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State of the Science and the Future of Cumulative Impact Assessment

Committee on State-of-the-Science and the Future of Cumulative Impact Assessment

Board on Environmental Studies and Toxicology

Division on Earth and Life Studies

Consensus Study Report

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This Consensus Study Report was reviewed in draft form by individuals chosen for their diverse perspectives and technical expertise. The purpose of this independent review is to provide candid and critical comments that will assist the National Academies of Sciences, Engineering, and Medicine in making each published report as sound as possible and to ensure that it meets the institutional standards for quality, objectivity, evidence, and responsiveness to the study charge. The review comments and draft manuscript remain confidential to protect the integrity of the deliberative process. We thank the following individuals for their review of this report:

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Although the reviewers listed above provided many constructive comments and suggestions, they were not asked to endorse the conclusions or recommendations of this report, nor did they see the final draft before its release. The review of this report was overseen by **SUSAN ANENBERG,** George Washington University, and **JOEL KAUFMAN (NAM),** University of Washington, responsible for making certain that an independent examination of this report was carried out in accordance with the standards of the National Academies and that all review comments were carefully considered. Responsibility for the final content rests entirely with the authoring committee and the National Academies.

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Contents

APPENDIXES

Acronyms and Abbreviations

AB	Assembly Bill
ADI	Area Deprivation Index
AEMP	Akwesasne Environmental Management Program
AHP	Analytic Hierarchy Process
CARE	Collective Benefit, Authority to Control, Responsibility, Ethics
CBPR	Community Based Participatory Research
CCI	California Climate Investments
CDC	Centers for Disease Control and Prevention
CEJST	Climate and Economic Justice Screening Tool
CEQ	Council on Environmental Quality
CES	CalEnviroScreen
CFR	Code of Federal Regulations
CIA	cumulative impact assessment
CIP	cumulative impacts paradigm
CPA	community participatory approach
CVI	Climate Vulnerability Index
DoD	U.S. Department of Defense
DOE	U.S. Department of Energy
DOT	U.S. Department of Transportation
EJI	Environmental Justice Index
EJIS	environmental justice impact statement
EIS	environmental impact statement
EPA	U.S. Environmental Protection Agency
FDA	Food and Drug Administration
FOIA	Freedom of Information Act
GIS	geographic information systems
HIA	health impact assessment
HPI	Healthy Places Index
IARC	International Agency for Research on Cancer
ICE	Indirect and Cumulative Effects
IPCS	International Programme on Chemical Safety
IRIS	Integrated Risk Information System
LSL	Lead service line
LSLR	Lead service line replacement
NAAQS	National Ambient Air Quality Standards
NASEM	National Academies of Sciences, Engineering, and Medicine

NEJAC	National Environmental Justice Advisory Council
NEPA	National Environmental Policy Act
NJDEP	New Jersey Department of Environmental Protection
NIEHS	National Institute of Environmental Health Sciences
NIH	National Institutes of Health
NRC	National Research Council
NTSB	National Transportation and Safety Board
OCAP	Ownership, Control, Access, and Possession
OEHHA	Office of Environmental Health Hazard Assessment
PCA	principal components analysis
PM	particulate matter
$PM_{2.5}$	fine particulate matter
RIA	regulatory impact analysis
SB	Senate Bill
SJVCHIP	San Joaquin Valley Cumulative Health Impacts Project
SVI	Social Vulnerability Index
TEK	traditional ecological knowledge
TRI	Toxics Release Inventory
TSCA	Toxic Substances Control Act
WHO	World Health Organization

Summary[1]

Every community across the United States faces impacts on their health and well-being from a wide range of sources including pollution of air, water, and soil and extreme events such as wildfires and major storms. Impacts may be heightened by factors such as unaffordable housing, limited or no access to healthcare, poverty, and unemployment. Cumulative impact assessment (CIA) is a tool to help environmental and other relevant decision-makers consider multiple factors in evaluating priorities and potential changes in local, state, tribal, and/or national policies or regulations, with a focus on improving health and well-being. In response to a request from the U.S. Environmental Protection Agency (EPA), this report provides recommendations on the state of the science of CIA and on fostering its application at the community, tribal, regional, state, and national levels.

CIA can be considered a natural expansion and enhancement of existing methods to assess the multiple factors that shape health and well-being and inform policy- and decision-making. CIA aims to go beyond existing practices that assess impacts of external factors one at a time, taking a more holistic approach that acknowledges multiple environmental exposures occur simultaneously and across the life course. Accordingly, this work builds on prior developments and advice from the National Academies on risk assessment and other methods that facilitate decision-making, even when information is incomplete. The committee's statement of task is provided in Box S-1.

BOX S-1
Statement of Task

An ad hoc committee of the National Academies of Sciences, Engineering, and Medicine (National Academies) will convene state-of-the-science workshops and develop a consensus report to advise on how EPA might further develop the scientific foundation underlying the practice of CIA.

The charge questions to the committee are as follows:

- How can elements of prior risk assessment advice from the National Academies, developments by EPA and others, and response from communities inform a holistic and inclusive approach to developing and implementing CIA?
- What types of stressors, both now and anticipated in the future, should be prioritized, characterized, and considered in combination in a CIA to best reflect overall burdens facing diverse communities and populations?
- How can CIA consider factors that may make a community more vulnerable to stressors, barriers to strengthening a community's ability to respond to stressors, and critical paths to improved community health and well-being in the future?
- How can community and tribal data and knowledge be incorporated into CIA?
- What approaches for assessing overall health and well-being are most useful for incorporating into CIA?
- How can uncertainty in CIAs be characterized?
- How can CIA be adapted to different communities, generalized to regional or national scale, and remain flexible for EPA's different programmatic needs?

[1] This summary does not include references. Citations for the information presented herein are provided in the main text.

A key aspect of the work of the report's authoring committee entailed public engagement and dialogue. From the start of its work, the committee engaged with community and tribal liaisons[2] from across the US to help design and implement their public engagements. As shown in Figure S-1, the committee convened six public workshops and open sessions across which they gathered input from more than 100 individuals. A separately published *Proceedings-in-Brief*[3] summarizes the committee's virtual workshop that sought input across the social, behavioral, and risk sciences, and included a liaison on each discussion panel. A *Proceedings of a Workshop Series*[4] summarizes the community-engaged workshop in New Orleans, Louisiana, the virtual liaison Town Hall, and the Colorado tribal engagement.

FIGURE 1 Overview of committee's public engagement plan.

AUDIENCES FOR THE COMMITTEE'S REPORT

Although the committee provides specific guidance to EPA, its recommendations are also generally applicable to the practice of CIA, including by other audiences for this report at the national, state, tribal, and community levels. Federal audiences include agencies making decisions on policies, budgetary prioritization and allocation, and protection of communities (e.g., the Departments of Energy, Transportation, Agriculture, Housing and Urban Development, as well as the Federal Emergency Management Agency, Food and Drug Administration, Centers for Disease Control and Prevention and its Agency for Toxic Substances and Disease Registry, and Consumer Product Safety Commission) and agencies supporting relevant data and research (including but not limited to the National Institutes of Health, National Science Foundation, National Aeronautics and Space Administration, National Oceanic and Atmospheric Administration, U.S. Geological Survey, U.S. Census Bureau, and Bureau of Labor Statistics). The committee's guidance is also broadly applicable to tribal nations and peoples throughout

[2] See Community and Tribal Liaison Biographical Sketches in Appendix B.
[3] National Academies of Sciences, Engineering, and Medicine. 2025. *State of the Science and the Future of Cumulative Impact Assessment: Proceedings of a Workshop–in Brief.* Washington, DC: The National Academies Press. https://doi.org/10.17226/29058.
[4] National Academies of Sciences, Engineering, and Medicine. 2025. *State of the Science and the Future of Cumulative Impact Assessment: Proceedings of a Workshop Series*. Washington, DC: The National Academies Press. https://doi.org/10.17226/29094.

the United States, state and local agencies, and U.S. communities not formally part of the government sector. The committee developed case studies addressing a variety of scenarios faced at the national, tribal, state, and community levels to guide implementation of CIA.

LESSONS FROM PAST WORK TO INFORM CUMULATIVE IMPACT ASSESSMENT

Over the past 40+ years, the National Academies have provided advice on methods for and approaches to environmental and human health assessments of risks and impacts to guide decision-making. Taken together, these National Academies reports provide rich and nuanced advice on the evolving state of knowledge, tools, methods, and technology. Box S-2 provides examples of these decision contexts and corresponding reports that provide relevant advice.

BOX S-2
Examples of Decisions Informed by Cumulative Risk and Impact Assessments

A variety of environmental and public health decisions can be supported by cumulative impact or risk assessments. Examples of National Academies reports that provide relevant advice or commentary for different types of decisions are given below.

