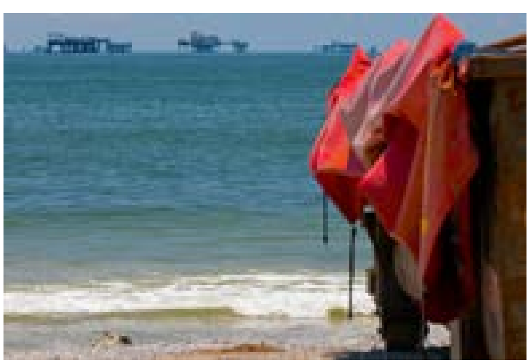
The Chemical Safety for Sustainability (CSS) NRP has been historically focused on chemicals and chemical mixtures research. Advancing research to inform cumulative impact assessments will be integrated throughout the CSS portfolio. While the focus of the CSS program is on research to evaluate health and environmental outcomes as a result of exposure to chemical stressors, addressing real-world exposures requires inclusion of both chemical and non-chemical stressors as important components of cumulative impact assessments. As such, CSS research will include a focus on chemical mixtures that may include research on exposure to and toxicity of chemical mixtures; non-targeted analysis methods to characterize mixtures of unknown composition as well as co-exposures to real-world mixtures; characterization of exposure to include investigation into social determinants of health and how non-chemical stressors combined with chemical stressors may impact health outcomes; and efforts to evaluate health disparities that may arise from unequal exposures to chemicals, including impacts from climate change and inequitable social and economic conditions. Research to support cumulative impact assessments will be coordinated across other NRPs (e.g., with the Sustainable and Health Communities NRP on non-chemical stressors and with Health and Environmental Risk Assessment NRP on chemical mixtures).



Health and Environmental Risk Assessment

The Health and Environmental Risk Assessment (HERA) NRP has predominantly focused on single chemical assessments and a smaller number of assessments of chemical mixtures. HERA assessments of chemical mixtures such as dioxins, total petroleum hydrocarbons, and polycyclic aromatic hydrocarbons have advanced the application of chemical mixture approaches, including application of toxicity equivalence factors, relative potency factors, and hazard indexes (EPA, 1993, 2009, 2010). As the need for evaluating multimedia exposures that incorporate chemical and non-chemical stressor interactions has increased, the HERA program has focused research on cumulative risk assessment methods and practices (Gernes et al*.*, 2016).

As the need for assessment of cumulative impacts expands, HERA will continue to focus on advancements and evaluation of cumulative and mixtures risk assessment approaches and models through case studies and publications. HERA aims to evaluate chemical mixtures methods and improve the estimation of health risks following exposure to disparate stressors in the Output, "Advance the application and evaluation of cumulative risk assessment methodologies, including assessment of chemical mixtures." Within HERA science assessments, HERA seeks to expand the identification and consideration of data and literature on differential risk to chemical stressors as a function of more than one co-exposure leading to greater qualitative and quantitative estimation of susceptibility. Through formal evaluation of existing data pertaining to the potential for effect modification or interactions between stressors, assessments may consider the potential influence of multiple co-exposures on the target exposure-response relationship.



Homeland Security

Through its focus on resilience equity, the Homeland Security (HS) NRP will ensure that information and tools include the multitude of stressors impacting a community when used to support incident response. Resilience to an incident is directly influenced by the cumulative impacts of the incident and other stressors within a community. The Homeland Security Research Program's "Systems-based Decision-making" research area focuses on determination of the most effective and efficient response and recovery actions following a wide-area contamination incident or natural disaster. Systems-based information, methods, and tools support decision-makers who need to understand the interdependencies between the built and natural environments and associated impacts from the connected response and recovery actions.

The research area entitled "Communities, Resilience, and Remediation" investigates the intertwined social and environmental variables that affect community resilience and vulnerability to chemical, biological, and radiological incidents, and other disasters. This research assesses and addresses community needs and vulnerabilities to ensure equitable incident management during disaster response and recovery by analyzing community-specific cumulative impacts and social implications of environmental cleanup and identifying interventions to better address concerns. Work in this Research Area includes frameworks and resources for tracking and assessing the long-term social impacts of incident response and recovery. As EPA develops a cumulative impact assessment framework and methods, HS will look for opportunities to apply them in response and recovery to homeland security incidents.

Sustainable and Healthy Communities

The Sustainable and Healthy Communities (SHC) NRP portfolio takes a holistic view, considering the interactions between people and their surroundings or, more specifically, the relationship between the environment and human health and well-being. This starts at the site level, recognizing that contaminated sites include a mix of pollutants. Through remediation and restoration and/or redevelopment, these sites can become community assets, helping to revitalize communities and tribes. SHC's work in Sustainable Materials Management aims to reduce contamination through understanding landfill management and beneficial reuse of materials and developing tools and approaches to examine life cycle impacts of materials. This holistic way of thinking is consistent with an understanding of cumulative impacts. SHC research examines stressors from the built, natural, and social environments, including health benefits, such as the benefits that nature provides through ecosystem goods and services, and their impacts on human health and well-being. For example, the SHC Program collaborated with state and tribal partners to develop and use new and existing information and approaches within a Total Environment Framework that accounts for chemical and non-chemical stressors to address cumulative health impacts for vulnerable groups (Tulve et al., 2016). The SHC program also used Science to Achieve, or STAR grants to assess more life-long health impacts of chemical exposures, especially in the context of children's health (EPA, 2017, 2020).

With cumulative impacts being a high priority for this Administration, and one of the cross-cutting research themes for ORD's FY23-26 Strategic Research Action Plans, SHC will build on our cumulative impact research in all areas across our research portfolio. SHC has developed two specific research areas: "Benefits from Remediation, Restoration, and Revitalization," and "Cumulative Impacts and Community Resilience," where the majority of work will focus on cumulative impacts, community resilience, and community capacity—recognizing that equity and environmental justice are critical considerations for community resilience and that climate change interacts with other chemical and non-chemical stressors to amplify their impacts. SHC will emphasize development of tools and analytical methods for understanding and implementing measures and maps of assets and vulnerabilities to analyze changes in cumulative impacts, such as those resulting from policy interventions, and ultimately lead to better outcomes for communities. This NRP will develop the science to characterize and quantify select interrelationships between chemical and non-chemical stressors, and to build community capacity to support community-driven solutions to cumulative impacts for environmental justice. SHC will use the recommendations from this report to better address cumulative impacts from contamination, climate, and other chemical and non-chemical stressors on health and the environment to improve community resilience.

