

EXTERNAL REVIEW DRAFT

Cumulative Impacts

Recommendations for ORD Research

United States Environmental Protection Agency
Office of Research and Development

January 2022

Preface

This white paper was developed to inform the Office of Research and Development's (ORD) FY23-26 Strategic Research Action Plans (StRAPs) under development by the six national research programs. This document was prepared by ORD's Cumulative Impacts Scoping Workgroup (Workgroup), which was comprised of experts from ORD, the Office of Environmental Justice (OEJ), and regional office representatives for environmental justice and research.

This document is an external review draft, which is available for public comment and forms the basis of a consultation with the EPA Science Advisory Board (SAB) on March 2, 2022. Following this consultation and public comment period, the paper will be revised based on the feedback received, resulting in a final published EPA Report the third quarter of fiscal year 2022.

The development of this white paper was based on input from EPA Programs and Regions, states, tribes, and community representatives, as well as previous recommendations from the National Environmental Justice Advisory Committee and the White House Environmental Justice Advisory Committee related to cumulative impacts. The draft white paper was reviewed internally by ORD senior leadership as well as staff across EPA Programs and Regions. This version of the white paper incorporates the feedback we received from this internal agency review.

Authors

Susan Julius, Co-Chair and Project Lead

Sarah Mazur, Co-Chair and Project Lead, Sustainable and Healthy Communities (SHC) Representative

Nicolle Tulve, Co-Chair and Technical Lead

Sean Paul, Project Manager

Nick Loschin, Assistant Project Manager and Logistics Support

Andrew Geller, ORD Senior Science Advisor, Environmental Justice

Angie Shatas, Air, Climate, and Energy (ACE) Representative

Kathie Dionisio, Chemical Safety for Sustainability (CSS) Representative

Beth Owens, Health and Environmental Risk Assessment (HERA) Representative

Sang Don Lee, Homeland Security (HS) Representative

Joe Williams, Safe and Sustainable Water Resources (SSWR) Representative

Joel Hoffman, Center for Computational Toxicology and Exposure (CCTE) Representative

Kyle Buck, Center for Environmental Measurement and Modeling (CEMM) Representative

Darcie Smith, Center for Environmental Solutions and Emergency Response (CESER) Representative

Tim Barzyk, Center for Public Health and Environmental Assessment (CPHEA) Representative

Onyemaechi Nweke, Office of Environmental Justice (OEJ) Representative

Charles Lee, Office of Environmental Justice (OEJ) Representative

Carole Braverman, Region 5 Representative

Matt Small, Region 9 Representative

Acronyms

ACE	Air, Climate, and Energy 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 Research Program
EJ	Environmental Justice
EPA	Environmental Protection Agency
HERA	Health and Environmental Risk Assessment Research Program
HSRP	Homeland Security Research Program
NAAQS	National Ambient Air Quality Standards
NEJAC	National Environmental Justice Advisory Council
NEPA	National Environmental Policy Act
OEJ	Office of Environmental Justice
ORD	Office of Research and Development
RA	Research Area
RFA	Request for Applications
SAB	Science Advisory Board
SDR	Solutions-Driven Research
SHC	Sustainable and Healthy Communities Research Program
SSWR	Safe and Sustainable Water Resources Research Program
STAR	Science to Achieve Results
StRAP	Strategic Research Action Plan
WHEJAC	White House Environmental Justice Advisory Council

Table of Contents

Preface i

Authors..... ii

Acronyms iii

Executive Summary..... 1

Introduction 3

Defining Cumulative Impact Assessment..... 5

Background and Context..... 9

Current ORD Research 12

Gaps and Barriers..... 17

Research Recommendations 22

Conclusions 28

References 29

Appendix A: Summary of Listening Sessions and Workshop..... A-1

Appendix B: Selected Recommendations from Environmental Justice Advisory CommitteesB-1

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 is 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 white paper 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 white paper offers operational definitions for "cumulative impacts" and "cumulative impact assessment" based on definitions developed by federal and state agencies, acknowledging that more formal, final definitions require a deliberative EPA-wide process. 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 operational definitions developed for this white paper are:

Cumulative Impacts *refers to the total burden – positive, neutral, or negative – from chemical and non-chemical stressors and their interactions that affect the health, well-being, and quality of life of an individual, community, or population at a given point in time or over a period of time.* Cumulative impacts include contemporary exposures in various environments where individuals spend time and past exposures that have lingering effects. Total burden encompasses direct health effects and indirect effects to people through impacts on resources and the environment that affect human health and well-being. Cumulative impacts provide context for characterizing the potential state of vulnerability or resilience of the community, i.e., their ability to withstand or recover from additional exposures under consideration.

Cumulative Impact Assessment *is the process of accounting for cumulative impacts in the context of problem identification and decision-making. It requires consideration and characterization of total exposures to both chemical and non-chemical stressors, as well as the interactions of those stressors, over time across the affected population.* Cumulative impact assessment explores how stressors from the built, natural, and social environments affect people, potentially causing or exacerbating adverse outcomes. It also accounts for health-mitigating factors or solutions aimed at improving health and well-being. The posited elements of a cumulative impact assessment include: community role throughout the assessment, and in particular, 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; past exposures, especially during vulnerable ages or lifestages; individual variability and behaviors; health and well-being benefits/mitigating factors; and evaluation of potential interventions that reduce cumulative impacts and improve community health and well-being.

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 to the community before making environmental policy decisions. These recommendations also stress using a participatory approach in cumulative impact assessments by involving 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. Toward that end, the Workgroup synthesized inputs from multiple engagement events with ORD partners both internal and external to the Agency to identify research gaps and barriers to conducting and translating the research, which 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 white paper fall into five broad categories:

- 1) **Establish the decision context and stakeholder engagement** – Focuses on identifying partners, policies, and decisions that cumulative impact assessment can inform, 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, social, and physical-chemical environments (Total Environment Framework) and identifying potential intervention points.
- 3) **Empower local decisions and actions** – 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 and citizen science data in research and decision-making, consistent with EPA efforts.
- 4) **Support science translation and delivery** – Includes translating approaches and results and increasing usability and user-centered design for scientific tools and products.
- 5) **Provide research management support for cumulative impact assessment** – Recognizes ORD needs to adapt to a new way of doing business by integrating research across National Research Programs and through partnerships to advance the science to support decision-making; supporting data infrastructure; developing the ORD workforce; and promoting a culture of community engagement.