- **Identifying communities for attention (e.g., investment) based on disproportionate impact; monitoring and tracking progress over time**
  - 2024 Constructing Valid Geospatial Tools for Environmental Justice
  - 2023 Transforming EPA Science to Meet Today's and Tomorrow's Challenges
- **Wide-impact decision-making such as siting large facilities, transportation planning, and development of national policies**
  - 2019 Vibrant and Healthy Kids: Aligning Science, Practice, and Policy to Advance Health Equity
  - 2012 Linking Community Visioning and Highway Capacity Planning
  - 2011 Improving Health in the United States: The Role of Health Impact Assessment
  - 2009 Science and Decisions: Advancing Risk Assessment
  - 1996 Understanding Risk: Informing Decisions in a Democratic Society
- **Routine decision-making such as in permitting small facilities**
  - 1996 Understanding Risk: Informing Decisions in a Democratic Society
- **Community/tribal-driven or -performed development of priorities and action plans**
  - 2023 Transforming EPA Science to Meet Today's and Tomorrow's Challenges
  - 2012 Exposure Science in the 21st Century: A Vision and a Strategy
  - 2009 Science and Decisions: Advancing Risk Assessment
- **Controlling use of chemicals in products and commerce**
  - 2019 Class Approach to Hazard Assessment of Organohalogen Flame Retardants
  - 2017 Using 21st Century Science to Improve Risk-Related Evaluations
  - 2008 Phthalates and Cumulative Risk Assessment: The Tasks Ahead
  - 1993 Pesticides in the Diets of Infants and Children
- **Developing guidance values or assessing risk, accounting for baseline concomitant exposures and population heterogeneity**
  - 2017 Approaches to Understanding the Cumulative Effects of Stressors on Marine Mammals
  - 2013 Assessing Risks to Endangered and Threatened Species from Pesticides
  - 2009 Science and Decisions: Advancing Risk Assessment
  - 1980 Drinking Water and Health, Volume 1

At EPA, the 1996 Food Quality Protection Act created the first requirement to consider cumulative risks from multiple chemicals, in the specific context of pesticide exposures. Following further developments over time, EPA published its *Interim Framework for Advancing Consideration of Cumulative Impacts* in November 2024. This framework defines cumulative impacts as “the totality of exposures to combinations of chemical and nonchemical stressors and their effects on health, well-being, and quality-of-life outcomes.” It does not require identification of all exposures and effects, instead focusing on those of greatest relevance to a specific decision context, building on recommendations and best practices from multiple National Academies reports.

In parallel, evolving approaches to CIA have been either required, utilized, or proposed in multiple states and communities. Geospatial policy tools, such as the State of California’s CalEnviroScreen, map cumulative impact indicators to inform statewide policies such as the targeting of investments. Other states including New Jersey and Massachusetts have also applied CIA to contexts such as facility siting and emissions permitting. In addition, CIA has also been enacted at the city level, such as in Chicago, to explicitly inform multiple municipal decisions ranging from land use and/or zoning to transportation planning.

Overall, the existing tools and methods applicable to CIA have evolved from three major “lineages” of assessment approaches, as depicted in Figure S-2. Each lineage has been generally applied to different decision contexts, and each has evolved to better address cumulative impacts. While distinct in origin and application, these three lineages—impact assessment, community assessment, and risk assessment methods—each contribute essential concepts, tools, and practices to the current understanding of CIA. Environmental impact assessments, for instance, are used to determine any significant environmental impacts of a project or proposal, while regulatory impact assessments evaluate the impacts and benefits of a range of alternative options to inform policy decisions. Health impact assessments provide a structured scientific approach to include health considerations in the decision-making process, often in the context of programs or policies that are not centered on health. Community assessments use mapping and other geospatial tools, addressing environmental and social factors that impact health and well-being as well as identifying positive amenities within communities. Risk assessment, while focusing on quantifying effects of chemical exposures on health, has increasingly recognized the potential contributions from nonchemical stressors. CIA can be considered an umbrella for these different lineages, and the committee’s conclusions and recommendations aim to better integrate them into a common conceptual foundation applicable across diverse contexts of use.

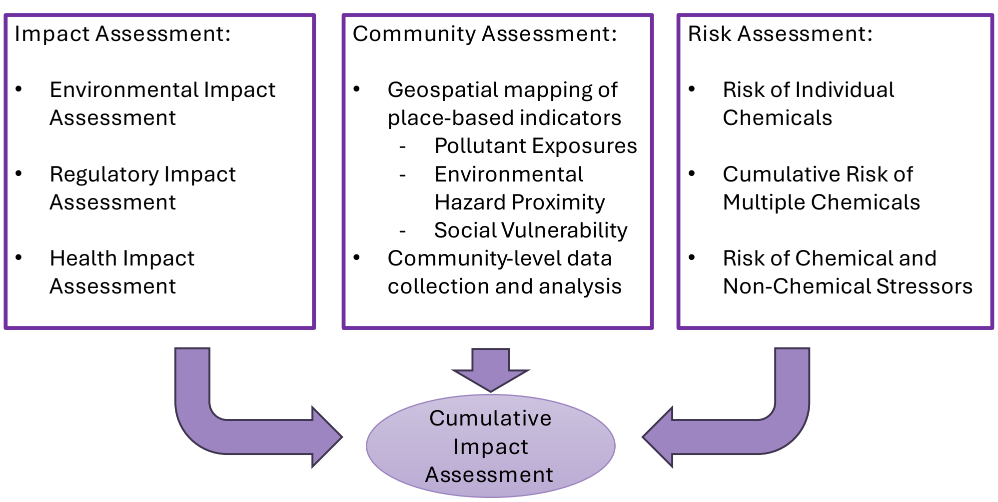

FIGURE S-2 Overview of major lineages of assessments informing cumulative impact assessment.

Conclusion 2-1: The importance of evaluating exposures to combinations of chemical and nonchemical stressors, which can interact to affect health and well-being, has been widely recognized for decades. EPA has partially implemented aspects of cumulative risk assessment, with uneven implementation across offices and programs. However, EPA has not generally moved beyond combining related chemicals that have a common mechanism of action or that affect the same general system (e.g., kidney). Nonchemical stressors are generally not addressed, and EPA has not fully acted upon prior National Academies recommendations or in a manner that is concordant with their definition of cumulative risk assessment.

Conclusion 2-2: Future applications of cumulative impact assessment (CIA) can draw from the wide range of datasets and insights available from the scientific literature and communities and from approaches of impact, community, and risk assessments. Central to CIA are the broad scope, decision-focused orientation, and methods to incorporate qualitative evidence used in impact assessments. Also important to CIA are the geospatial analysis methods within community assessments that support rapid comparisons of locations and populations, along with the tools associated with risk assessment that quantify exposure and health risk with characterization of uncertainty.

Conclusion 2-3: EPA's interim framework, including its definitions of key terms, provides a useful starting point for conceptualizing cumulative impacts. It reflects lessons learned from assessment practices and facilitates the development and improvement of decision-relevant tools. However, the interim framework lacks key steps such as monitoring and evaluation (whether of process, impact, or outcome) and does not provide sufficient information on implementation. Advancing cumulative impact assessment will require multidisciplinary approaches for various environmental decision-making contexts, and implementation will vary due to jurisdictional limitations and resources.

Recommendation 2-1: EPA should update and expeditiously finalize its cumulative impact assessment framework to include a multistep process that is driven by ongoing meaningful engagement and includes monitoring and evaluation of decisions implemented. Specifically, the recommended steps for the practice of cumulative impact assessment are: (1) initiate with meaningful engagement; (2) define scope and formulate problem; (3) assess health and well-being, stressors, and resources; (4) inform planning, policy, and/or decisions; and (5) undertake monitoring and evaluation of process, impact, or outcomes.

The recommended steps of CIA are elaborated in Figure S-3. Ongoing meaningful engagement with interest holders, defined as groups with legitimate interests in the issue under consideration, is an essential aspect of the recommended process. Through this process, CIA can help build and strengthen relationships, support transparency, and reflect the full scope of what affects community health and well-being. This recommended process, applicable to a broad range of actors and interest holders, is designed to be both structured and flexible, reflecting advice from National Academies reports and lessons learned from risk, community, and impact assessment practices.

DATA AND KNOWLEDGE FOR CUMULATIVE IMPACT ASSESSMENT

The committee engaged scientists, community leaders, regulators, and other interest holders to gather information on the data and knowledge essential for CIA. Three committee engagements, summarized in the *Proceedings,* specifically aimed to amplify community and tribal voices by inviting participants to share their lived experiences in small-group discussions. In consultation with the liaisons, the committee designed discussion questions as detailed in Box S-3.

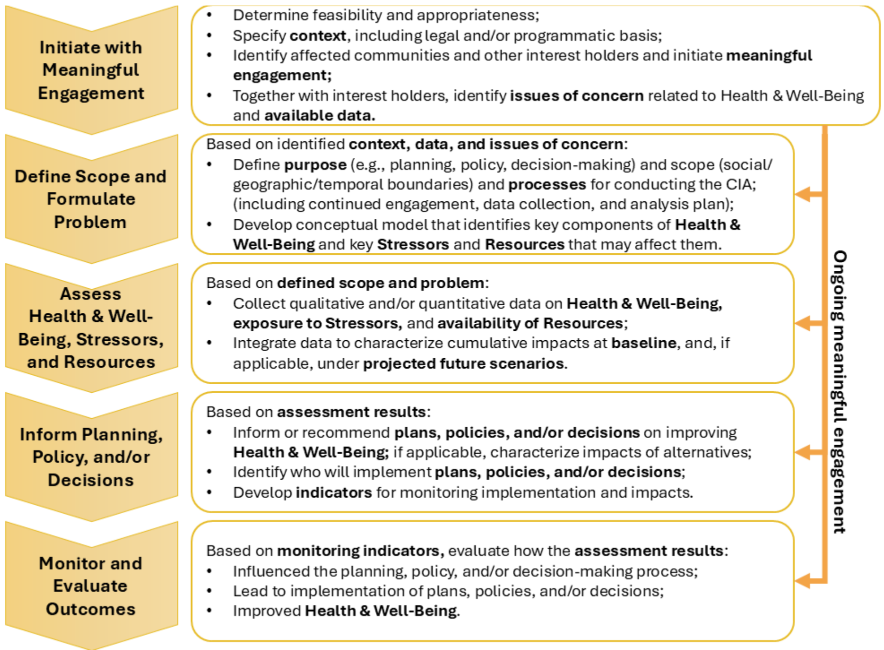

FIGURE S-3 Five-step process for cumulative impact assessment recommended by the committee.