Safe and Sustainable Water Resources

The Safe and Sustainable Water Resources (SSWR) NRP is committed to robust research and scientific analyses to support innovative scientific and technological solutions that ensure clean water to equitably protect people's health and livelihood, protect and restore watersheds and aquatic ecosystems, and strengthen the economy. Through three interrelated topics—Watersheds, Nutrients and Harmful Algal Blooms (HABs), and Water Treatment and Infrastructure—SSWR's research carries specific near- and long-term goals designed to yield practical tools and solutions for ensuring sustainable and equitable water resources that adhere to the congressional mandates found in the Safe Drinking Water Act, the Clean Water Act, and other legislation.

SSWR plans to take a *One Health* approach to collaborative problem solving which recognizes the interconnection between people and ecosystems at local, regional, and national levels. For example, SSWR's chemical mixtures bioassay research supports the understanding and development of ambient water quality criteria critical to protecting aquatic ecosystems and human health. SSWR also develops tools and conducts risk management research on exposures to groups of regulated and unregulated contaminants in drinking water (e.g., disinfection byproducts, opportunistic pathogens, PFAS, and lead) to assess the impact of these stressors on health and well-being. These areas of research have been, and will continue to be, an SSWR focus with expansions to address these factors in the context of cumulative impacts to communities.

An example of a cumulative impact assessment is the coordinated Chesapeake Bay solutions-driven research effort across SSWR, ACE, and SHC. The effort will develop approaches and methods to restore, conserve, and monitor wetlands, tidal marshes, and sea grasses in a coastal community using natural and social science research methods and to evaluate the benefits of carbon sequestration and community engagement. This engagement with the community is being conducted through existing partnerships (e.g., NGOs and academia). Participatory science will be used to monitor and analyze potential water quality improvements that can lead to re-establishment of ecosystem services through natural infrastructure restoration activities. This effort will empower the community with knowledge and tools to build resilience to flooding, storm surge, coastline erosion, and habitat degradation. It is hoped that the results will not only create more resilient ecosystems but also improve human health, safety, and well-being.

Gaps and Barriers

Research Gaps

Research gaps were identified during ORD's listening sessions and workshops with multiple groups of partners and stakeholders. ORD will focus on these knowledge gaps and data areas to improve support for a robust research agenda to inform cumulative impact assessments.

Stressor Identification and Characterization

Although there is ongoing research on identifying and characterizing chemical and non-chemical stressors, research gaps remain. Stressor identification includes both chemical stressors, such as exposure to harmful pollutants; and non-chemical stressors, such as lack of access to healthcare or greenspace, systemic racism, and long-term impacts of exposure to violence. A variety of challenges may exist related to the characterization of these stressors, such as lack of data at the appropriate temporal or spatial scales, lack of knowledge of biomarkers to identify exposure to certain stressors, and variability in the impacts of stressor exposure at different lifestages throughout the lifecourse.

Identification and characterization of chemical and non-chemical stressors must go beyond single-stressor evaluations and ORD must be deliberate in its selection of combinations of stressors to study. By definition, cumulative impact assessment considers multiple stressors together to understand the effects of such combinations on health; however, the appropriate combinations of stressors to study must be prioritized. To illustrate, the state of New Jersey's environmental justice policy mandates the evaluation of 31 chemical and non-chemical stressors in its cumulative impact assessments but the number of combinations of stressors a single community can theoretically face is far beyond the capacity of any research enterprise (NJDEP, 2021a). Stressors selected for inclusion in an assessment may not be exhaustive in terms of representing the full range of impacts on a given community. Stressors may not be equally important, where risk or impact might ultimately be apportioned to a subset of stressors; and there can be interdependencies among stressors, implying the desirability of identifying indicators that represent independent sources of stress. Thus, the lack of information on how and why to prioritize certain combinations of stressors over others is a significant research gap. High-priority combinations of stressors must be studied to understand exposure pathways, biological responses, and the nature of stressor interactions and their connection to health outcomes.

The need for broader outcome measurements is also a gap in existing research. Addressing this gap requires consideration of impacts beyond health, such as well-being (including mental well-being) and quality of life. Quality of life includes outcomes more broadly associated with the location of environmental burdens and assets. For example, the siting of a facility may have detrimental impacts on property values, which leads to lower spending on local infrastructure (Affuso et al., 2010). Similarly, lack of assets in a community, such as greenspace, may limit social interactions and outdoor recreation. In each of these cases, outcomes could manifest as decreased community safety, transportation challenges, and decreased place-attachment (Markevych et al., 2017). All of these are important in the consideration of cumulative impacts, especially in communities and tribes with environmental justice concerns.

Not all stressors fall under the purview of EPA's regulatory mandates. While many chemical stressors do, many non-chemical stressors, such as access to medical care, family stress, or community violence, are not factors that can be regulated by EPA. However, because EPA actions and decisions to protect human health and the environment interact with or are affected by the cumulative impacts of both chemical and non-chemical stressors, both must be assessed to understand the full impact of a decision or action. This approach implies that cooperation across agencies often will be necessary to address disproportionate burdens in communities and tribes, though it will depend on the context.

Methods

New methods need to be developed to inform cumulative impact assessment. Specific examples are included here and led to the development of the broader points captured in the recommendations section. Specific needs include methods to do the following:

a. ***Combine quantitative and qualitative data on stressors to inform a cumulative impact assessment***. A vast array of mixed methods has been developed and applied in recent decades, particularly in the social science research. There are opportunities, however, for developing methods of mixing quantitative natural scientific data with qualitative social data, and for characterizing uncertainty more effectively when applying mixed methods.

b. ***Characterize the cumulative impacts of multiple decisions at once.*** Environmental decisions are rarely made in a vacuum. A new emissions permit, for example, can be issued in the same community in which another new emissions permit was recently issued, thus producing two new stressor sources in quick succession. Adding onto this, the full landscape of decisions in question often includes multiple decision-making authorities, such as permitting decisions alongside regulatory and community investment decisions. Cumulative impact assessments ought to capture the impacts of each of these decisions individually as well as the combined impacts, which may not simply be additive.