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 partners both inside and outside the Agency. This paper is responsive to reviews by partners from across the Agency and represents only the beginning of collaboration and engagement with them to develop an integrated cumulative impact research portfolio to inform decision-making at all levels.

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). This was confirmed 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 chemical¹ and non-chemical² stressors³ using the best available science, as stated in EPA’s Draft 2022-2026 Strategic Plan (EPA, 2021a). The landmark environmental statutes EPA draws its authority from, including but not limited to the Toxic Substances Control Act (TSCA), Clean Air Act (CAA), and Safe Drinking Water Act (SDWA), 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 pollutant/single exposure paradigm is not suited to the reality that individuals, communities, and tribes who are exposed to numerous pollutants from a wide array of sources through multiple media and pathways varying 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 may accumulate over time, from one or more sources in the built, natural, and social environments, affecting individuals and communities in positive, negative, or neutral ways (Clougherty *et al.*, 2014; Glass *et al.*, 2009). Solving longstanding, recalcitrant environmental health problems, including health disparities exacerbated by racial and social injustice, will require addressing cumulative impacts to provide an accurate and realistic assessment of the combined effects from chemical and non-chemical stressors that can inform decision making at all levels. To support federal, state, tribal, and community decision-making, ORD must

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, negative, or neutral) in health, well-being, and quality of life (either now or into the future) (Tulve *et al.*, 2016).

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 white paper 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 was comprised of 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 representatives and experts 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. This document incorporates revisions based on comments received from internal Agency review. 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.

Defining Cumulative Impact Assessment

The earliest known definition of cumulative impact assessment was published in the California Environmental Quality Act in 1970. Over the years, definitions of cumulative impact assessment 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 considered by the Workgroup:

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

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 - <https://www.federalregister.gov/documents/2021/10/07/2021-21867/national-environmental-policy-act-implementing-regulations-revisions>

the burdened community of the proposed new facility or expansion of an existing facility” (NJ, 2020).

ORD 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).

Defining cumulative impacts relative to cumulative risk assessment and in a way that accounts for broad EPA and stakeholder needs, and meets ORD’s research objectives and capabilities, requires a deliberative process that directly engages stakeholders on this topic. Because this process was beyond the scope of the Workgroup, we chose to move forward with operational definitions of the terms ‘cumulative impacts’ and ‘cumulative impact assessment.’ These definitions were developed through background research on the topic, along with information learned through the workshops and listening sessions. 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 of cumulative impact assessment.

Cumulative Impacts *refers to the total burden – positive, neutral, or negative – from chemical and non-chemical stressors and their interactions that affect the health,- well-being, and quality of life of an individual, community, or population at a given point in time or over a period of time.* Cumulative impacts include contemporary exposures in various environments where individuals spend time and past exposures that have lingering effects. Total burden encompasses direct health effects and indirect effects to people through impacts on resources and the environment that affect human health and well-being. Cumulative impacts provide context for characterizing the potential state of vulnerability or resilience of the community, i.e., their ability to withstand or recover from additional exposures under consideration.

Cumulative Impact Assessment *is the process of accounting for cumulative impacts in the context of problem identification and decision-making. It requires consideration and characterization of total exposures to both chemical and non-chemical stressors, as well as the interactions of those stressors, over time across the affected population.* Cumulative impact assessment explores how stressors from the built, natural, and social environments affect people, potentially causing or exacerbating adverse outcomes. It also accounts for health-mitigating factors or solutions aimed at improving health and well-being. The posited elements of a cumulative impact assessment include:

- a. Community role throughout the assessment, and in particular, identifying problems and potential intervention decision points to improve community health and well-being
- b. Combined impacts across multiple chemical and non-chemical stressors
- c. Multiple sources of stressors from the built, natural, and social environments
- d. Multiple exposure pathways across media
- e. Community vulnerability
- f. Past exposures, especially during vulnerable ages or lifestages
- g. Individual variability and behaviors

- h. Health and well-being benefits/mitigating factors
- i. Evaluation of potential interventions that reduce cumulative impacts and improve community health and well-being

Cumulative impact assessments use range of data and information supported by correlations between stressors and adverse health 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, treating unknown effects of co-exposures to non-chemical stressors as risks, even if causal mechanisms are not fully understood, to protect against these unknowns.

Figure 1, adapted from Tulse 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. Health⁵, well-being⁶, and quality of life⁷ at each lifestage throughout the lifecourse are influenced by all other components (Silva *et al.*, 2018; Tulse *et al.*, 2016; WHO, 1948). Chemical and non-chemical stressors can come from the built, natural, and social environments, which collectively are referred to as the total environment. Additionally, activities and behaviors and lifestyle considerations, as well as systems biology (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 in understanding how cumulative impacts influence health, well-being, and quality of life at the individual, family, and community levels.