BOX S-3
Discussion Questions

1. What are the main stressors experienced in your community now?
2. What will be the main stressors in the future—in the next 10–20 years?
3. What makes your community more vulnerable to stressors?
4. What are the barriers to strengthening your community's ability to respond to stressors?
5. What is your future vision of improved community health and well-being?
6. What is the most important aspect for our committee to consider?
7. What are special considerations or concerns that should be highlighted to ensure children are properly included in CIAs? [a]
8. What are the opportunities to improve decision-making tools by incorporating tribal knowledge and data? [b]

[a] Only used during the virtual liaison Town Hall.
[b] Only used during the Colorado tribal engagement.

These sessions, together with the review of National Academies reports and developments by EPA and others, revealed a wide and dynamic range of stressors (e.g., environmental, political, economic, cultural) and other factors that may affect health and well-being in communities. These factors may interact in complex ways, such as increasing vulnerability, creating barriers to strengthening resilience, and hindering the paths to improved community health and well-being. Importantly, definitions of health and well-being also vary, highlighting the need for meaningful engagement when addressing cumulative impacts. Furthermore, EPA's conceptual approaches to CIA have historically emphasized negative factors, while numerous National Academies reports, health impact assessments, and concepts such as salutogenesis have also highlighted the importance of positive factors that promote and support health and well-being.

Conclusion 3-1: EPA's interim framework provides a starting point for conceptualizing cumulative impacts, but there is a need for expansion to account for the multiple dimensions of health and well-being for individuals and communities. To address key issues identified and discussed during the committee's information-gathering process, cumulative impact assessment (CIA) would benefit from conceptually separating biological and structural factors into those that promote disease and distress (stressors) from those that promote health and well-being and decrease vulnerability to stressors (resources). Additionally, CIA can be broadened to reflect the deep interconnection between people, animals, and the natural environment and enrich concepts of health and well-being to include physical, mental, emotional, material, social, and spiritual components. Finally, it is necessary to highlight the critical importance of the context of decision-making and provide consideration for different spatial and temporal scales, including past, present, and future.

Recommendation 3-1: In EPA's final framework, and in the practice of cumulative impact assessment, the conceptual paradigm for cumulative impacts should be expanded to encompass the following three concepts:

- **Health and well-being: A broad umbrella encompassing multiple dimensions—including physical, mental, emotional, material, social, and spiritual aspects;**
- **Stressors: Factors that undermine health and well-being; and**
- **Resources: Factors that promote health and well-being.**

Figure S-4 elaborates on the committee's recommended cumulative impacts paradigm (CIP) to characterize and address both stressors and resources. These operate at multiple levels to affect individual and community health and well-being. The CIP respects tribal sovereignty and American Indian and Alaska Native legal self-governance as a critical aspect of understanding local context and the role of data democratization for CIA. The CIP can be applied throughout the recommended steps shown in Figure S-3. The CIP provides a broad basis for developing an inventory of data, indicators, and metrics for use in CIA. Additionally, the CIP highlights the need for and challenges of combining environmental with socioeconomic stressors and resources within communities, addressing potential complex relationships within and across factors, and ultimately translating them to measure and improve overall health and well-being.

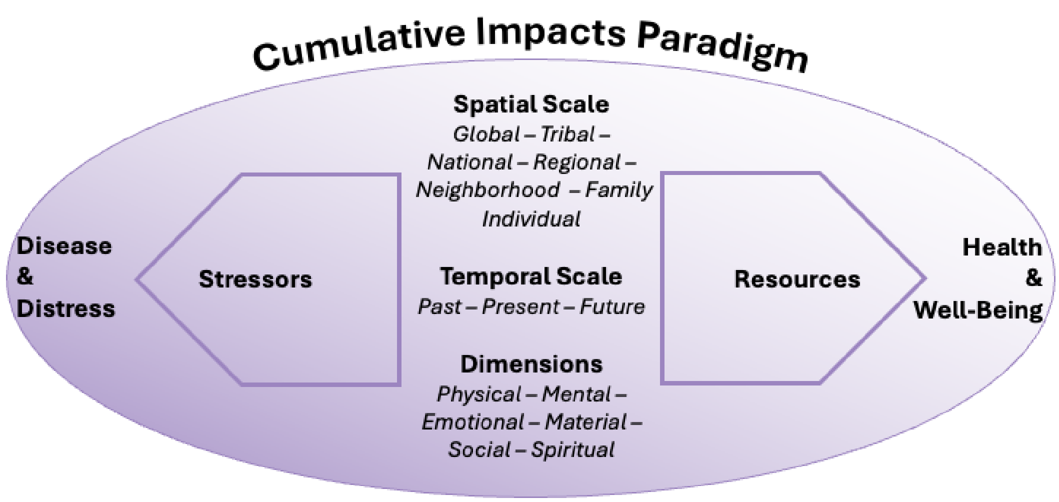

FIGURE S-4 Cumulative impacts paradigm to characterize and address stressors and resources that affect individual- and community-level health and well-being.

Conclusion 3-2: The types of stressors to prioritize, characterize, and consider in combination in a cumulative impact assessment to best reflect overall burdens facing diverse communities and populations may encompass a range of environmental, political, economic, historical, and cultural factors. Similarly, types of resources may vary, including across spatial and temporal scales. A broad consideration of the different stressors faced by and resources available to communities, tribes, and other interest holders can help to facilitate meaningful engagement.

Recommendation 3-2: EPA and other entities should implement existing best practices for meaningful engagement in the context of cumulative impact assessments. Through this process, they should gather and incorporate data and knowledge originating from communities and tribal nations, including traditional ecological knowledge.

METHODOLOGICAL APPROACHES FOR ASSESSING OVERALL HEALTH AND WELL-BEING

Examples of the numerous methodological approaches for CIA are provided in EPA's *Interim Framework for Advancing Consideration of Cumulative Impacts.* The committee's methodological recommendations support the use of existing approaches outlined by EPA as well as expanded sources of evidence and information drawn broadly from scientific advances in the fields of public health, toxicology, epidemiology, exposure science, and other related disciplines including economics, human ecology, anthropology, sociology, psychology, and demography.

These approaches for assessing overall health and well-being vary by decision context—each approach has strengths and limitations, uncertainties, and opportunities for advancement. For assessments of the geographic distribution of cumulative burdens, the most common methods for combining multiple heterogeneous indicators are additive or multiplicative composite indexes and count-based matrix approaches. Toxicology, epidemiology, and exposure science form the basis of authoritative evidence reviews[5] (or systematic reviews) supporting hazard and risk assessments of chemicals and complex mixtures. These assessments can support a range of decisions, such as regulation, exposure reduction, or occupational health monitoring, including when the supporting evidence is less than certain. The findings can be applied in CIAs to prioritize individual or co-occurring chemical stressors and inform their interactions with nonchemical stressors, with epidemiological methods providing real-world evidence in human populations and/or geographic contexts. Economic methods and studies also provide evidence of the impact of stressors on health and well-being, leveraging natural experiments and administrative dataset(s). Advances in exposure science, such as wearable technologies for personal monitoring, can provide more accurate methods to characterize real-life exposures with less bias. Advances in exposomics provide data-driven methods to assess the biological effects of the totality of environmental exposures and social stressors for unbiased discovery of drivers of disease at scale. A life-course framework provides an important foundation for thinking about cumulative impacts, highlighting timing and critical windows of exposure, life transitions, and transgenerational and multilevel interactions in exposure to stressors and in vulnerability factors. Successful integration across these methods will need to build on diverse community lived experiences and practitioner expertise from policymakers, planners, economists, and public environmental health scientists throughout the CIA process.

Conclusion 4-1: EPA provides examples of methods for assessing cumulative impacts, but information is lacking on how to select, apply, and integrate them. The most commonly applied methods are composite-index- or matrix-based approaches in a geospatial context, which have been used at national, state, and local levels and in a range of contexts.

[5] Reviews produced by governmental agencies and international agencies (i.e., EPA, National Toxicology Program, U.S. state agencies, foreign governmental agencies, European Union, International Agency for Research on Cancer/World Health Organization, etc.).

Conclusion 4-2: There is a need to implement cumulative impact assessments (CIAs) that consider multiple chemical and social stressors and resources simultaneously through spatial and temporal dimensions without paralyzing decisions because of uncertainties due to analytical complexity or missing data. Approaches are needed to facilitate evidence-based CIAs while prioritizing timely decisions to support future protection of health and well-being, using rapid methods as appropriate, leveraging existing authoritative or systematic reviews, and applying default assumptions to account for uncertainty.

Recommendation 4-1: In their final framework and their practice of cumulative impact assessment (CIA), EPA should specify how to select and apply appropriate approaches for CIA to assess overall health and well-being based on decision context, engaging with affected populations in the process. Key issues the framework should address include how to:

- **Integrate comprehensive perspectives (e.g., life-course approach, systems thinking, One Health) into CIA;**
- **Integrate both qualitative and quantitative data that allow for identification, prioritization, and characterization of health and well-being, stressors, resources, and metrics that best reflect the overall cumulative impacts that communities face; and**
- **Prioritize timely decision-making using existing tools, data, and evidence syntheses even when there is limited knowledge and data gaps and uncertainties exist by:**
  - **Applying composite-index- or matrix-based methods for rapid CIA, when appropriate;**
  - **Utilizing existing authoritative or systematic reviews, when available; and**
  - **Delineating and justifying "default" assumptions to account for uncertainty associated with data and knowledge gaps with a bias toward action and against underestimation of cumulative impacts. At minimum, EPA should develop a "default" factor for quantifying measures of risk and hazard when formal methods are lacking to account for enhancement of chemical effects from concomitant exposures to other stressors.**

Conclusion 4-3: Advancing cumulative impact assessment relies on maintenance and expansion of authoritative data and databases that document impacts of a wide range of stressors, resources, and multiple aspects of health and well-being and how their combined effects are also impactful. Existing authoritative information sources include EPA's CompTox databases, Chemical and Products database, the Toxic Release Inventory database, Risk-Screening Environmental Indicators, as well as other federal (Centers for Disease Control and Prevention, Bureau of Labor Statistics, U.S. Census Bureau, Department of Transportation, National Aeronautics and Space Administration, National Oceanic and Atmospheric Administration, U.S. Geological Survey, Food and Drug Administration, U.S. Department of Agriculture, U.S. Department of Housing and Urban Development, and Federal Bureau of Investigation), state, and international data resources.