c. ***Develop, combine, and validate indicators for one or more health, well-being, and quality of life outcomes that provide relative or absolute measures of exposure or impact***. Many indicators exist as proxies for exposure or to estimate impacts, but methods of combining indicators to address the wide variety of decision contexts are still needed. One example of combined indicators is the Environmental Quality Index, which compiles data from "air, water, land, built, and sociodemographic environments to provide a county-by-county snapshot of overall environmental quality across the entire U.S." (Lobdell, 2014).

d. ***Develop best practices for identification and characterization of disproportionately impacted and overburdened communities***. The need for best practices is made clear by a recent study that identified a variety of criteria that can inform designations of communities with environmental justice concerns (Baptista, 2021).

e. ***Use biomarkers to identify exposures to multiple chemicals or impacts of chemical and non-chemical stressors***. Recent research supports the concept that lifetime exposures to chemical and non-chemical stressors produce biological susceptibility, and that this susceptibility can be further exacerbated by exposure to environmental chemicals (Geronimus *et al.*, 2015; Ward-Caviness, Russell*, et al.*, 2020). Additional research is needed to further identify biomarkers of exposure and bioindicators of vulnerability and cumulative impact.

f. ***Integrate multiple streams of data, including data from participatory science and traditional ecological knowledge***. Data collected through participatory science and traditional ecological knowledge often come with special obligations to maintain privacy rights and preserve data, while also presenting unique data quality and generalizability challenges. Efforts such as EPA's Participatory Science Vision will enable progress in these areas (EPA, 2022d).

g. ***Characterize health-benefiting assets of a community, such as measuring the benefits of green space and ecosystem services***. Characterizing community assets will call for the full estimation of cumulative impacts, rather than focusing exclusively on the health-harming effects of stressors.

h. ***Identify and account for historical stressor exposures in cumulative impact assessments***. Because disproportionate impacts are inexorably linked to historical stressor exposure, best practices for identifying and accounting for historical stressor exposures will be necessary for conducting cumulative impact assessments.

i. ***Evaluate the cumulative impacts/benefits of various types of interventions***. As policies addressing cumulative impacts continue to diffuse throughout the country, the value of intervention evaluation will increase, with greater emphasis on crafting and implementing well-targeted policies.

While many methods and approaches have been developed and applied to selected issues for specific contexts and are considered acceptable given contemporary scientific standards, the use of these methods and approaches for cumulative impact assessments needs scientific vetting in addition to understanding how they suit EPA's and other decision-makers' legal and regulatory requirements. The methodological gaps highlighted above are also highly integrated with the elements of a cumulative impact assessment.

Data

Significant data gaps exist that make cumulative impact assessments more difficult to conduct. Here, we focus on the lack of high-resolution spatial and temporal data, some of the ways those data gaps are beginning to be addressed, and the reliance on non-EPA data-collection sources (both environmental and socioeconomic) to inform cumulative impact assessments. The data deficiencies discussed below pose significant challenges to EPA's ability to conduct and translate cumulative impact assessments, as well as EPA's ability to build the scientific foundation for cumulative impact assessments in the first place. While many of these data gaps are not entirely unfamiliar to those who are active in community-engaged research and research on disproportionately impacted populations, ORD is uniquely positioned to address these gaps by integrating these lessons across its research programs.

Cumulative impact assessments to inform local and site-specific decisions often need environmental and socioeconomic data at high-resolution temporal and spatial scales, such as the census block or finer. The costs of monitoring equipment and the lack of data collection infrastructure make it challenging to collect reliable data at fine spatial and temporal scales. These challenges are experienced in urban areas, which often struggle to collect reliable monitoring data at hyperlocal levels, and in rural and tribal areas, which struggle to obtain and place affordable monitoring technologies in relatively remote locations. A variety of creative techniques have been developed over the years to fill data gaps in urban areas, such as using telephone pole-mounted monitors or even mounting monitors on backpacks, and in rural areas, such as using vehicle-mounted air quality monitors. Fine-scale data goes beyond spatial and temporal characteristics. There is also a significant need to produce data regarding individual and community lifestyles.

While macro-level data provides important insights into the scale and scope of chemical and pollution exposure issues, micro-level data on the types of products used by individuals and under what circumstances is often necessary to characterize exposure risks in the real world. For example, two recent publications combine data from EPA's Chemical and Products Database (CPDat), with individual product use data from The Nielsen Company to identify likely exposures to combinations of chemicals in frequently used household products and characterize health risks from such exposures (Carberry et al., 2022; Stanfield et al., 2021). Lastly, data on historical pollution exposures is sorely lacking, making it challenging to connect multiple exposures across time. EPA has several alternative ways of addressing the issues above, including modeling techniques and alternate data sources such as participatory science projects and qualitative data, yet incorporation of these data sources into cumulative impact analyses still needs scientific vetting. Decisions on which technologies and techniques best fill data gaps, such as the gaps mentioned above, should be informed by a combination of scientific standards, partner needs, and cost considerations.

Another data challenge relates to data collection and maintenance by non-EPA sources. A substantial amount of EPA's research is reliant on data collected and maintained by external institutions. This is a normal part of the research process and is necessary for EPA (and other research institutions) to go about its work. However, relying on data sources that are not immediately under the Agency's control brings with it some risks that should be accounted for. In some cases, long-standing data-collection services may change over the years and jeopardize the use of their data. Examples of other data challenges are changing census boundaries, requiring the use of interpolation techniques to enable certain cross-census analyses (Schroeder, 2017), and discontinuities in time series data, such as when a new measurement or analysis method is introduced (van den Brakel et al., 2020). Cases such as these require that EPA track and, when necessary, develop its own techniques for dealing with changes to data collection methods. In other cases, data collection programs may systematically fail to collect accurate measurements in contexts, locations, or populations of particular concern. For example, a recent study published by the Urban Institute estimated that Black and Hispanic Americans likely were the most undercounted racial and ethnic groups in the 2020 census (Elliott et al., 2021). Further, the major socio-demographic data collection efforts generally focus their efforts on residential populations, rather than on both residential populations and those same populations in the workforce. This disconnect hinders researchers' abilities to estimate exposures to stressors within individuals throughout the 24-hour day. Although these data collection efforts are out of EPA's control, systemic biases such as these may reduce the validity or utility of cumulative impact analyses, so special attention must be paid to asymmetric data collection accuracy across contexts, populations, and location.