While the content of this white paper is largely focused on the science of cumulative impact assessment to support 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 is useful for understanding cumulative exposures to chemical and non-chemical stressors from a public health perspective; however, the terminology developed and applied in this white paper is responsive to the need to identify cumulative health and

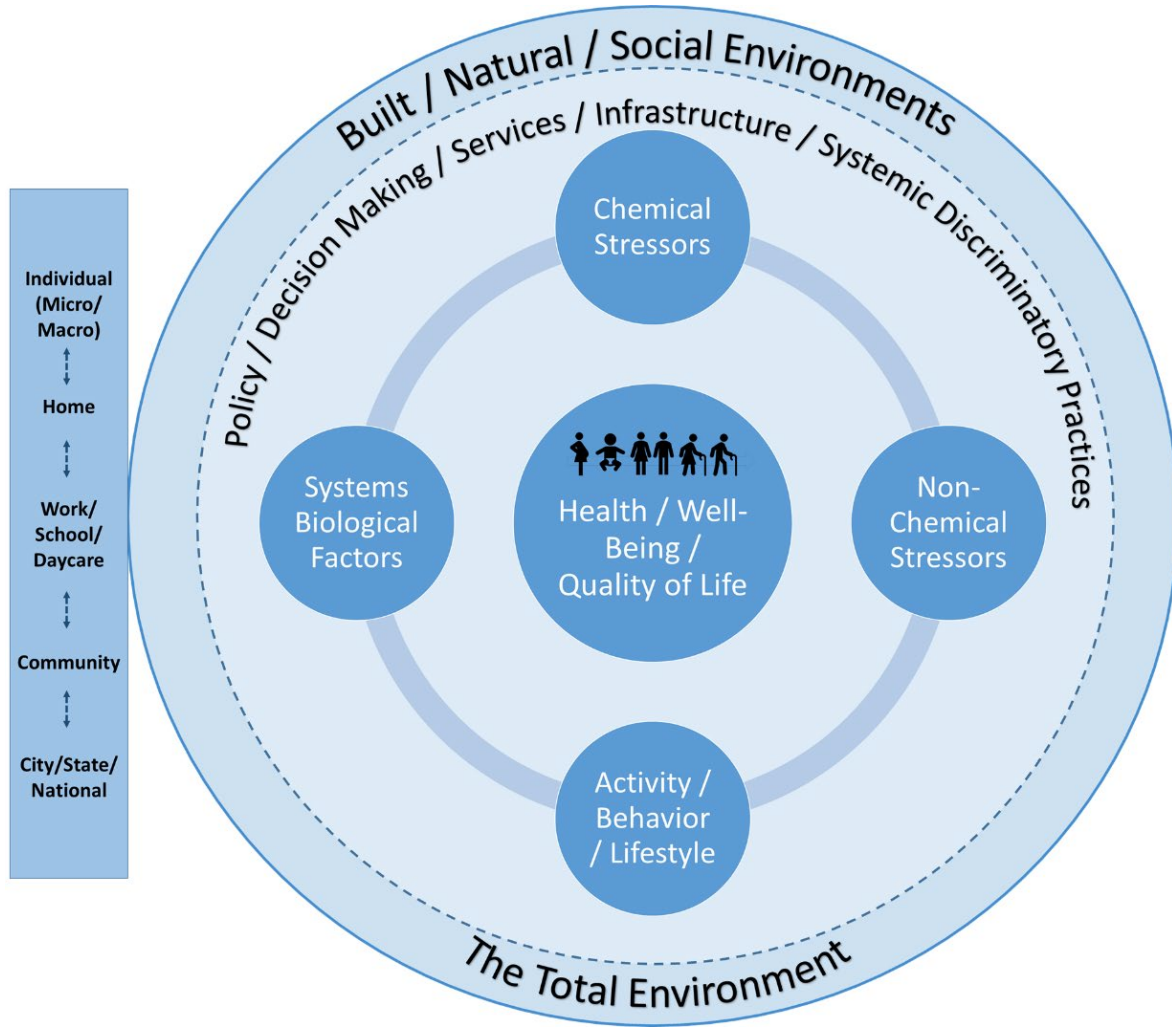
⁵ The WHO defines health as "a state of complete physical, mental, and social well-being and not merely the absence of disease and infirmity."

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).

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.

well-being effects from combinations of chemical and non-chemical stressors and potential interventions to support Agency actions needed to alleviate these effects.

Figure 1. Positive/neutral/negative influences on health, well-being, and quality of life from the total (built, natural, social) environment.



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 then be translated to facilitate the explicit inclusion of cumulative impacts in decision-making to achieve EPA's priority of equitable outcomes across communities and tribes.

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). 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, social, and physical-chemical environments (Alves *et al.*, 2012; Gallagher *et al.*, 2015; PAHO, 2013).

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. These recommendations 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 EJ communities. The Workgroup considered the NEJAC and WHEJAC recommendations when developing the recommendations found in this white paper. 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 (EPA, 2011). Decision contexts span national regulatory, permitting and enforcement actions to local land-use decisions. Because a broad range of decisions can theoretically be informed through consideration of cumulative impacts, cumulative impact assessments may require different methods and approaches targeted to the specific decision. For example, Lee (2021) posited a fit-for-purpose continuum of approaches to integrating disproportionate impact analysis into decision-making, in which the type, scale, and quantification of analyses are driven by the decision context itself (Lee, 2021). We note that there are differences between how a community may understand or experience cumulative impacts and how EPA or other decision makers may be able to implement cumulative impact assessment through our authorities. For example, EPA's regulatory authorities are generally media-specific making it difficult to truly address cumulative impacts through these mechanisms. These differences highlight the importance of working closely with partners to understand the decision context and develop and apply fit-for-purpose approaches.

The Workgroup developed a generic decision framework to consider cumulative impact assessment research questions and needs related to various decision contexts (Figure 2). In Figure 2, the inner circle represents the decision at hand and the outer circle expands beyond the decision to represent factors the community experiences. When considering cumulative impacts, questions can help frame the thinking around a cumulative impact assessment and may begin with the total burden a community faces. Example questions may include:

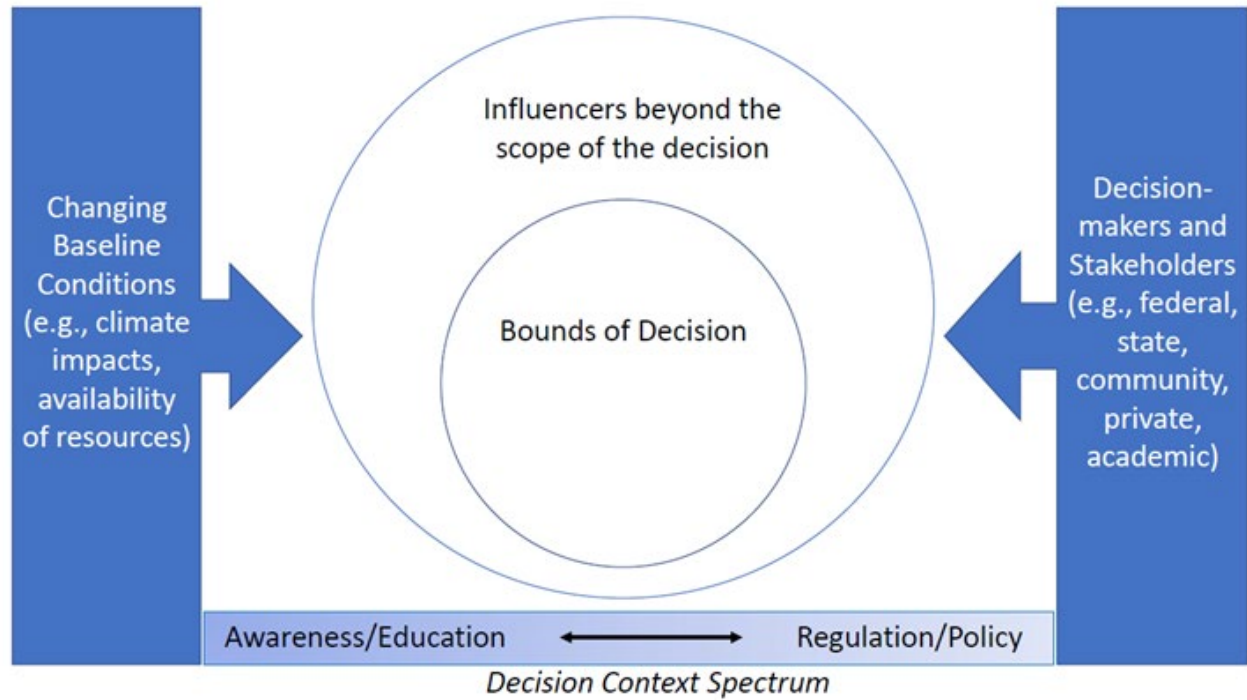
- *What is the baseline condition for the identified population/community? This should include socioeconomic, environmental, and health data as available, including information on pre-existing vulnerabilities and historical exposures.*
- *What are racial/ethnic and income gaps in the baseline environmental/health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

Additionally, cumulative impact assessments may address other questions such as:

- *What are the impacts (positive, negative, neutral) 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?*

On the left-hand side of Figure 2, the blue box with the arrow emphasizes the need to consider how changing baseline conditions, caused by factors such as climate change, affect the total burden, either directly or indirectly. On the right-hand side of Figure 2, the blue box indicates there are various decision-makers and stakeholders involved in cumulative impact assessment, from local to national scale and across sectors. Finally, the bar on the bottom of Figure 2 shows that cumulative impact assessment can be used for different purposes, from awareness and education to regulation and policy, and will likely require increasing levels of rigor and complexity as one moves from left to right. The central circles of the diagram recognize that circumstances of a given decision may not address a community's full burden from cumulative impacts. In those cases, other mechanisms may be needed to address factors outside the reach of a given decision. With this framework in mind, researchers can begin to identify the decision context and associated data, tools, and methods needed for a cumulative impact assessment, and whom to engage and involve from the community in all phases of the process.

Figure 2. Workgroup's generic decision framework



Current ORD Research

This section provides an overview of past and ongoing research on cumulative impact assessments or elements of them across ORD's six national research programs. While not all research described below explicitly uses the terminology in this white paper, this research represents a cross-section of work done on topics including multi-pollutant mixtures, social determinants of health, and development of assessment methods and more. This section also provides a high-level overview of the directions each research program is taking over the next four years (FY23-26), the details of which will be informed by this white paper.

Air, Climate, and Energy

One objective of the Air, Climate, and Energy Research Program (ACE) 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, in addition, often has other complicating factors (e.g., socio-economic) that can affect the impacts of the exposures.

Recognizing that the exposures can be complex, ACE research evaluates the health and ecological effects of exposures to individual pollutants and multi-pollutant mixtures, including both more regional criteria pollutants and more local air toxics, as well as how the impacts of these exposures can be modified by co-exposures to other pollutants or to 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 various 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 *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 disparities (e.g., neighborhood characteristics, education, and income) that contribute to health disparities and inequities. 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. ACE is supporting 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.” ACE also has an Output “Methods to measure personal and community level exposures to air pollution” that 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.

Chemical Safety for Sustainability

The Chemical Safety for Sustainability (CSS) program has been historically focused on chemicals and chemical mixtures. 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 (NTA) 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 chemical exposure, including impacts from climate change and inequitable social and economic conditions. Research to support cumulative impact assessments will be coordinated across other national research programs, e.g., with SHC on non-chemical stressors and with HERA on chemical mixtures.

Health and Environmental Risk Assessment

The Health and Environmental Risk Assessment (HERA) Research Program 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 practice (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) Research Program 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 Research Area 7, titled “Systems-based Decision Making”, 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. Research Area 8, “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. The Outputs in Research Area 8 assess and address 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) Research Program 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 (Almeter *et al.*, 2018; Harwell *et al.*, 2021). 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 STAR RFAs 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 focus 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, Research Area 9, “Benefits from Remediation, Restoration, and Revitalization” and Research Area 10, “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 and tribes. SHC 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 white paper 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) Research Program 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 aquatic ecosystems and human health. Critical factors in a water-focused cumulative impact assessment will be the impact of chemical stressors on source and recreational waters, particularly nutrients and algal toxins, and drinking water distribution system management and treatment effectiveness and cost, including identification of lead service lines and reducing lead exposure from lead service lines and premise plumbing. 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.