Recommendation 4-2: Government entities responsible for collection and curation of data related to stressors, resources, and health and well-being—including but not limited to EPA, the Centers for Disease Control and Prevention, Bureau of Labor Statistics, U.S. Census Bureau, U.S. Department of Transportation, National Aeronautics and Space Administration, National Oceanic and Atmospheric Administration, U.S. Geological Survey, Food and Drug Administration, U.S. Department of Agriculture, and state and local health and environmental agencies—should maintain, update, and expand datasets and infrastructure for public access and crosswalks across agencies.

Conclusion 4-4: Advancing cumulative impact assessment also requires synthesizing and integrating existing evidence on how health and well-being are affected by exposure to stressors and access to or availability of resources. Existing authoritative syntheses of evidence include federal (by EPA Integrated Risk Information System, Agency for Toxic Substances and Disease Registry, and National Toxicology Program), state (e.g., California, Minnesota, New York) and international (e.g., International Agency for Research on Cancer (for carcinogens), International Programme on Chemical Safety, World Health Organization and Food and Agricultural Organization Joint Meeting on Pesticide Residues, European Commission, European Chemicals Agency, and others) sources. Such authoritative syntheses are compilations of the most up-to-date data available at the time of their development and provide concise summaries of how stressors affect health and well-being. However, these authoritative sources have focused mainly on individual agents, the majority of which are chemicals or lifestyle/behavioral factors.

Recommendation 4-3: EPA, National Institutes of Health, National Science Foundation, National Aeronautics and Space Administration, and other government research funding agencies should support the numerous opportunities available to advance analysis and integration of existing multidisciplinary research into cumulative impact assessment, including:

- **Maintaining and enhancing authoritative resources generated by EPA (e.g., Integrated Risk Information System) and other federal and international bodies (e.g., Centers for Disease Control and Prevention, International Agency for Research on Cancer);**
- **Synthesizing the current knowledge base across the domains of (1) health and well-being, (2) stressors, and (3) resources, to the extent feasible developing systematic scoping reviews, systematic evidence maps, or systematic reviews to inventory factors and indicators; and**
- **Communicating results of authoritative and systematic reviews for use by the general public and identifying potential actions that arise from findings.**

Conclusion 4-5: Continued research on and development of data and methods to support interdisciplinary approaches and integration across methods would support more informative cumulative impact assessments. Opportunities to advance these methods draw from an array of fields, including toxicology, epidemiology, exposure science, statistics and data science, economics, human ecology, demography, and Indigenous knowledge systems.

Recommendation 4-4: Federal agencies and other funding bodies (e.g., EPA, National Institutes of Health, foundations) should advance new research that fills data and methodological gaps needed to address existing uncertainties and improve assessment of health and well-being in cumulative impact assessment.

THE PATH FORWARD: PRACTICAL APPLICATION OF CUMULATIVE IMPACT ASSESSMENT

To illustrate the applicability of their proposed approach, the committee developed case studies to explore the flexibility of CIA for different decision contexts. These case studies illustrate the following aspects of the committee's conclusions and recommendations for CIA:

- Applying CIA to retrospective and anticipatory assessments of existing and proposed regulations is valuable for characterizing overall health implications and population-specific impacts (e.g., the extent to which regulations may improve health and well-being, causal inference studies, and natural experiments related to changes in environmental exposures, such as power plant closures).

- Temporal and spatial variability of cumulative impacts for stressors and resources can be elucidated through CIA.
- Using CIA in disaster preparedness, response, and recovery could have ameliorated some issues in previous events that were challenging for community members (e.g., after the train derailment in East Palestine, Ohio). In addition, performing baseline assessments as part of disaster planning is important to anticipate and prepare for the cumulative impacts of disasters, including industrial incidents such as chemical spills and extreme events such as wildfires, flooding, and heat waves to support fair and targeted response strategies.
- CIA also offers value in evaluating chemical classes and mixtures, particularly where existing regulatory frameworks address substances individually. There is a need to integrate social context and community knowledge with advanced scientific methods to better understand the effects of classes of chemicals and chemical mixtures. In addition, evidence from mechanistic biology, computational science, and epidemiology, and considering high-risk exposure scenarios and vulnerable populations can be informative. Composite exposure and risk metrics can support precautionary approaches and help fill data gaps related to differential exposures and various health effects across population groups.

Conclusion 5-1: The case studies underscore the applicability of cumulative impact assessment to many different decision contexts. Entities undertaking cumulative impact assessment, including EPA, other national entities, states, and localities need to be flexible to accommodate different community contexts, scales, and programmatic needs while learning from prior experiences in specific communities. Cumulative impact assessments that promote data transparency, access, and linguistic inclusion are likely to have more relevance for and reach to diverse end users and be more reproducible and scalable.

Conclusion 5-2: Based on the case studies, the committee's recommended cumulative impacts paradigm and accompanying five-step process can increase the effectiveness of actions to improve health and well-being. However, additional information is needed on designing cumulative impact assessments for different communities, scales, and programmatic needs (Step 2) and developing monitoring and evaluation strategies that ensure progress toward improved health and well-being (Step 5).

Recommendation 5-1: With respect to the assessment design (Step 2 of the recommended five-step process), EPA's final framework and the practice of cumulative impact assessment should include guiding/diagnostic questions to facilitate adaptability and generalizability to different communities, scales, and programmatic needs, including:

- **When cumulative impact assessment is appropriate rather than health impact assessment, cumulative risk assessment, or other approaches;**
- **Appropriate scope and detail of a proposed cumulative impact assessment, given resource and time constraints as well as community and decision-making contexts, with options ranging from in-depth cumulative impact assessment processes to rapid cumulative impact assessments to address an immediate concern based on readily available data;**
- **Scope of actions available to the regulatory agencies involved and trade-offs among them;**
- **How best to assess and measure the effectiveness of existing and future policies and regulations; and**
- **Anticipatory applications of cumulative impact assessment and potential for reducing impacts across myriad populations and communities.**

Recommendation 5-2: With respect to monitoring and evaluation (Step 5 of the recommended five-step process), EPA's final framework and the practice of cumulative impact assessment should include strategies for:

- **Incorporating both technical indicators and community-defined quantitative and/or qualitative metrics;**
- **Using both retrospective and anticipatory approaches to examine whether/how patterns and population distributions of cumulative impacts are changing over time; and**
- **Supporting ongoing program adjustments to better achieve program goals.**

Conclusion 5-3: A mature application of cumulative impact assessment adopted by many national and state entities is the use of composite-index- or matrix-based approaches for baseline assessments of cumulative burdens to identify communities for specific policy interventions, such as facility siting limitations and targeting of investments for enhancing resources; however, improvements to methodologies, data availability, and comprehensiveness are still needed. These structured methods provide a replicable and scalable foundation for screening, prioritization, and evaluation.

Recommendation 5-3: EPA and other national entities, states, and localities should expand use of composite-index- or matrix-based approaches for baseline assessments of cumulative burdens to identify communities for interventions to improve health and well-being. Examples of interventions that can be informed by these types of cumulative impact assessment include:

- **Facility siting decisions and permit approvals or renewals;**
- **Site remediation;**
- **Resource investment allocation; and**
- **Enhanced regulatory protection and enforcement.**

Conclusion 5-4: Capacity building is needed for entities undertaking cumulative impact assessment, including EPA, other national entities, states, and localities, in several areas:

- *Meeting communities, myriad interest holders, and decision-makers where they are to effectively engage them throughout the cumulative impact assessment process. For example, this means understanding what a community actually wants and needs, what resources they already have, what challenges they face, and what their priorities are.*
- *Developing tools that are accessible for myriad end users and that communities and decision-makers can apply locally, on their own.*
- *Developing processes and tools that integrate community knowledge with advanced scientific methods to assess or predict effects of chemical classes and exposures to multiple chemicals over the life course, taking into account the social context.*

Recommendation 5-4: EPA and other national entities, states, and localities should develop, or support development of, tools, best practices, and requisite training to increase capacity at the community, state, and national scales for conducting cumulative impact assessment in diverse contexts. Specific priorities include:

- **Data warehouses and software tools that enable customized development of baseline assessments of health and well-being, stressors, and resources;**
- **Tools that incorporate local, community, and tribal data along with governmental datasets;**
- **Tools that can rapidly include multiple indicators in implementing composite scoring, indexing, or matrix-based approaches;**

- **Retrospective and anticipatory case studies and best practices to demonstrate successful implementation of cumulative impact assessments; and**
- **Tools to integrate social context and community knowledge with scientific methods for assessing the effects of classes of chemicals and chemical mixtures.**

1
Introduction

Cumulative impact assessment (CIA) is a tool to help environmental and other relevant decision-makers consider multiple factors in evaluating priorities and potential changes in local, state, tribal, and/or national policies or regulations, with a focus on improving health and well-being. Every community across the United States faces impacts on their health and well-being. These impacts may arise from a wide range of sources such as pollution of air, water, and soil (including from industrial accidents); natural events (including wildfires and major storms); and from limited access to health care, unaffordable housing, poverty, and unemployment. Impacts may be heightened or attenuated by economic, social, and other factors. CIA can help explore how different options for decisions related to, for example, zoning and permitting, may impact the community and can be considered in the broader context of these various environmental and structural factors.