Another important data gap includes sources of data that sit outside the traditional data collection methods employed by mainstream science. These include data collected through participatory science efforts and information developed and maintained through non-Western (i.e., indigenous) knowledge systems. Data gathered through participatory science efforts can be part of the solution for addressing the need for hyperlocal spatial and temporal data. EPA published its Vision for Participatory Science in June 2022, which seeks to "guide EPA on the use of participatory science in its programs to increase public engagement and understanding and to take actions to investigate and mitigate environmental problems" (EPA, 2022d). This vision identifies three goals for facilitating the adoption and integration of participatory science in decision-making, including (1) to develop relationships with communities; (2) to work with tribal nations to support the use of participatory science and traditional ecological knowledge; and (3) to work alongside communities to address environmental justice concerns through activities such as providing technical assistance, tools, and training to communities seeking to conduct participatory science.

These data challenges are also contingent upon the decision context in question. Many regulatory programs implemented by the EPA apply regulatory thresholds based on absolute values, while other programs, such as the state of New Jersey's environmental justice law, mandate action based on relative stressor levels (in that case, comparing stressor levels in one census block group versus others in the state). Further, certain decisions, such as many regulatory and permitting decisions, require specific data inputs to inform a decision, while others do not face such strict requirements. This suggests a need to collect and maintain data to fulfill these multiple needs.

Barriers to Conducting and Translating Research

The identified research gaps represent important opportunities for ORD to contribute to the existing body of knowledge on the science to support cumulative impact assessment. However, several barriers to conducting and translating this research have also been identified, including ORD workforce research expertise, partnerships, and resources and their stability. These are described in more detail in this section.

ORD Workforce Research Expertise

Adapting ORD's workforce research expertise will take time and can be considered a barrier to conducting cumulative impact research to meet immediate needs. The Workgroup identified insufficient skill sets and expertise in areas such as chemical mixtures, social sciences, and translational science. These limitations are being addressed through additional hiring, and through the recent establishment of an internal Agency-wide Social and Environmental Science Exchange (a community of practice of social scientists across EPA). However, actions such as these will only be effective if implemented under the auspices of a workforce strategy that is aligned with ORD's cumulative impact assessment research agenda. In addition to the skills gap, underrepresentation of researchers with real-world experiences related to overburdened communities and tribes may impair ORD's ability to engage and build trust with these communities. Research teams that lack racial, ethnic, and gender diversity are more likely to experience challenges when working with communities of diverse backgrounds because those teams may include not only a narrower range of perspectives to inform their work, but also an increased susceptibility to blind spots and implicit biases (Merriam et al., 2001; Muhammad et al., 2015). Federal executive action and EPA-wide policy announcements have made clear that hiring a diverse workforce is necessary to appropriately meet the needs of community and tribal partners (EOP, 2021b). Meeting these internal skills and diversity gaps will require a combination of hiring additional staff consistent with Agency scientific and diversity, equity, and inclusion priorities, and training existing staff in cultural sensitivity and other relevant skills.

Partnerships

Cumulative impact assessment can inform decisions in multiple contexts, including at the national, state, tribal, or local scale. Establishing partnerships with decision-making authorities and non-governmental organizations throughout the research process is critical to ensuring research is appropriately directed toward those who are responsible for making use of the body of knowledge. Coordination with partners on cumulative impact assessments is critical for success, but is often time and resource intensive, both in terms of establishing relationships and developing data-sharing agreements. Sensitivities surrounding data collection and data sharing are important factors in this type of work.

ORD researchers also need to consider the unique challenges and opportunities when engaging with tribal and community partners in the research process. First and foremost, trust must underpin any collaboration with communities and tribes. As we heard from the community panel of the Cumulative Impacts workshop, there may be historical barriers to gaining this trust, most notably failures of federal and state agencies to solve problems that have been endemic to such communities. Second, research conducted in collaboration with tribal and community partners may be challenged by institutional biases within scientific fields toward, for example, institutional review board practices that are not adaptable to community-based science, and a failure to recognize the sovereign status of tribes and their diverse cultural practices (Brown et al., 2010; Saxton et al., 2015). At the same time, collaboration with community and tribal partners creates opportunities to incorporate traditional ecological knowledge and values into research design, which will make research findings more relevant and actionable for tribal partners (Whyte, 2013).

Partnerships with universities and K-12 institutions are also an important aspect of fostering a diverse, well-qualified workforce. EPA's approach to university and pre-university capacity building has been through the establishment of partnerships with universities and Science, Technology, Engineering, and Mathematics (STEM) outreach programs at the K-12 level. But capacity-building does not end at the establishment of an MOU with a college or university or of a new STEM program. These partnerships and programs must be sufficiently resourced and supported to enable their full use, both in terms of staffing to these programs, as well as the follow-through with hiring and programmatic decisions that maximize the benefits of these relationships.

Finally, EPA is a federal institution responsible for building knowledge and improving public health across the Nation. ORD, working in partnership with program and regional partners, will engage intensively with communities and tribes when appropriate, but is constrained by limited resources. There are far more communities and tribes than EPA has the capacity to work with hand-in-hand. ORD will need to be deliberate in its selection of partners to facilitate research generalizability where possible and make inferences from that cumulative impact research to larger sets of communities and tribes across the Nation.

Resources and Their Stability

Most gaps and barriers are influenced by the availability of resources, both in the short- and long-term. Resource constraints take many forms. One reliable indicator of community-based participatory research is the long-term commitment of funding and resources to the planning and implementation of a project (Davis & Ramírez-Andreotta, 2021). This requires resources from ORD to both plan and follow through on research projects, but also stable resources from other Agency and community partners to ensure long-term project stability.

Recent evidence has indicated that conducting research at the community level can be more resource intensive than research that does not directly engage communities. Community-based research requires particular attention to the unique challenges a community faces, as well as a long-term commitment to ensure successful implementation (Davis & Ramírez-Andreotta, 2021). That being said, community-based research, if implemented correctly and sufficiently resourced, can produce results that are more rigorous, relevant, and have greater impact for the communities of interest (Balazs & Morello-Frosch, 2013).

Research planning should consider the risks of unstable resources across budget cycles. Most research projects require multiple years of sustained work, and failure to follow through on the research translation process will impair partner capabilities and undermine stakeholder relationships. Partnering with EPA groups—such as Superfund Community Involvement Coordinators or Regional EJ Coordinators, who have established trusting relationships with communities—will help with sustaining relationships in the long-term. In addition, project planning and implementation may need to look at other ways to carry out the research at reduced levels or under compressed timelines if resource levels are not sustained, such as modular or incremental approaches to carrying out the research and ensuring that there is sufficient internal capacity to deliver results to partners.