To highlight an example of a cumulative impact assessment, SSWR is focusing research on the resilience of wetlands and the environmental, economic, and community benefits in a coastal community, in

coordination with ACE and SHC. SSWR's role in this solutions-driven research effort will be in the development of approaches to restore or conserve coastal sea grass, salt marsh, or wetland resources, and to develop the methods to monitor the results of implementing these approaches. These approaches will engage community and citizen scientists in restoration, monitoring, and analysis of the potential water quality improvements from restoration activities, all of which are factors in cumulative impact assessments.

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 lifestyles throughout the lifecycle.

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 EJ 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, 2021). 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 inter-dependencies 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:

- a. Combine quantitative and qualitative data on stressors to inform a cumulative impact assessment.
- b. Characterize the cumulative impacts of multiple decisions at once (e.g., permitting multiple facilities in an area).
- c. Develop and combine stressors/indicators for one or more health and well-being outcomes that provide relative or absolute measures of exposure or impact.
- d. Standardize (in absolute and relative ways) identification and characterization of disproportionately impacted and overburdened communities.
- e. Use biomarker identification for exposures to multiple chemical or non-chemical stressors.
- f. Integrate multiple streams of data, including data from community and citizen science and traditional ecological knowledge.
- g. Characterize health inequities within and across communities and at varying spatial scales.
- h. Characterize health-benefiting assets of a community, such as measuring the benefits of green space.
- i. Identify and account for historical stressor exposures in cumulative impact assessments.
- j. Evaluate the cumulative impacts/benefits of various types of interventions.

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.

Data

Significant data gaps exist that make cumulative impact assessments more difficult to implement. 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.

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 scales. These challenges are experienced both by 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 (EPA, 2021b; Frey *et al.*, 2020; Huang *et al.*, 2019). Collection of finer spatial scale data is only one way of resolving this issue. EPA has a number of alternative ways of

addressing this issue, including modeling techniques and alternate data sources such as community and citizen 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 portion of its 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 institution) 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). 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 the asymmetric data collection accuracy across contexts, populations, and location.

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). 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 of 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 (Merriam *et al.*, 2001; Muhammad *et al.*, 2015). This is not unique to ORD. 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 needed 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).

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 and generalize research conclusions 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, and require particular attention to the unique challenges a community faces, as well as require 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 summarized above, 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, and the NEJAC and WHEJAC recommendations (EPA, 2016, 2021c).

Cumulative impact assessment should be developed and applied with a bias for action⁸, 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've 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: 1) Establish decision context and stakeholder engagement; 2) Address scientific considerations for meeting partner needs; 3) Empower local decisions and actions; 4) Support science translation and delivery; and 5) Provide research management support for cumulative impact assessment. A summary of these categories is below, followed by the recommendations themselves. The white paper and recommendations have been reviewed by the ORD Executive Council and Program and Regional Office partners.

Establish the Decision Context and Stakeholder 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 accomplished in the immediate term.

Address Scientific Considerations for Meeting Partner Needs: Recommendations in this category include developing fit-for-purpose approaches to characterize assets⁹, vulnerabilities, and overall cumulative impacts through incorporating holistic approaches that address exposures to chemical and non-chemical stressors from the built, natural, social, and physical-chemical environments (e.g., Total Environment Framework), and identifying potential intervention points. Cumulative impacts include historical and concurrent pollution exposure, burden of environmentally linked disease, and stressors found in the built, natural, and social environments.

⁸ 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).

⁹ ORD defines assets as those natural, social, and economic resources that increase community resilience and well-being and are important to protect and grow.

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 Health Impact Assessment (HIA), DNA/epigenetic measures of cumulative exposure, Adverse Outcome Pathway (AOP) networks, Toxicity Equivalence Factors (TEFs), differential risk/dose response, and hazard indices (semiquantitative).

Empower Local Decisions and Actions: 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 community and citizen 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 that consider community needs. Communications, outreach, and projects that focus on increasing community capacity and expanding Solutions Driven Research (SDR) 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. Research coordination 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. The timing of the research need (see Box) is indicated for each recommendation. 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): Within the time frame of FY23-26 ORD Strategic Research Action Plans (StRAPs)*
- *Long-term (LT): Beyond the time frame of FY23-26 ORD Strategic Research Action Plans*

- **Establish Decision Context and Stakeholder Engagement**

1. Identify the breadth of partners, policies, decisions, and tools that cumulative impact assessment can inform at the federal, state, tribal, and local level. (I)
 - 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, as requested, on cumulative impact assessment implementation at the Agency. (I)

2. Engage with partners from across the Agency 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 internal partners (e.g., programs and regions) and external stakeholders (e.g., universities, nonprofits, state organizations) 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 clarifying how ORD research can benefit them. (I, ST, and LT)
 - a. Invest in developing long-term relationships with communities directly with program and regional partners or through academic or boundary organizations, such as local health departments or NGOs. (I, ST, and LT)
- **Address Scientific Considerations for Meeting Partner Needs**
 1. Develop fit-for-purpose approaches to quantify assets, vulnerabilities, and net environmental health burden 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. 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)
 2. Incorporate holistic approaches into EPA research to more fully characterize exposures to stressors from the built, natural, social, and physical-chemical environments 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, 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. 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. (ST and LT)
 - c. Explore the applicability of using novel approaches for understanding health disparities in disproportionately impacted and overburdened communities. (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 outcomes related to regulated pollutants. (LT)
 4. Evaluate the impacts of policies and interventions aimed at both reducing vulnerability and increasing environmental benefits in disproportionately impacted and overburdened communities from combined exposures to both chemical and non-chemical stressors. (ST and LT)
- **Empower Local Decisions and Actions**
 1. Help communities understand and manage cumulative impacts by going beyond problem identification to identify solutions to community-specific needs through providing access to data, making it transparent, providing resources and how to use them, and providing technical support. (I, ST, and LT)
 2. 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)
 3. 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. Translate ORD community-based research approaches and results across geographic and social/political/environmental contexts. (ST and LT)
3. 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. (I and ST)
 - a. Develop ways that EPA can provide compensation and other benefits for community participation in research. (I)
 - b. Develop methods to streamline processes to collect non-chemical stressor data. (ST)
 2. 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)
 3. 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)
 4. 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)
 5. 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. Identify and address gaps and barriers for conducting effective community engagement. (I and ST)
 - c. Ensure sufficient financial support and incentives for ORD scientists to engage in community-based participatory research methods. (I, ST, and LT)
 - d. Establish processes to gather feedback from tool and data users to improve product usability and accessibility. (ST and LT)
 - e. 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)
6. Form federal and public-private partnerships to develop multi-agency approaches to advance cumulative impact research and policy. (I, ST, 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)