In response to a request from the U.S. Environmental Protection Agency (EPA), this report aims to advance the scientific foundation and hence the practice of CIA, in line with EPA's responsibilities and authorities. Importantly, the work builds on prior advice from the National Academies contained in a number of seminal reports, including recent reports on using new approach methods to inform efforts to protect susceptible and vulnerable populations (NASEM, 2023) and constructing geospatial tools to characterize impacts (NASEM, 2024). In many reports, the National Academies have posited frameworks or provided advice to address long-standing challenges—such as the need for practical and timely decision-making in the face of gaps in data and knowledge. The committee's work also builds on developments by EPA and others in cumulative risk and impact assessment and responses from communities to these efforts. The committee extends this historical expertise using an interdisciplinary approach to identify and address the key challenges and opportunities for progress. It aims to provide practical guidance on the state of the science of CIA and its application at the community, state, and national levels.

This chapter introduces the committee's task, outlines its approach, and describes the committee's public engagement plan and information-gathering activities. It also addresses the audiences of this report. Key terms are defined, and the organization of subsequent chapters is outlined.

THE COMMITTEE'S TASK

The committee convened in response to EPA's request included expertise in the physical, chemical, biological, environmental, and social and behavioral sciences. Collectively, the committee's expertise was appropriately broad and comprised anthropology, community-engaged participatory research, data science, economics, epidemiology, psychology, public health, public policy, risk and impact assessment, sociology, and toxicology (see Appendix A for biographical information on the committee). The committee was asked to convene state-of-the-science workshops and engage in other information-gathering activities and provide advice to EPA to advance the practice of CIA. The verbatim statement of task is provided in Box 1-1.

COMMITTEE'S APPROACH TO THE TASK

To address its task, the committee developed a public engagement plan for its information-gathering activities, during which the committee sought input across the social, behavioral, and risk sciences, communities, tribes, EPA, other federal agencies, state and local entities, and the general public.

In addition, the committee reviewed technical publications, including from the published literature, relevant National Academies reports, frameworks to promote data democratization and sovereignty for Indigenous peoples, and documents from government agencies. All materials submitted to the committee by outside parties, including from community members, were also reviewed. In addition to the open sessions shown in Figure 1-1, closed meetings of the committee as a whole and in subgroup were also held from June 2024 to August 2025. Closed sessions were used to discuss the approach to the statement of task, plan public engagements, share reflections after each public session, discuss scientific issues and impact methods, and to advance progress on this report.

BOX 1-1

Statement of Task

An ad hoc committee of the National Academies of Sciences, Engineering, and Medicine (National Academies) will convene state-of-the-science workshops and develop a consensus report to advise on how EPA might further develop the scientific foundation underlying the practice of cumulative impact assessment.

The charge questions to the committee are as follows:

1. How can elements of prior risk assessment advice from the National Academies, developments by EPA and others, and response from communities inform a holistic and inclusive approach to developing and implementing cumulative impact assessment?
2. What types of stressors, both now and anticipated in the future, should be prioritized, characterized, and considered in combination in a cumulative impact assessment to best reflect overall burdens facing diverse communities and populations?
3. How can cumulative impact assessment consider factors that may make a community more vulnerable to stressors, barriers to strengthening a community's ability to respond to stressors, and critical paths to improved community health and well-being in the future?
4. How can community and tribal data and knowledge be incorporated into cumulative impact assessment?
5. What approaches for assessing overall health and well-being are most useful for incorporating into cumulative impact assessment?
6. How can uncertainty in cumulative impact assessments be characterized?
7. How can cumulative impact assessment be adapted to different communities, generalized to regional or national scale, and remain flexible for EPA's different programmatic needs?

Community and Tribal Engagement

A key aspect of the committee's approach to the statement of task entailed community and tribal engagement. From the start of the study, the committee engaged with a group of liaisons from across the United States to facilitate incorporation of community and tribal knowledge and perspectives (see Appendix B). Members of the liaison group were solicited through a nomination process similar to that used for National Academies committees. The nominations process was initiated at the time of committee formation, and enrollment continued for the study duration. The liaisons provided input into the agenda for the committee's public meetings, developed discussion questions for the meetings, provided data or resources for the committee to consider, and suggested reviewers for the report for consideration by National Academies staff. The committee's public engagement plan was organized with the input of the community and tribal liaison group members, as illustrated in Figure 1-1.

FIGURE 1-1 Overview of committee's public engagement plan.

The committee's public engagement plan had strengths and limitations. The liaison group included members from different communities across the United States with lived experience of cumulative impacts. They afforded an opportunity to provide a broad, national perspective to the committee. Nonetheless, smaller community-based organizations or tribes may not have participated due to capacity or other constraints. The liaison group had the opportunity to network with each other and had repeated interactions with National Academies staff and the committee through virtual sessions, strengthening their relationship with the study. The virtual meetings allowed for improved access, including to those liaisons unable to meet in person. The committee also sought additional in-depth input through in-person engagements that were open only to local participants, one of which focused specifically on conversations with local tribal members. Nonetheless, the in-person engagements were limited to two events because of the time constraints of the study. While modest financial support was provided for in-person participants in the form of a token of appreciation, some could not participate due to lack of funding or other challenges. Attendance may have been improved had additional funding to support participation in the meetings been available. Further, the perspectives gained were focused on the volunteers who joined the liaison group, the places where the events were conducted, and the individuals who chose to participate.

Information-Gathering Engagements

Four of the committee's meetings included public sessions. Table 1-1 summarizes the committee's information gathering conducted during the open sessions and workshops. Overall, the committee conducted six public workshops and open sessions across which they gathered input from more than 100 individuals.

The committee's open session with practitioners and community members on the application of CIA is summarized in Box 1-2.

TABLE 1-1 Information-Gathering Engagements

Event	Date	Location	Participants
Hybrid Open Session during first meeting	July 22, 2024	Washington, D.C. and virtual	EPA, liaisons
Virtual workshop	October 15, 2024	Virtual	Social, behavioral, and risk scientists, liaison discussants
Open session with practitioners during sixth meeting	October 22, 2024	Virtual	Community members and practitioners from local, state, and federal governments
Community-engaged workshop and site visit	November 20, 2024	New Orleans, LA	Local community members, liaisons
Virtual townhall during eighth meeting	December 12, 2024	Virtual	Liaisons
Colorado tribal engagement during tenth meeting	February 12, 2025	Aurora, CO	Local tribal members

BOX 1-2
Open Session with Community Members and Practitioners

During the committee's sixth meeting, on October 22, 2024, the committee gathered information through a panel discussion on case examples of cumulative impact assessment (CIA) implemented by government agencies at federal, state, and/or local levels. Community members and practitioners providing different government perspectives explored and discussed example applications of CIA. For further details, see the full recording and transcript of the session and the event page[a]; the meeting agenda and biographical information on the speakers are also available in Appendix C.

The invited panelists were as follows:

- Sandra Baird, Chief, Toxicology Division, Office of Research and Standards, Massachusetts Department of Environmental Protection
- Sabine Lange, Chief, Toxicology, Risk Assessment, and Research Division, Texas Commission on Environmental Quality
- Nicky Sheats, Director, Center for the Urban Environment, John S. Watson Institute for Urban Policy and Research, Kean University
- Meredith Williams, Director, California Department of Toxic Substances Control (*through September 2024*)
- Ann Wolverton, Senior Research Economist, National Center for Environmental Economics, U.S. Environmental Protection Agency.

Following an overview presentation by the invitees, a panel discussion moderated by committee members focused on the following questions:

- What are other types of decisions (besides permitting and zoning) to which you would you like to apply CIA?
- What are research or data gaps and resource needs to improve CIA going forward?
- How do you envision the future CIA?
- What is the most important aspect of CIA for our committee to consider?

Main takeaways were as follows:

- CIAs have been implemented at various levels of government, with examples covering local, state, regional, and national settings for the committee to learn and build from.

continued

BOX 1-2 *continued*

- CIA is not one-size-fits-all. The decision and regulatory contexts, local priorities, and place-based measures of stressors are critical considerations in designing assessments.
- Meaningful community engagement is key to the success of CIAs.
- CIAs benefit from a broadened consideration of stressors to encompass structural and cultural factors, overall environmental quality, and community well-being.
- Despite significant gaps in data, analyses, and resources needed to improve the approach, timely decisions in the face of uncertainty can be made using existing tools.

[a] See https://vimeo.com/1011350372?p=1l and https://www.nationalacademies.org/event/43813_10-2024_state-of-the-science-and-the-future-of-cumulative-impact-assessment-meeting-6.

The committee therefore gathered information in a focused way from the following:

- *Scientists*: The October 2024 Virtual Workshop sought input across social, behavioral, and risk sciences, with participants from academic and private research organizations, nongovernmental organizations, and government agencies discussing fundamental concepts and methods pertinent to CIA. A member of the liaison group was included on each discussion panel.
- *Communities*: The committee gathered information from different communities across the United States through their interactions with the liaison group in open session, including both workshops, the open session with practitioners, the liaison Town Hall, and the tribal engagement in Colorado. The committee reviewed written materials, including those submitted from community members, on activities ongoing in cities and communities within the United States.
- *Tribes*: The committee gathered relevant information directly from tribal members, including through their workshops, the tribal engagement in Aurora, Colorado, and other open sessions.
- *EPA*: The committee reviewed all material provided from EPA, including material presented publicly during the July 2024 open session and EPA's draft interim CIA framework (EPA, 2024). The committee also reviewed past guidance to EPA provided in prior National Academies reports as well as the applicable needs across different EPA programs (e.g., chemical regulation under the Toxic Substances Control Act).
- *Other Federal Agencies and State and Local Entities*: The committee gathered information on relevant state laws and activities and heard perspectives from regulatory scientists on implementation of CIAs at the state level.
- *General Public*: All the public sessions included a real-time opportunity for the committee to engage with public participants via an oral public comment period or through use of an online portal for written comments. Participants were also encouraged to provide written comments to the committee at any time during the course of the study, and submissions were maintained as part of the project's public access file. The committee reviewed all material submitted to it from the public.