Research Recommendations

Building from the broad input we received from partners and stakeholders, including the identified gaps and barriers, the Workgroup developed a list of research recommendations. We solicited input through a number of activities and documents, including cumulative impact listening sessions with states and tribes; a Cumulative Impact Workshop; other ORD planning workshops, such as the Environmental Justice Research Workshop and the Community Capacity Research Workshop; ORD's consultation with the Board of Scientific Counselors (BOSC) in July 2021 on barriers to incorporating equity and environmental justice in research and community and citizen science; ORD's 2016 Environmental Justice Research Roadmap; from NEJAC and WHEJAC recommendations (EPA, 2016, 2021b); and from SAB consultation and public comments.

Cumulative impact assessment should be developed and applied with a bias for action[12], which entails finding solutions that improve the health and well-being of a community. These recommendations include ideas from the broader Agency Equity Team conversations on this topic (e.g., decision framework, technical support) and identify timeframes for the recommendations based on the Workgroup's understanding of partner needs and priorities in conjunction with ORD capabilities. We have also deliberately included recommendations that span ORD's six National Research Programs, recognizing this issue will take a whole of ORD approach. Toward this broad goal, the recommendations fall into five categories, which are shown in Figure 3 and described below:

1) Establish decision context and partner engagement.
2) Address scientific considerations for meeting partner needs.
3) Empower local decisions and actions through science.
4) Support science translation and delivery.
5) Provide research management support for cumulative impact assessment.

These categories emphasize the importance of the decision context and embed the scientific research within that broader context, including up-front engagement with stakeholders through ensuring science research within that broader context, including up-front engagement with stakeholders through ensuring science translation and delivery responsive to needs. A summary of these categories is below, followed by the recommendations themselves. The report and recommendations have been reviewed by ORD's Executive Council and by EPA program and regional office partners.

[12] NEJAC's 2004 report on Ensuring Risk Reduction in Communities with Multiple Stressors: Environmental Justice and Cumulative Risks/Impacts, discusses the concept of a "bias for action," defining it as scientific approaches that are combined with other key strategies to make a meaningful difference in the health of impacted partners (NEJAC, 2004).

Figure 3. Recommendations for Research to Support Cumulative Impact Assessments.

Establish the Decision Context and Partner Engagement: These recommendations focus on identifying partners, policies, and decisions that cumulative impact assessment can inform, establishing trust with partners, and engaging with them throughout the research process. ORD will work with program and regional offices across EPA to integrate research with partners' policy and decision needs. Since these recommendations form the foundation for recommendations in the categories below, most need to be addressed immediately.

Address Scientific Considerations for Meeting Partner Needs: Recommendations in this category include developing fit-for-purpose approaches to characterize assets[13], vulnerabilities, and overall cumulative impacts through incorporating holistic approaches that address exposures to chemical and non-chemical stressors from the built, natural, and social environments (e.g., Total Environment Framework); and identifying potential intervention points. In addition to the stressors just mentioned, cumulative impacts include historical and concurrent pollution exposure, and the burden of environmentally linked disease.

Examples of existing tools that could be adapted for this purpose include EnviroAtlas, Environmental Quality Index (EQI), the Risk Screening Environmental Indicators (RSEI) model, and the Environmental Justice Screening and Mapping tool (EJSCREEN). Methods include HIA, DNA/epigenetic measures of

[13] ORD defines assets as those natural, social, and economic resources that increase community resilience and well-being and are important to protect and grow.

cumulative exposure, Adverse Outcome Pathway networks, Toxicity Equivalence Factors, differential risk/dose response, and hazard indices (semiquantitative).

Empower Local Decisions and Actions Through Science: These recommendations provide solutions through training and technical support infrastructure around EPA methods and tools. They also include support for community-generated data and information for use in cumulative impact assessments. These recommendations tie into larger EPA efforts to increase the use of participatory science in research and decision-making. Existing examples specific to these recommendations are expansion of work already done on low-cost air sensors, equipment advances to measure cumulative exposures, and predictive modeling for exposures.

Support Science Translation and Delivery: These recommendations include translating approaches and results and increasing usability and user-centered design for scientific tools and products to meet community needs. Communications, outreach, and projects that focus on increasing community capacity and expanding Solutions Driven Research are specific examples that address this group of recommendations (Maxwell et al., 2019).

Provide Research Management Support for Cumulative Impact Assessment: These recommendations recognize that ORD needs to adapt to a new way of doing business. Coordination on cumulative impacts research across national research programs is essential for ORD to make a marked advancement in the science to support decision-making, including data infrastructure and interoperability, recruitment and workforce development, and partnerships and community engagement.

More detailed recommendations within each category are presented in the numbered list below. The timing of the research need (see Box) is indicated for each recommendation. This timing is based on a combination of our ability to address the recommendation in the short-term as well as the urgency of the need. It does not indicate that long-term recommendations are of lower importance. These recommendations, if followed, will provide the scientific underpinnings needed to support defensible decisions that EPA program and regional offices and communities make.

- **Immediate (I):** Highest priority, should start as soon as possible
- **Short-term (ST):** Begin within the time frame of FY23-26 ORD Strategic Research Action Plans (StRAPs)
- **Long-term (LT):** Begin beyond the time frame of FY23-26 ORD StRAPs

Establish the Decision Context and Partner Engagement

1. Identify the breadth of partners, policies, decisions, and tools that cumulative impact assessment can inform at the federal, state, tribal, and local levels. (I, ST)
   a. Summarize current strategies, available data and tools, and promising practices that account for cumulative impacts in analytical and decision-making frameworks, such as rulemaking, permitting, and enforcement, including existing approaches at the state, tribal, and local levels. (I)
   b. Contribute to the cross-EPA effort to develop a framework of cumulative impact decision contexts through mapping science needs with decision contexts in a fit-for-purpose manner that can contribute to cumulative impact solutions. (I)

c. Provide technical support to program and regional offices, as requested, on cumulative impact assessment implementation at the Agency. (I)

2. Engage with Agency programs and regions and external stakeholders to translate research into action. (I, ST, and LT)
   a. Identify and employ best practices for community engagement, particularly in disproportionately impacted and overburdened communities. (I, ST, and LT)
   b. Collaborate with EPA programs and regions and external stakeholders to assist in meeting cumulative impact science needs. (I, ST, and LT)