Conclusions

Integrating cumulative impact assessment into ORD research will require ongoing support, coordination across National Research Programs, and close working relationships with partners both inside and outside the Agency. Within ORD, coordination across national programs during research planning is intended to ensure the highest priority needs are addressed in an integrated way to advance the science of cumulative impact assessment to support 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. This can be accomplished during research planning by following up on comments received about partner needs and priorities during the review of this white paper, partner participation in Research Area Coordination Teams (RACTs), ORD participation in Agency Equity Team activities, and other intentional discussions. As research planning and implementation happens in close coordination and collaboration with partners, we can learn from each other and our partners how to work with states, tribes, and communities so that our research effectively supports their efforts to address cumulative impacts at all levels.

References

- AEP. (2020). *Cumulative Impacts*. Retrieved from CEQA Portal: http://ceqaportal.org/tp/AEP%20CEQA%20Portal_Cumulative%20Impacts.pdf
- Affuso, E., de Parisot, C. V., Ho, C.-S., & Hite, D. (2010). The impact of hazardous waste on property values: The effect of lead pollution. *Urbani izziv*, 21(2), 117-126.
- Almeter, A., Tashie, A., Procter, A., McAlexander, T., Browning, D., Rudder, C., . . . Araujo, R. (2018). A Needs-Driven, Multi-Objective Approach to Allocate Urban Ecosystem Services from 10,000 Trees. *Sustainability*, 10(12), 4488. doi:10.3390/su10124488
- Alves, S., Tilghman, J., Rosenbaum, A., & Payne-Sturges, D. C. (2012). U.S. EPA Authority to Use Cumulative Risk Assessments in Environmental Decision-Making. *International Journal of Environmental Research and Public Health*, 9(6), 1997-2019. doi:10.3390/ijerph9061997
- Balazs, C. L., & Morello-Frosch, R. (2013). The Three Rs: How Community-Based Participatory Research Strengthens the Rigor, Relevance, and Reach of Science. *Environmental Justice*, 6(1), 9-16. doi:10.1089/env.2012.0017
- Brown, P., Morello-Frosch, R., Brody, J. G., Altman, R. G., Rudel, R. A., Senier, L., . . . Simpson, R. (2010). Institutional review board challenges related to community-based participatory research on human exposure to environmental toxins: A case study. *Environmental Health*, 9(1), 39. doi:10.1186/1476-069x-9-39
- National Environmental Policy Act Implementing Regulations, (1978).
- Clougherty, J. E., Shmool, J. L. C., & Kubzansky, L. D. (2014). The Role of Non-Chemical Stressors in Mediating Socioeconomic Susceptibility to Environmental Chemicals. *Current Environmental Health Reports*, 1(4), 302-313. doi:10.1007/s40572-014-0031-y
- Davis, L. F., & Ramírez-Andreotta, M. D. (2021). Participatory Research for Environmental Justice: A Critical Interpretive Synthesis. *Environmental Health Perspectives*, 129(2), 026001. doi:10.1289/ehp6274
- Elliott, D., Martin, S., Shakesprere, J., & Kelly, J. (2021). Simulating the 2020 Census.
- EOP. (2021a). *Advancing Racial Equity and Support for Underserved Communities Through the Federal Government*. Federal Register: National Archives and Records Administration Retrieved from <https://www.federalregister.gov/documents/2021/01/25/2021-01753/advancing-racial-equity-and-support-for-underserved-communities-through-the-federal-government>
- EOP. (2021b). *Diversity, Equity, Inclusion, and Accessibility in the Federal Workforce*. Federal Register: National Archives and Records Administration Retrieved from <https://www.federalregister.gov/documents/2021/06/30/2021-14127/diversity-equity-inclusion-and-accessibility-in-the-federal-workforce>
- EPA. (1993). *Provisional guidance for quantitative risk assessment of polycyclic aromatic hydrocarbons* (Vol. 600): Environmental Criteria and Assessment Office, Office of Health and Environmental Assessment, US Environmental Protection Agency.
- EPA. (1997). *Guidance on Cumulative Risk Assessment: Part 1. Planning and Scoping*. Retrieved from https://www.epa.gov/sites/default/files/2015-01/documents/cumrisk2_0.pdf
- EPA. (1999). *Consideration Of Cumulative Impacts In EPA Review of NEPA Documents* (EPA 315-R-99-002). Retrieved from <https://www.epa.gov/sites/default/files/2014-08/documents/cumulative.pdf>
- EPA. (2003). *Framework for Cumulative Risk Assessment* Retrieved from https://www.epa.gov/sites/default/files/2014-11/documents/frmwrk_cum_risk_assmnt.pdf
- EPA. (2009). *Provisional Peer-Reviewed Toxicity Values for Complex Mixtures of Aliphatic and Aromatic Hydrocarbons (CASRN Various)*. Retrieved from <https://cfpub.epa.gov/ncea/pprtv/documents/TotalPetroleumHydrocarbonsAliphaticLow.pdf>