A separately published *Proceedings-in-Brief* (NASEM, 2025a) summarizes the virtual public workshop that sought input across social, behavioral, and risk sciences, and included a member of the community and tribal liaison group included on each discussion panel. A *Proceedings of a Workshop Series* (NASEM, 2025b), also published separately, summarizes three of the community and tribal engagements conducted by the committee: the community-engaged workshop in New Orleans, Louisiana; the virtual Town Hall with liaisons; and the tribal engagement event in Aurora, Colorado.

AUDIENCES OF THE REPORT

The committee envisions several different audiences of their report, in line with their charge to consider how CIA can be adapted to different communities, generalized to regional or national scale, and remain flexible for EPA's different programmatic needs. These audiences are addressed in detail below.

EPA and Federal Agencies

EPA is the sponsor of this study, and the committee specifically addresses the strengths and weaknesses of EPA's draft *Interim Framework for Advancing Consideration of Cumulative Impacts* (EPA, 2024), including specific ways in which it may be improved. The committee's report provides guidance and case studies applicable to EPA's different programmatic needs and is also applicable to cumulative impact activities in EPA regional offices. The report is also addressed to other federal agencies responsible for emergency response as well as those involved in gathering and disseminating national-level data on various factors important for understanding cumulative impacts at the national, regional, state, and community levels.

Tribal Nations

The perspectives gained from information gathering from the tribal engagement discussed above are reflected in the committee's proposed framework for CIA, and guidance for implementation is elaborated through a case study. The committee's proposed cumulative impacts paradigm respects tribal sovereignty and American Indian and Alaska Native legal self-governance as a critical aspect of understanding local context and the role of data democratization for CIA. The committee's guidance provides a basis for developing a comprehensive and accurate picture of the resources and challenges facing these communities.

States

The committee's proposed framework for CIA and guidance for implementation is applicable to regulators and policymakers throughout the United States.

Communities

The committee's proposed framework for CIA and guidance for implementation is broadly applicable to U.S. communities. Specific case studies addressing a variety of scenarios that communities may face are elaborated as an aid to implementation.

KEY TERMS

Cumulative impact assessment relies on insights and methods across multiple domains. This report identified three types of assessments that most influence and inform the practice of CIA: risk assessment, community assessment, and impact assessment. A general definition and description of the relevant aspects of these methods are provided below.

- **Risk assessment.** Risk assessment compiles, synthesizes, and analyzes the scientific evidence of the effects of stressors on health; identifies hazards; and typically produces quantitative measures of risk or harm from the exposures. EPA has used risk assessments to inform decisions, with an early focus on assessing the health risks of individual chemicals gradually evolving to assessing the risk of multiple chemicals. More recently, EPA has aspired to include nonchemical stressors such as psychosocial factors in combination with chemicals in cumulative risk assessments.

- **Community assessments.** Community assessments use mapping and other geospatial tools that enable the visualization and comparison of myriad stressors impacting a community, including both environmental and social factors that impact health and well-being. For example, indicators can be developed for pollution burden, socioeconomic deprivation, lack of educational opportunity, and population vulnerability. These assessments also involve identification of positive amenities within communities. The tools have evolved over time to have an increasing emphasis on cumulative impacts, including through the scoring of indicators, and integration into groups or overall scores to give a measure of impact for a specific place in comparison with other places.
- **Impact assessments.** Impact assessments, which are broader in scope than chemical risk assessments, evaluate the impact of a proposed regulation, policy, program, or project. They explicitly incorporate both quantitative and qualitative information while including multiple factors causing harm. One such method is health impact assessment (HIA), which evaluates impacts on human health and well-being from proposed projects or policies that typically do not consider health. The process for conducting an HIA has had many commonalities with those of environmental impact statements and environmental assessments, required under the National Environmental Policy Act of 1969. These assessments focus on impacts on the natural environment but can include impacts on health. Regulatory impact assessments, done by EPA since the 1970s, describe the potential societal benefits and costs of the regulation, and ultimately the net health and other benefits, some of which are not quantified.

Some terms used by EPA in its risk and cumulative impact assessments are provided in Box 1-3. EPA refers to chemical and nonchemical stressors, largely because of its regulatory mandate to address chemical exposures while acknowledging the influence of nonchemical stressors that can amplify risk. This report uses this terminology when referring to activities specific to EPA or other agencies tasked with environmental protection, while utilizing broader language when appropriate to reflect different decision contexts.

EPA's definition of cumulative impact also uses the terms "well-being" and "quality of life" outcomes, with human well-being defined as "the degree to which an individual, family, or community can be characterized as being happy, healthy, and prosperous" and quality of life defined as "individuals' perceptions 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." This aligns with the widely utilized World Health Organization definitions, a reasonable point of reference for the discussions in this report:

> Well-being is a positive state experienced by individuals and societies. Similar to health, it is a resource for daily life and is determined by social, economic and environmental conditions. Well-being encompasses quality of life, as well as the ability of people and societies to contribute to the world in accordance with a sense of meaning and purpose. (WHO, n.d.)

EPA also provides a definition of meaningful engagement in its 2024 *Interim Framework for Advancing Consideration of Cumulative Impacts* (see Box 1-4).

BOX 1-3
EPA Definitions of Cumulative Risk, Cumulative Impact, and Related Terms

EPA recently reaffirmed its definitions of key terms related to cumulative risk and cumulative impact as follows (EPA, 2025):

- **Aggregate exposure.** The sum of exposures to a single stressor from all sources by multiple routes over multiple periods (EPA, 2019).
- **Cumulative exposure.** An accounting of exposures to multiple stressors and sources by multiple pathways and routes over multiple periods (Zartarian and Schultz, 2010).
- **Cumulative impacts.** The totality of exposures to combinations of chemical and nonchemical stressors and their effects on health, well-being, and quality-of-life outcomes (EPA, 2022).
- **Cumulative impact assessment.** The process of accounting for cumulative impacts in the context of problem identification and decision-making. Cumulative impact assessments consider exposures to both chemical and nonchemical stressors at each life stage throughout the life course and apply to individuals, geographically defined groups, or definable population groups (EPA, 2024).
- **Cumulative risk assessment.** An analysis, characterization, and possible quantification of the combined risks to health and/or the environment from multiple agents and/or stressors (EPA, 2003).
- **Nonchemical stressor.** A stressor that is not based on chemical exposure, which could include biological or physical factors and activities that directly or indirectly adversely affect health or increase vulnerability to chemical stressors. The term is often used to refer to psychological or social stressors that might also act as an exposure-response modifier to other stressors (EPA, 2003; Tulve et al., 2016).

BOX 1-4
EPA Definition of Meaningful Engagement

- Providing timely opportunities for members of the public to share information or concerns and participate in decision-making processes;
- Fully considering public input provided as part of decision-making processes;
- Seeking out and encouraging the involvement of persons and communities potentially affected by federal activities by:
  - Ensuring that agencies offer or provide information on a federal activity in a manner that provides meaningful access to individuals with limited English proficiency and is accessible to individuals with disabilities;
  - Providing notice of and engaging in outreach to communities or groups of people who are potentially affected and who are not regular participants in federal decision-making; and
  - Addressing, to the extent practical and appropriate, other barriers to participation that individuals may face; and
- Providing technical assistance, tools, and resources to assist in facilitating meaningful and informed public participation, whenever practicable and appropriate. (EPA, 2024)

ORGANIZATION OF THE REPORT

The committee organized its report to reflect the overarching elements of its charge. Chapter 2 addresses the first charge question to the committee and addresses lessons from past work to inform CIA. Based on these lessons, the committee outlines a five-step approach to CIA in Chapter 2 (see Figure 2-4), specifically: (1) initiate meaningful engagement (as defined above in Box 1-4), to be continued through all subsequent steps; (2) define scope and formulate problem; (3) assess health and well-being, stressors, and resources; (4) inform planning, policy, and/or decisions; and (5) monitor and evaluate outcomes.

The steps of CIA are then addressed in detail in Chapters 3–5. Chapter 3 addresses the first and second steps of the process by describing the data and knowledge for CIA, including the insights gained through the committee's information-gathering sessions. Chapter 3 concludes with a conceptual paradigm to characterize and address stressors and resources that affect individual- and community-level health and well-being. Chapter 4 then addresses the third step of the CIA process by presenting methods and approaches for assessing overall health and well-being. The final chapter, Chapter 5, provides example applications at different levels of implementation, guiding use of the proposed framework. Among other topics, Chapter 5 provides recommendations specifically relevant to the second and fifth steps of the committee's recommended process (i.e., CIA design, as well as monitoring and evaluation).

Several appendixes are then provided. Appendix A provides committee biographies, and liaison biographies are in Appendix B. Public meeting agendas are provided in Appendix C. Appendix D provides a summary of National Academies reports relevant to the committee's charge, serving as a supplemental table for Chapter 2.

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2
Origins and Advancement of Cumulative Impact Assessment

This chapter addresses the following charge question:

> *How can elements of prior risk assessment advice from the National Academies, developments by EPA and others, and response from communities inform a holistic and inclusive approach to developing and implementing cumulative impact assessment?*

To address this charge question, this chapter summarizes and synthesizes relevant scientific approaches to assessing cumulative impacts, advice from prior National Academies reports, developments by EPA, developments by others, state and local efforts, and perspectives of communities. The chapter concludes with the committee's recommendations based on the trajectory over time of cumulative impact assessment (CIA) and related methods.

SCIENTIFIC UNDERPINNING OF CUMULATIVE IMPACTS ON HEALTH

Addressing cumulative risk or impact is critically important in ultimately understanding the etiology of diseases and disorders and thus advancing their prevention or treatment. It has been repeatedly acknowledged for decades that many human diseases and disorders arise from exposures to multiple risk factors or stressors. Correspondingly, people are exposed concurrently and sequentially to multiple risk factors or stressors across the lifetime. Even though CIA extends beyond what can be captured within toxicological or epidemiological studies, it is valuable to understand the historical and foundational information these disciplines provide. Although authoritative reviews or systematic reviews in this area are sparse, the data from individual studies, insights from multiple prior National Academics reports and governmental efforts, and the community feedback (see Chapter 3) underscore the importance of this topic.