3. Provide a foundation of trust by operating to "do no harm," working in true partnership with communities and communicating how ORD research can benefit them. (I, ST, and LT)
   a. Invest in developing long-term relationships with communities directly through collaboration with EPA program and regional offices, other federal agencies, and through academic or boundary organizations, such as local health departments or NGOs. (I, ST, and LT)
   b. Explore the potential ethical implications of innovative research that may identify differential health impacts for certain categories of people to inform the development of ethics guidelines. (I)

Address Scientific Considerations for Meeting Partner Needs

1. Develop fit-for-purpose approaches to quantify assets, vulnerabilities, and net environmental health burdens in communities for use in environmental decision-making. (I, ST, and LT)
   a. Develop standardized approaches for specific decision contexts to define and identify disproportionately impacted and overburdened communities, considering thresholds of concern. (ST)
   b. Identify and differentiate chemical stressors and their sources. (ST and LT)
   c. Evaluate the applicability of EPA tools and/or community-used tools for cumulative impact assessments to support decision-making, including approaches to assess and evaluate potential interventions. (I and ST)
   d. Develop, apply, and refine methods, tools, and approaches to document the state-of-the-science for different decision contexts to advance the use of cumulative impact assessment in these decision contexts. (ST and LT)
   e. Explore the use of both qualitative and quantitative data and information to estimate cumulative impacts that capture local and traditional ecological knowledge, other key unquantifiable factors, or community and citizen science projects. (ST and LT)
   f. Conduct research to account for systemic racism in cumulative impact assessment; explore the causal roots of environmental health disparities, including place-based factors such as historical federal, state, and local policies, and apply robust measures of exposure to societal stress. (LT)
   g. Develop and apply economic methodologies, such as non-market valuation, to measure the economic impacts of stressors and health burdens and assess the distribution of these damages. (LT)
   h. Include consideration of trade-offs or shifts in the burden of pollution across time or space. (ST and LT)

    i. Develop and apply methods to characterize uncertainty in assessments where causality is not known or where decisions must be robust to uncertain future outcomes. (I, ST, and LT)

2. Incorporate holistic approaches into EPA research to characterize cumulative exposures more fully to stressors from the built, natural, and social environments over one's lifetime and how exposures to these stressors can be modified by interventions. (ST and LT)
    a. Identify data gaps and collect data that includes information on experiences of racism, social and economic stress, and marginalization. (ST and LT)
    b. Develop methods to incorporate human mobility and migration data and related exposure information into cumulative impact assessments. (LT)
    c. Analyze the effect of ecological changes from development, pollution, natural disasters and extreme weather events, and climate change, in combination with other chemical and non-chemical stressors, on human health and well-being. (ST and LT)
    d. Explore surrogate non-chemical stressors (e.g., race) as an indicator of total vulnerability at the community level. (ST and LT)
    e. Partner with other agencies and institutions to develop long-term prospective cohorts and longitudinal data as well as continuous monitoring data across the Nation. (ST and LT)
    f. Develop, advance, and evaluate methods and models for estimating exposures and risks to chemical mixtures and their interactions with non-chemical stressors. Expand the identification and consideration of data and literature on differential risk to chemical stressors as a function of more than one co-exposure in science assessments. (ST and LT)

3. Identify, characterize, and evaluate environmental health disparities and well-being impacts most prevalent in disproportionately impacted and overburdened communities and identify potential intervention points. (ST and LT)
    a. Generate needed data related to human health effects research on chemical mixtures and quantify hazard indices for multiple endpoints in chemical dose-response assessments. (ST and LT)
    b. Address interactions of chemical and non-chemical stressors through methods such as (early) biomarkers of exposure, effect, vulnerability, and disease onset. (I, ST, and LT)
    c. Explore the applicability of using novel approaches for understanding health disparities in disproportionately impacted and overburdened communities, making sure to distinguish urban, ex-urban and rural stressors and urban, ex-urban and rural designations of vulnerable populations. (ST and LT)
    d. Explore contributions of a multimedia exposure approach, epidemiological approach, and toxicological approach for decision contexts using cumulative impact assessment and identify opportunities in which these approaches are complementary. (ST)
    e. Develop new or select existing indicators to track progress of interventions on health and well-being outcomes related to regulated pollutants. (LT)

4. Evaluate the impacts of policies and interventions aimed at both reducing vulnerability and increasing benefits to the environment and disproportionately impacted and overburdened communities from combined exposures to both chemical and non-chemical stressors. (ST and LT)

Empower Local Decisions and Actions through Science

1. Identify and address gaps and barriers for conducting effective community engagement. (I and ST)

2. Help communities understand and manage cumulative impacts by going beyond problem identification to help them identify solutions through providing access to data, making it transparent, providing resources and how to use them, and providing technical support. (I, ST, and LT)

3. Support fit-for-purpose use of community-generated data and information in cumulative impact assessments for decision-making. (ST and LT)
   a. Work with partners and stakeholders to gather and use community and citizen science in cumulative impact assessments. (ST and LT)
   b. Develop and apply tools and best practices to use community-generated measurements and scientific results in environmental decision-making that are commensurate with the decision context and are beneficial to community outcomes. (ST and LT)

4. Provide training and technical support infrastructure around EPA methods, guidance for best practices, and tools for cumulative exposure assessment. (I, ST, and LT)

Support Science Translation and Delivery

1. Apply cumulative impact assessment with a bias for action, which entails quickly finding and delivering solutions that improve the health and well-being of a community. (I, ST, and LT)

2. Characterize, assess, and convey uncertainties in assessing cumulative impacts in a way that educates, informs, and supports decisions. (I, ST, and LT)

3. Translate ORD community-based research approaches and results across geographic and social/political/environmental contexts and scales. (ST and LT)

4. Increase usability and user-focused (human-centered) design of scientific tools, products, and communication methods. Identify standardized data summaries/interpretations that can be reported to community stakeholders even if they lack resources and time to work with a tool themselves, thereby supporting uptake of information into decision-making. (ST and LT)

Provide Research Management Support for Cumulative Impact Assessment

1. Design and implement methods to facilitate integration of cumulative impact research into ORD's National Research Programs and Centers to meet partner needs and evaluate ORD's success in accomplishing these recommendations. (I and ST)
   a. Facilitate cross-program and cross-product collaborations to move the science forward through innovation and new ways of thinking. (I)
   b. Develop more mechanisms that integrate knowledge and researchers from diverse disciplines (sociology, anthropology, economics, epidemiology, engineering, environmental science, biology, statistics, toxicology, chemistry, etc.) to address the complexity of the total environment. (I and ST)
   c. Develop and apply an approach for evaluating implementation of these recommendations. (I)