- EPA. (2010). *Recommended Toxicity Equivalence Factors (TEFs) for Human Health Risk Assessments of 2,3,7,8-Tetrachlorodibenzo-p-dioxin and Dioxin-Like Compounds* (100-R-10-005). Retrieved from <https://www.epa.gov/risk/documents-recommended-toxicity-equivalency-factors-human-health-risk-assessments-dioxin-and>
- EPA. (2011). *Plan EJ 2014: Legal Tools*. Retrieved from <https://www.epa.gov/sites/default/files/2015-02/documents/ej-legal-tools.pdf>
- EPA. (2016). *Environmental Justice Research Roadmap*. Retrieved from https://www.epa.gov/sites/production/files/2017-01/documents/researchroadmap_environmentaljustice_508_compliant.pdf
- EPA. (2017). Using a Total Environment Framework (Built, Natural, Social Environments) to Assess Life-long Health Effects of Chemical Exposures. *Grantee Research Project* Retrieved from https://cfpub.epa.gov/ncer_abstracts/index.cfm/fuseaction/recipientdisplay/rfa_id/630/records_per_page/ALL
- EPA. (2020). Center for Early Lifestage Vulnerabilities to Environmental Stressors. *Grantee Research Project* Retrieved from https://cfpub.epa.gov/ncer_abstracts/index.cfm/fuseaction/recipientdisplay/rfa_id/669/records_per_page/ALL
- EPA. (2021a). *Draft FY 2022-2026 EPA Strategic Plan*. Retrieved from <https://www.epa.gov/system/files/documents/2021-10/fy-2022-2026-epa-draft-strategic-plan.pdf>
- EPA. (2021b, 10/05/2021). EPA Expands Air Monitoring Capabilities to Support Wildfire-Impacted States, Tribes and Their Frontline Firefighters. Retrieved from <https://www.epa.gov/sciencematters/epa-expands-air-monitoring-capabilities-support-wildfire-impacted-states-tribes-and#:~:text=The%20VAMMS%20was%20developed%20by,a%20sample%20to%20measure%20PM2.5>
- EPA. (2021c). *U.S. Environmental Protection Agency Board of Scientific Counselors Executive Committee: Virtual Meeting Summary*. Retrieved from https://www.epa.gov/system/files/documents/2021-10/bosc_ec_summary_10-06-2021-amg_lbj.pdf
- Frey, C. H., Gadre, D., Singh, S., & Kumar, P. (2020). Quantification of Sources of Variability of Air Pollutant Exposure Concentrations among Selected Transportation Microenvironments. *Transportation research record*, 2674(9), 395-411.
- Gallagher, S. S., Rice, G. E., Scarano, L. J., Teuschler, L. K., Bollweg, G., & Martin, L. (2015). Cumulative risk assessment lessons learned: A review of case studies and issue papers. *Chemosphere*, 120, 697-705. doi:10.1016/j.chemosphere.2014.10.030
- Gernes, R., Hertzberg, R., MacDonell, M., Rice, G., Wright, J. M., Beresin, G., . . . Hipp, J. A. (2016). Estimating greenspace exposure and benefits for cumulative risk assessment applications. *EPA/600/R-16/025. Cincinnati, OH: US Environmental Protection Agency, Office of Research and Development*. 109 p. <https://cfpub.epa.gov/ncea/risk/recordisplay.cfm?deid=314417>, 1-109.
- Glass, T. A., Bandeen-Roche, K., McAtee, M., Bolla, K., Todd, A. C., & Schwartz, B. S. (2009). Neighborhood Psychosocial Hazards and the Association of Cumulative Lead Dose With Cognitive Function in Older Adults. *American Journal of Epidemiology*, 169(6), 683-692. doi:10.1093/aje/kwn390
- Harwell, M. C., Jackson, C., Kravitz, M., Lynch, K., Tomasula, J., Neale, A., . . . Parry, K. (2021). Ecosystem services consideration in the remediation process for contaminated sites. *Journal of Environmental Management*, 285, 112102. doi:<https://doi.org/10.1016/j.jenvman.2021.112102>
- Huang, K., Bi, J., Meng, X., Geng, G., Lyapustin, A., Lane, K. J., . . . Liu, Y. (2019). Estimating daily PM2.5 concentrations in New York City at the neighborhood-scale: Implications for integrating non-

- regulatory measurements. *Science of the Total Environment*, 697, 134094.
doi:<https://doi.org/10.1016/j.scitotenv.2019.134094>
- Lee, C. (2021). Confronting Disproportionate Impacts and Systemic Racism in Environmental Policy. *Envtl. L. Rep.*, 51, 10207.
- Markevych, I., Schoierer, J., Hartig, T., Chudnovsky, A., Hystad, P., Dzhambov, A. M., . . . Nieuwenhuijsen, M. J. (2017). Exploring pathways linking greenspace to health: Theoretical and methodological guidance. *Environmental Research*, 158, 301-317.
- Maxwell, K., Hubbell, B., & Eisenhauer, E. (2019). Institutional insights on integrating social and environmental science for solutions-driven research. *Environmental Science & Policy*, 101, 97-105. doi:<https://doi.org/10.1016/j.envsci.2019.08.003>
- Merriam, S. B., Johnson-Bailey, J., Lee, M.-Y., Kee, Y., Ntseane, G., & Muhamad, M. (2001). Power and positionality: negotiating insider/outsider status within and across cultures. *International Journal of Lifelong Education*, 20(5), 405-416. doi:10.1080/02601370120490
- Miller, G. W., & Jones, D. P. (2014). The Nature of Nurture: Refining the Definition of the Exposome. *Toxicological Sciences*, 137(1), 1-2. doi:10.1093/toxsci/kft251
- Muhammad, M., Wallerstein, N., Sussman, A. L., Avila, M., Belone, L., & Duran, B. (2015). Reflections on researcher identity and power: The impact of positionality on community based participatory research (CBPR) processes and outcomes. *Critical Sociology*, 41(7-8), 1045-1063.
- NEJAC. (2004). *Ensuring Risk Reduction in Communities with Multiple Stressors: Environmental Justice and Cumulative Risks/Impacts*. Retrieved from <https://www.epa.gov/sites/production/files/2015-02/documents/nejac-cum-risk-rpt-122104.pdf>
- NEJAC. (2014). *NEJAC Comments to EPA Plan EJ 2014* Retrieved from <https://www.epa.gov/sites/default/files/2015-02/documents/plan-ej-2014-comments-0511.pdf>
- NJ. (2020). *New Jersey Environmental Justice Law*. Retrieved from <https://www.nj.gov/dep/ej/docs/ej-law.pdf>
- NJDEP. (2021). *6th EJ Rulemaking Stakeholder Meeting*. Retrieved from <https://www.nj.gov/dep/ej/docs/ej-pres-20210624.pdf>
- PAHO. (2013). *Health impact assessment: Concepts and guidelines for the americas*. Retrieved from <https://www.paho.org/hq/dmdocuments/2014/health-impact-assessment-concepts-and-guidelines-2013.pdf>
- Saxton, D. I., Brown, P., Seguinot-Medina, S., Eckstein, L., Carpenter, D. O., Miller, P., & Waghiyi, V. (2015). Environmental health and justice and the right to research: institutional review board denials of community-based chemical biomonitoring of breast milk. *Environmental Health*, 14(1). doi:10.1186/s12940-015-0076-x
- Schroeder, J. P. (2017). Hybrid areal interpolation of census counts from 2000 blocks to 2010 geographies. *Computers, Environment and Urban Systems*, 62, 53-63. doi:10.1016/j.compenurbsys.2016.10.001
- Silva, R. A., Rogers, K., & Buckley, T. J. (2018). Advancing Environmental Epidemiology to Assess the Beneficial Influence of the Natural Environment on Human Health and Well-Being. *Environmental science & technology*, 52(17), 9545-9555. doi:10.1021/acs.est.8b01781
- Tulve, N., Ruiz, J. D. C., Lichtveld, K., Darney, S. P., & Quackenbos, J. J. (2016). Development of a Conceptual Framework Depicting a Childs Total (Built, Natural, Social) Environment in Order to Optimize Health and Well-Being. *Journal of Environment and Health Science*, 2(2), 1-8. doi:10.15436/2378-6841.16.1121
- van den Brakel, J., Zhang, X., & Tam, S. M. (2020). Measuring discontinuities in time series obtained with repeated sample surveys. *International Statistical Review*, 88(1), 155-175.