When considered from a physiological perspective, different risk factors may produce a common downstream effect, even though this is achieved through different molecular or cellular mechanisms. For example, reductions in levels of the androgen male hormones leading to male reproductive system dysfunction in rats can be caused by a variety of factors. In one study, exposures to a mixture of 15 different pesticides and phthalates, each known individually to produce male reproductive tract defects by reducing androgens, were administered together at doses each of which by itself was without observable effect, but which together resulted in toxicity (Conley et al., 2021). This and other such studies show the potential for cumulative toxicity, in this case, male reproductive toxicity, even at exposure levels where individual chemicals were without observable effect, and different chemicals acted via different molecular mechanisms. Ultimately, the combination of these chemical exposures culminated in the reduction of levels of androgens and produced male reproductive tract defects.

Nonchemical risk factors also act on the body's physiological processes and may interact with chemical exposures to produce effects. Experimental animal studies have shown interactive effects, including those of chemical and nonchemical stressors. For example, early studies indicated that exposures of rats to stressors (such as early maternal separation from pups) could enhance the effects of lead (Pb) exposure during pregnancy on brain neurotransmitter alterations seen in offspring such that it appeared to produce effects comparable to a higher exposure concentration of Pb. Moreover, maternal exposures to Pb and stress enhanced the behavioral toxicity seen in offspring (Virgolini et al., 2008). In some of these studies, effects were only seen under conditions of combined Pb exposure and stress (Cory-

Slechta et al., 2013). Such interactions have not been limited to Pb exposure. For example, in adult rats, exposures to stress in combination with low doses of pyridostigmine bromide, DEET, and permethrin were found to show neurochemical and neuropathological alterations that were not found in response to either alone (Abdel-Rahman et al., 2004). In rats exposed to social stress, effects of exposures to particulate matter air pollution were also enhanced, suggesting that chronic stress could alter the respiratory response to air pollution (Clougherty et al., 2010).

Epidemiological literature provides numerous examples of health effects caused by chemical exposures amplified by nonchemical risk factors (e.g., McHale et al., 2018). As an example, an early review article reinforced the ways in which air pollution can interact with socioeconomic position (which itself can also be a proxy for numerous individual nonchemical stressors) to influence adverse health outcomes (O'Neill et al., 2003). As a second example, combined prenatal exposures to psychosocial stress and chemical exposures (i.e., air pollution, metals) has been shown to elicit greater health effects in children than either taken in isolation, with the observation that their co-occurrence is widespread (Padula et al., 2020). There has been a large and robust literature on epidemiological mixtures methods, which have emphasized the health effects of combined exposures to multiple chemicals but have increasingly included nonchemical exposures such as stress or poor nutrition (e.g., Joubert et al., 2022).

Epidemiological and toxicological findings across many years are therefore consistent with the often acknowledged understanding that most human diseases and disorders arise from interactions of multiple factors. These include environmental, structural, and genetic factors, psychosocial stressors, and social and economic factors such as poverty, rather than a single etiologic factor (Schriml et al., 2023; Varshavsky et al., 2023). In some cases, exposure to one risk factor may not be sufficient to produce observable adverse consequences, but exposure to multiple stressors may overcome physiological compensation processes and result in adverse health consequences (Rider, 2022). The picture is further complicated by the contribution to variable responses from extrinsic exposures, chemical and nonchemical, as well as from the wide range of intrinsic factors such as age. As depicted in Figure 2-1, some factors contribute to ill health, whereas others contribute to resiliency. It shows the complex interaction of such factors, which vary over the lifetime.

The inclusion of multiple risk factors in scientific research and in decision-making contexts will assist in ultimately understanding human diseases and disorders, identifying responsible factors and important interactions of such factors and thereby leading to improvement in public health protection. Defining the impact on public health by a single risk factor in isolation, rather than in a cumulative context, clearly mischaracterizes the ultimate likelihood of adverse consequences on human health and well-being.

ADVICE FROM PREVIOUS NATIONAL ACADEMIES REPORTS

Over the past 50 years the National Academies have provided advice to federal agencies and other entities on approaches for assessing environmental and human health risks and impacts. This committee was tasked with reviewing how this prior risk assessment advice "can inform a holistic and inclusive approach to developing and implementing cumulative impact assessment." While a formal systematic review was beyond the committee's scope, the committee approached this task by identifying relevant reports through a librarian search, without date limit, of National Academies publications that contained the term "cumulative." Fifty-three reports were identified, of which 39 were committee consensus studies, 9 were workshop or symposium proceedings or summaries, and 5 were contractor-written reports developed under the auspices of the National Academies Transportation Research Board. Additional relevant National Academies reports were also found during the review. Appendix D tabulates all the reports found, gives an overview of the purpose or committee charge, describes the usage of the term "cumulative" pertaining to assessments or impacts, and notes the advice given on assessments and methods of relevance to the committee's charge.

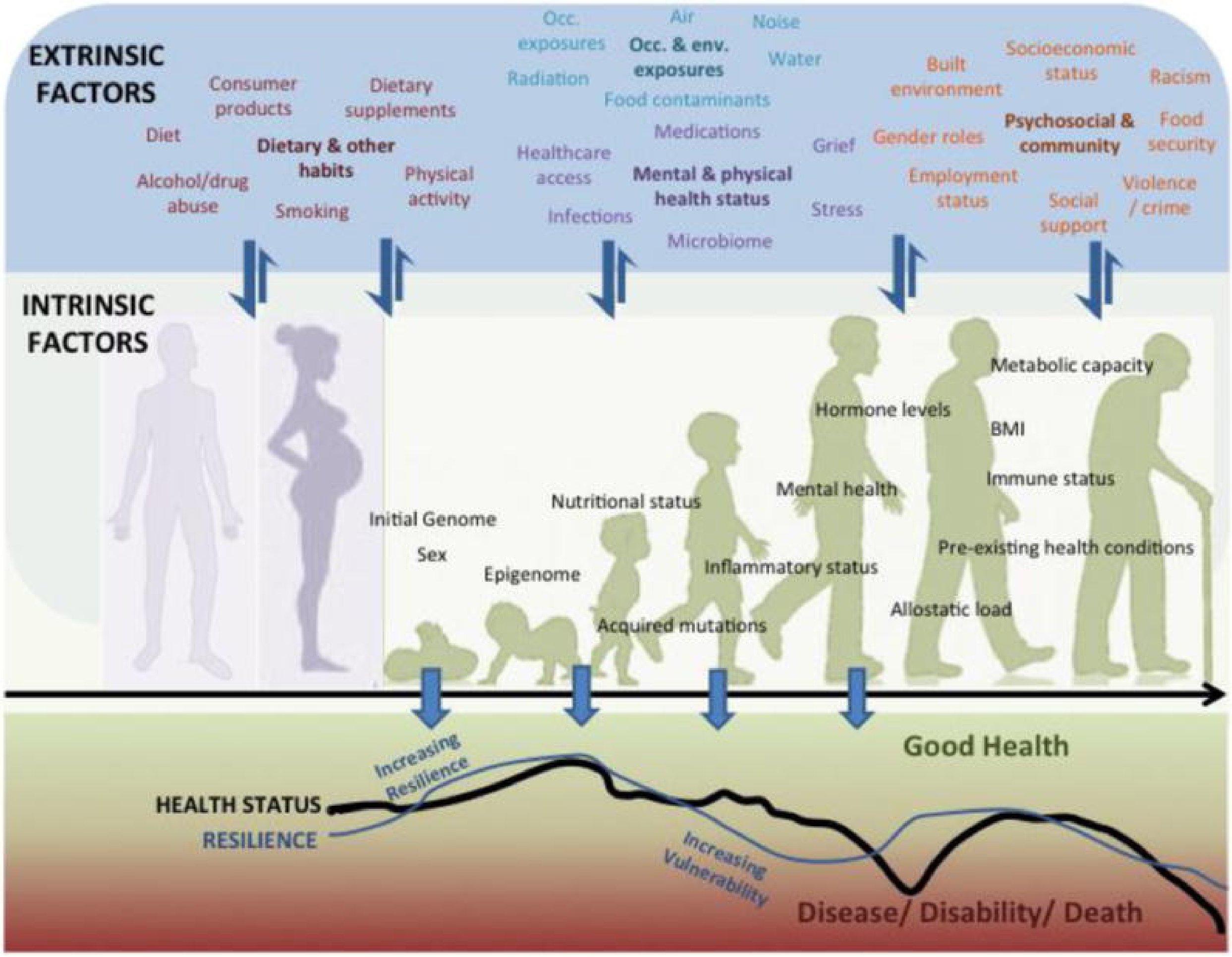

FIGURE 2-1 Example depiction of the influence of multiple factors on health.
SOURCE: McHale et al., 2018.

Taken together, National Academies reports provide rich, nuanced, and evolved advice on tools, methods, and terminology for assessments intended to support decision-making based on the state of knowledge and practice at the time the advice was provided. Box 2-1 provides examples of the types of decisions supported by these tools and methods and of the National Academies reports that provide relevant advice in those areas. Some tools, such as health impact assessment (HIA), are adaptable to a range of decision types, and thus this should not be taken as a singular mapping of tools and advice to each type of decision.

Overarching themes of the National Academies reports include strategies for determining the scope of the assessment, characterizing and accounting for uncertainty, and designing the assessment to ensure decision relevance, along with insight about specific tools that could facilitate the implementation of various types of assessments. Collectively, these reports reinforce that many of the techniques and approaches needed for informative CIA are readily available. They reflect the evolution over time of practice and understanding and provide a robust foundation for the current state of the science of CIA.