2. Develop ethics guidelines for conducting cumulative impact research and provide training on the guidelines to ORD researchers. (ST)
3. Support the use of community-generated data and information. (I, ST, and LT)
    a. Develop systems for community-generated data that can be easily used by the public and EPA. These systems should also provide appropriate metadata descriptions that allow data to be used with more traditional government data collection methods. (ST)
    b. Make EPA data and modeling platforms more readily accessible to communities for data sharing and use in EPA decision-making. (ST and LT)
    c. Establish ownership agreements based on cultural sensitivities for data generated by communities and tribes. (I, ST, and LT)
4. Maximize interoperability and integration of environmental data and tools. (I, ST, and LT)
    a. Maximize interoperability between available datasets and tools relevant to cumulative impact assessments. (ST and LT)
    b. Consider how to use and integrate multiple, emerging, or alternative streams of data. (I, ST, and LT)
    c. Examine how to bridge gaps in knowledge and data to bring disparate models used across disciplines together to support cumulative impact assessments. (I, ST, and LT)
    d. Plan for the long-term maintenance and use of scientific tools and data. (ST and LT)
5. Develop the workforce and enhance the recruitment pipeline. (I, ST, and LT)
    a. Provide training and technical support to scientists in key areas for cumulative impact assessments, including community engagement, science translation, and research studying the combinations of chemical and non-chemical stressors. (I, ST, and LT)
    b. Fill key knowledge gaps, such as in the social sciences, through permanent hiring, term/temporary appointments, and partnerships with EPA offices, other agencies, and external organizations. (I, ST, and LT)
    c. Hire consistent with Agency diversity, equity, inclusion, and accessibility goals. (I, ST, and LT)
    d. Provide training and technical support to communities to foster interest in STEM and share information on EPA training and employment opportunities. (ST and LT)
6. Promote a culture of community engagement. (I, ST, and LT)
    a. Provide training on community engagement and community capacity and provide resources to support staff. (I and ST)
    b. Ensure sufficient financial support for research, and incentives for ORD scientists to engage in community-based participatory research methods. (I, ST, and LT)
    c. Establish processes to gather feedback from tool and data users to improve product usability and accessibility. (ST and LT)
    d. Recognize that not all research lends itself to engaging communities directly and not all researchers have the skills to conduct that engagement themselves. (I, ST, and LT)
    e. Develop ways that EPA can provide compensation and other benefits for community participation in research. (I)
    f. Develop methods to streamline processes to collect non-chemical stressor data. (ST)
7. Form federal and public-private partnerships to develop multi-agency approaches to advance cumulative impact research and policy. (I, ST, and LT)

a. Leverage partnerships between communities and non-ORD entities that already exist and have established trust. (I, ST, and LT)
b. Use public-private partnerships and challenges/prizes to engage non-governmental entities in cumulative impact research. (ST and LT)
c. Partner with other federal agencies to leverage resources, data, and complementary expertise to collectively advance the science of cumulative impacts.

Conclusions

Integrating cumulative impacts into ORD research will require ongoing support, coordination across National Research Programs (NRPs), and close working relationships with partners both inside and outside the Agency. Within ORD, coordination across NRPs during research planning is intended to ensure the highest priority needs are addressed in an integrated way to advance the science to support cumulative impact assessment for decision-making. Ongoing discussions with partners about their decision contexts and research needs are essential for the success of this paradigm shift in ORD's research portfolio and in clarifying the decision contexts to which the research will be applied. These conversations are occurring real-time as EPA and external stakeholders continue to explore applications of cumulative impact assessment to their decisions.

To hold ourselves accountable and deliver on an Administration priority, ORD will be tracking our research progress against the recommendations in this report. As research planning and implementation happens in close coordination and collaboration with EPA programs and regions, we can continue to refine and improve our research and develop resources. This will allow us to continue expanding the capabilities of researchers, EPA programs and regions, and external stakeholders to do cumulative impacts research and assessment to effectively support decision-making.

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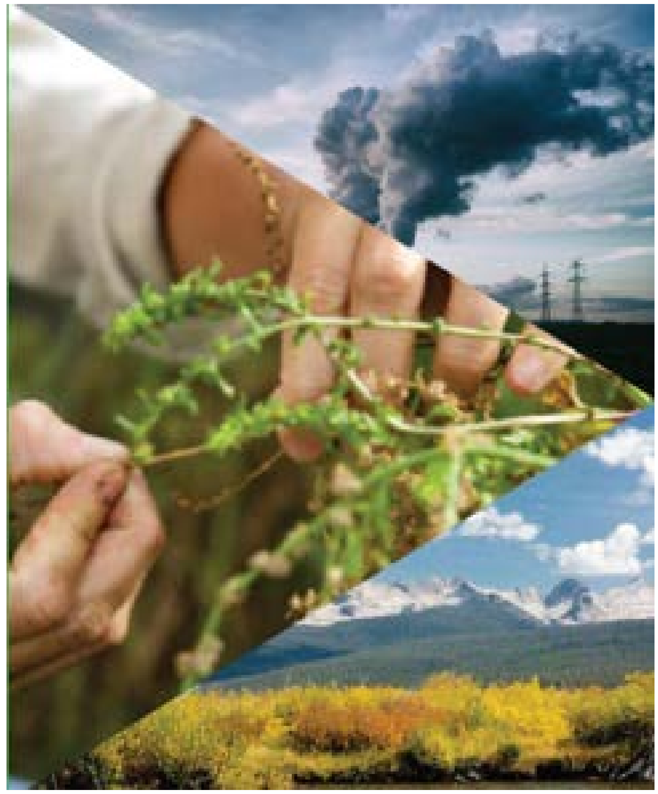
Appendix A: Summary of Listening Sessions and Workshop

Listening Sessions



In the fall of 2021, ORD conducted four early engagement listening sessions to help understand tribal, state, and local-level research needs: two sessions were held for tribes, and two sessions were held for states and local agencies. The sessions gave them the opportunity to convey concerns and research interests early in our research planning process. Guiding questions relevant to cumulative impacts were provided in advance to help them prepare.