- Ward-Caviness, C. K., Pu, S., Martin, C. L., Galea, S., Uddin, M., Wildman, D. E., . . . Aiello, A. E. (2020). Epigenetic predictors of all-cause mortality are associated with objective measures of neighborhood disadvantage in an urban population. *Clinical Epigenetics*, 12(1). doi:10.1186/s13148-020-00830-8
- Weitekamp, C. A., Stevens, T., Stewart, M. J., Bhave, P., & Gilmour, M. I. (2020). Health effects from freshly emitted versus oxidatively or photochemically aged air pollutants. *Science of the Total Environment*, 704, 135772.
- WHEJAC. (2021). *Final Recommendations: Justice40 Climate and Economic Justice Screening Tool & Executive Order 12898 Revisions*. Retrieved from <https://www.epa.gov/sites/default/files/2021-05/documents/whiteh2.pdf>
- WHO. (1948). *Constitution of the World Health Organization*. Retrieved from <https://apps.who.int/gb/bd/PDF/bd47/EN/constitution-en.pdf?ua=1>
- Whyte, K. P. (2013). On the role of traditional ecological knowledge as a collaborative concept: a philosophical study. *Ecological Processes*, 2(1), 7. doi:10.1186/2192-1709-2-7
- Wild, C. P. (2005). Complementing the Genome with an "Exposome": The Outstanding Challenge of Environmental Exposure Measurement in Molecular Epidemiology. *Cancer Epidemiology Biomarkers & Prevention*, 14(8), 1847-1850. doi:10.1158/1055-9965.epi-05-0456

Appendix A: Summary of Listening Sessions and Workshop

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 states and tribes had the opportunity to speak uninterrupted about their institutions' experiences, concerns, or needs on the topic of cumulative impact assessment. This round-robin was facilitated by an ORD staff member and was attended by all six of ORD's National Research Programs. The listening portion was stimulated by the following "guiding questions":

1. *What does the issue of cumulative impacts mean to you?*
 - a. *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.*

ORD held a two-part workshop on Near- and Long-Term Research Priorities to Support Community/State/Tribal/Federal Decision-Making. Part I of the workshop brought together ORD scientists and internal 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, especially for disproportionately impacted communities. Part I 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 II of this 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 I 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 summarized as well 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 is 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 communities total environment and translation for communities
- Embrace a bias for action

Appendix B: Selected Recommendations from Environmental Justice Advisory Committees

Report	Selected Recommendations
NEJAC, 2004	<p>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:</p> <p>Lay the scientific basis for incorporating vulnerability into EPA assessment tools, strategic plans, and research agendas;</p> <p>Establish an Agency wide framework for holistic risk-based environmental decision making and incorporation of Tribal Traditional Lifeways in Indian Country;</p> <p>Strengthen EPA’s social science capacity and community expertise;</p> <p>Initiate community-based, collaborative, multi-media, risk reduction pilot projects;</p> <p>Provide resources for community-based organizations;</p> <p>Develop and utilize tools for targeting and prioritization of communities needing urgent intervention;</p> <p>Conduct scientific and stakeholder dialogues in ways that enhance scientific understanding and collaborative problem-solving ability; and</p> <p>Integrate the concepts of the NEJAC’s Cumulative Risks/Impacts Report (outlined above) EPA’s strategic and budget planning processes.</p>
NEJAC, 2014	<p>Target specific compliance strategies and enforcement actions to address problems that affect overburdened communities.</p> <p>Seek remedies in enforcement actions that benefit overburdened communities affected by the non-compliance</p> <p>Convene the 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.</p> <p>Evaluate the extent to which current practices and policies actually are contributing to poor environmental quality and health outcomes in certain communities.</p> <p>Develop consistent State guidance on incorporating environmental justice principles in permit actions.</p>
WHEJAC, 2014	<p>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.</p> <p>Several recommendations for indicators for a Justice40 screening tool</p> <p>Several recommendations for goal and purpose of the Justice40 screening tool</p>