The listening sessions were multi-hour events that began with welcoming remarks from ORD senior leadership and brief overviews of recent and current ORD work on cumulative impact research. The listening portion of the sessions occupied most of the time and were conducted in a round-robin format in which representatives of tribes, states, and local agencies had the opportunity to speak uninterrupted about their experiences, concerns, or needs on the topic of cumulative impact assessment. This engagement was facilitated by an ORD staff member and was attended by staff from all six of ORD's National Research Programs.

Below are the guiding questions that were provided to tribes in advance and used to help facilitate the sessions:

1. *What does the issue of cumulative impacts mean to you? Does your Tribe have a formal definition of cumulative impacts or what characteristics are considered associated with the topic (e.g., chemical only, including non-chemical stressors, timescale, impacts both positive and negative)?*
2. *What are your Tribe's major priorities or concerns with respect to cumulative impacts (e.g., what are the types of cumulative impacts or stressors that are of the greatest concern)?*
3. *What are the decisions your Tribe makes regarding the challenges faced by exposure to multiple non-chemical (e.g., built/social environment) and chemical stressors? How can EPA's research support those decisions?*
4. *Are there challenges in addressing cumulative impacts that your Tribe faces where additional knowledge or scientific discovery could be helpful?*

Below are the guiding questions that were provided to states and local agencies in advance and used to help facilitate the sessions:

1. *What does the issue of cumulative impacts mean to you? Does your state or local Agency have a formal definition of cumulative impacts or what characteristics are considered associated with the topic (e.g., chemical only, including non-chemical stressors, timescale, impacts both positive and negative)?*
2. *What is your state's or local agency's major priorities or concerns with respect to cumulative impacts (e.g., what are the types of cumulative impacts or stressors that are of the greatest concern)?*
3. *Are there challenges in addressing cumulative impacts that your state or local agency faces where additional knowledge or scientific discovery could be helpful? Challenges could include the following:*
    a. *Ambient air quality and deposition and human and ecosystem exposures to criteria pollutants and air toxics, along with stressors from the built and social environment and climate change.*
    b. *Sources and exposure and hazard information for chemicals (including safer alternatives), chemical mixtures, and emerging materials and technologies.*
    c. *Health disparities and differing sensitivity within populations and communities, including those with environmental justice and equity concerns.*
    d. *Multiple stressors affecting communities during incident response.*
    e. *Resiliency of communities to the cumulative impacts of contamination, climate change, and other chemical and nonchemical stressors that affect health and the environment.*
    f. *Ambient water quality and exposures to chemical mixtures of criteria pollutants.*

Workshop

ORD held a two-part workshop on near- and long-term research priorities to support community/state/tribal/federal decision-making. Part 1 of the workshop brought together ORD scientists and internal Agency partners to identify critical EPA-relevant decisions and activities in need of cumulative impact assessments related to marginal and total changes to human health and well-being, particularly for disproportionately impacted communities. It featured a presentation and facilitated discussion by external experts who work directly with state and local governments on cumulative impact assessments, as well as an internal panel discussion featuring senior leaders from across EPA Program offices and regions.

Part 2 of the workshop included community-level perspectives on how cumulative impact assessments are or can be applied to real-world decisions. There were also presentations that provided overviews of Part 1 of the workshop, results from the cumulative impacts listening sessions with tribes and state and local agencies, and draft recommendations on cumulative impacts for research planning. The community-level perspectives were provided by individuals with extensive experience advocating for local environmental justice issues in their communities. Breakout groups were assembled around national, state/tribal, and local decision contexts. Each began with an example decision/analysis to stimulate discussion around guiding questions. Key points and recommendations from each of the four (one national, one state/tribal, and two local) breakout groups were summarized back in plenary with all participants, and are listed below:

- We need more on cumulative impacts to do what we've been charged to do in the climate and equity executive orders.
- Cumulative impacts are the "holy grail of environmental justice."
- We are at a pivot point in EPA's maturity and information/data availability and computing capacity to empower communities.
- Community capacity: there are Agency needs/uses and community uses/needs.
- We need quantitative information beyond screening approaches.
- Look at what we have in terms of tools and focus on targeted uses for these issues.
- Parallel tracks in terms of pursuing the research and development and seeking partners' help to understand needs. Also consider cross-program/cross-agency approaches for solutions.
- We need to tackle the hard science that we haven't done to push the ball forward.
- Consider the community's total environment.
- Consider translation resources for communities.
- Embrace a bias for action.

Appendix B: Selected Recommendations from Environmental Justice Advisory Committees

Report	Selected Recommendations
NEJAC, 2004	The Agency should adopt the following actions to ensure risk reduction in disadvantaged, underserved and environmentally overburdened communities and reflect the Agency's bias for action in addressing cumulative risk and impacts: • Lay the scientific basis for incorporating vulnerability into EPA assessment tools, strategic plans, and research agendas. • Establish an Agency-wide framework for holistic, risk-based environmental decision-making and incorporation of Tribal Traditional Lifeways in Indian Country. • Strengthen EPA's social science capacity and community expertise. • Initiate community-based, collaborative, multi-media, and risk reduction pilot projects. • Provide resources for community-based organizations. • Develop and utilize tools for targeting and prioritization of communities needing urgent intervention. • Conduct scientific and stakeholder dialogues in ways that enhance scientific understanding and collaborative problem-solving ability. • Integrate the concepts of the NEJAC's Cumulative Risks/Impacts Report (outlined above) into EPA's strategic and budget planning processes.
NEJAC, 2014	• Target specific compliance strategies and enforcement actions to address problems that affect overburdened communities. • Seek remedies in enforcement actions that benefit overburdened communities affected by non-compliance. • Convene federal, state, tribal, community, business, academic and NGO representatives to develop scientifically valid, understandable, and practicable outcome measures for populations and geographic areas disproportionately impacted by government actions, including permitted activities. • Evaluate the extent to which current practices and policies actually are contributing to poor environmental quality and health outcomes in certain communities. • Develop consistent state guidance on incorporating environmental justice principles in permit actions.
WHEJAC, 2014	• Account for the greater risks that fenceline communities face, including cumulative exposures to many chemicals which makes them more susceptible to harm from individual chemicals in the development of risk management rules for the first 10 TSCA chemicals. • Several recommendations for indicators for a Justice40 screening tool. • Several recommendations for a goal and purpose of the Justice40 screening tool.