BOX 2-1
Examples of Decisions Informed by Cumulative Risk and Impact Assessments

A variety of environmental and public health decisions can be supported by cumulative impact or risk assessments. Examples of National Academies reports that provide relevant advice or commentary on different types of decisions are given below.

- **Identifying communities for attention (e.g., investment) based on disproportionate impact; monitoring and tracking progress over time**
  - 2024 Constructing Valid Geospatial Tools for Environmental Justice
  - 2023 Transforming EPA Science to Meet Today's and Tomorrow's Challenges
- **Wide-impact decision-making such as siting large facilities, transportation planning, and development of national policies**
  - 2019 Vibrant and Healthy Kids: Aligning Science, Practice, and Policy to Advance Health Equity
  - 2012 Linking Community Visioning and Highway Capacity Planning
  - 2011 Improving Health in the United States: The Role of Health Impact Assessment
  - 2009 Science and Decision: Advancing Risk Assessment
  - 1996 Understanding Risk: Informing Decisions in a Democratic Society
- **Routine decision-making such as in permitting small facilities**
  - 1996 Understanding Risk: Informing Decisions in a Democratic Society
- **Community/tribal-driven or -performed development of priorities and action plans**
  - 2023 Transforming EPA Science to Meet Today's and Tomorrow's Challenges
  - 2012 Exposure Science in the 21st Century: A Vision and a Strategy
  - 2009 Science and Decision: Advancing Risk Assessment
- **Controlling use of chemicals in products and commerce**
  - 2019 A Class Approach to Hazard Assessment of Organohalogen Flame Retardants
  - 2017 Using 21st Century Science to Improve Risk-Related Evaluations
  - 2008 Phthalates and Cumulative Risk Assessment: The Tasks Ahead
  - 1993 Pesticides in the Diets of Infants and Children
- **Developing guidance values or assessing risk, accounting for baseline concomitant exposures and population heterogeneity**
  - 2017 Approaches to Understanding the Cumulative Effects of Stressors on Marine Mammals
  - 2013 Assessing Risks to Endangered and Threatened Species from Pesticides
  - 2009 Science and Decision: Advancing Risk Assessment
  - 1977 Drinking Water and Health: Volume 1

Scope of the Assessment

Individual chemical risk versus cumulative risk versus CIA

The importance of conducting a cumulative assessment over an individual chemical risk assessment is covered in all National Academies reports that speak to the issue. Early reports framed the choice as assessing the risk associated with a single chemical versus assessing the risk associated with multiple chemical exposures. Later reports emphasized the benefits of a more expansive coverage of stressors, including nonchemical stressors such as biological, radiological, physical, structural, historical, social, and psychosocial, in characterizing health risks at baseline or the health benefits of exposure reductions. These reports also emphasized that characteristics of cumulative risk do not necessarily need to be expressed quantitatively, and that the assessment should highlight the exposed population (particularly vulnerable groups) rather than an individual pollutant source (e.g., NRC, 2009).

In *Science and Decisions: Advancing Risk Assessment,* the committee also reinforced some of the definitional challenges and potential distinctions between cumulative risk assessment and cumulative impact assessment. They proposed “that cumulative risk assessment be defined as evaluating an array of stressors (chemical and nonchemical) to characterize—quantitatively to the extent possible—human health or ecologic effects, taking account of such factors as vulnerability and background exposures.” On the other hand, “Cumulative impact assessment would consider a wider array of end points, including effects on historical resources, quality of life, community structure, and cultural practices (CEQ, 1997),” and would “generally include the outputs of cumulative risk assessment and other considerations” (NRC, 2009, p. 224). The 2009 committee therefore highlighted that there are multiple aspects of CIA that are outside of cumulative risk assessment. The scope of the CIA envisioned by the 2009 committee appears to include a broader range of endpoints (e.g., effects on historical resources) than the current EPA definition (see Box 1-3).

National Environmental Policy Act assessments

Under the National Environmental Policy Act (NEPA), CIA has had a very specific meaning, captured in law (rescinded in 2025). As reported in *Approaches to Understanding the Cumulative Effects of Stressors on Marine Mammals*:

> NEPA regulations require agencies to include in each EIS [Environmental Impact Statement] an evaluation of direct, indirect, and cumulative impacts associated with the action and proposed alternatives. Cumulative impact is defined for these purposes as “the impact on the environment which results from the incremental impact of the action when added to the other past, present, and reasonably foreseeable future actions regardless of what agency (federal or nonfederal) or person undertakes such other actions.” (NASEM, 2017, p. 12)

Appendix D tabulates some of the National Academies’ advice on NEPA assessments.

Well-being and quality-of-life outcomes

These domains are not directly covered under traditional or cumulative risk assessment, and National Academies committees charged with providing EPA advice on its risk assessments have generally not reviewed them with any depth of analysis. However, possible effects on health and well-being are a core objective of HIA, and a tool for its evaluation in HIA scoping exercises is described in NRC (2011a).

In the context of evaluating impacts of transportation decisions on the quality of life, the Transportation Research Board (2012, pp. 36–37) discussed a four-step process for assessing quality of life and provided categories for evaluation (i.e., economic competitiveness; environmental stewardship; transportation and mobility; public health, safety, and security; social and cultural resources; community development; governance and public services).

Consideration of beneficial impacts in addition to adverse impacts

Several National Academies reports have emphasized the importance of including an analysis of the potential for beneficial impacts. For example, the National Research Council HIA committee described HIA as “a structured process that uses scientific data, professional expertise, and stakeholder input to identify and evaluate public-health consequences of proposals and suggests actions that could be taken to minimize adverse health impacts and optimize beneficial ones.” (NRC, 2011, p. 3). The committee explicitly included consideration of beneficial health effects throughout its recommended multistep process for conducting an HIA.

In a similar vein, the committee that authored *Vibrant and Healthy Kids: Aligning Science, Practice, and Policy to Advance Health Equity* called on the community to "Recognize the impact of both adverse and enriching experiences across the life course and cumulative effects on health and well-being" (NASEM, 2019, p. 367) and recommended a number of policies and actions that would have beneficial impacts and promote health. The *Science and Decisions* committee also provided for context and support for weighing both the benefits and risks of different decision options (NRC, 2009).

Consideration of "baseline"

In ecological assessment under NEPA, considering baseline (e.g., the state of an impacted species population excluding the exposure being introduced) is an essential component in assessing cumulative impacts. The committee that authored *Assessing Risks to Endangered and Threatened Species from Pesticides* provided guidance to several agencies on how to consider baseline in the context of endangered species exposure to pesticides: "population models provide an appropriate framework for incorporating baseline conditions and projected future cumulative effects into the assessment" (NRC, 2013, p. 133). That committee could not determine a scientific basis for excluding past and present conditions (the environmental baseline) from the consideration of cumulative effects and therefore used that broad definition in its evaluation. Similarly, the *Science and Decisions* committee advised:

> Noncancer effects do not necessarily have a threshold. . . . Background exposures and underlying disease processes contribute to population background risk and can lead to linearity at the population doses of concern... The committee therefore recommends a consistent, unified approach for dose-response modeling that includes formal, systematic assessment of background disease processes and exposures, possible vulnerable populations, and modes of action that may affect a chemical's dose-response relationship in humans. (page 9) (NRC, 2009, p. 9)

Uncertainty

Early National Academies reports through to recent ones highlight uncertainty. These reports particularly focus on the lack of certainty or knowledge pertaining to the results of the analysis as an inherent challenge in conducting risk assessment, which could become more complex with an increasing number of exposures explicitly incorporated.

Drinking Water and Health: Volume I, published in 1977, and later reports in the series were congressionally mandated under the Safe Drinking Water Act of 1974 to support EPA's development of drinking water standards under the act. The 1977 report developed a framework for setting target protection levels for substances in drinking water in the face of uncertainty of risks of contaminants individually and in combination. "There is ... great uncertainty in estimating the magnitude of the risk to health that ingestion of contaminants in water may produce. An additional problem is to take into account the combined effects of two or more contaminants" (NRC, 1977, p. 12). It applied an uncertainty factor to a maximum no observed adverse effect level to derive an acceptable daily intake level for noncarcinogenic chemicals and assumed a no-threshold model to estimate the acceptable daily intake for carcinogens.

In the 1983 publication, *Risk Assessment in the Federal Government: Managing the Process* ("The Red Book"), the committee stated:

> The dominant analytic difficulty is pervasive uncertainty. Risk assessment draws extensively on science, ... However, data may be incomplete, and there is often great uncertainty in estimates of the types, probability, and magnitude of health effects associated with a chemical agent, of the economic effects of a proposed regulatory action, and of the extent of current and possible future human exposures. These problems have

> no immediate solutions. . . . To make judgments amid such uncertainty, risk assessors must rely on a series of assumptions. (NRC, 1983, p. 11)

The Red Book reinforced that these assumptions require uniform guidelines for carrying out risk assessment, including inference options or defaults that would allow for analyses to be conducted and decisions to be made even when the ideal empirical information is lacking.

In *Understanding Risk: Informing Decisions in a Democratic Society,* the committee acknowledged the developing analytical procedures used to describe assessment uncertainty and stressed the importance of identifying and focusing "on uncertainties that matter to understanding risk situations and making decisions about them" (NRC, 1996, p. 109) through a deliberative process to understand them. "The important uncertainties are those that create important differences in the assessed outcomes and may therefore affect preferences among the available risk decisions." (NRC, 1996, p. 109). The report offered advice and precautions for conducting the assessment and stressed:

> Uncertainty analysis and its users should remain aware of the fact that both the analysis and people's interpretations of it can be strongly affected by the social, cultural, and institutional context of the decision setting and the formal or perceived role of the various participants, which can exert pressure toward perceiving more or less uncertainty, or different kinds of uncertainty, than would otherwise be recognized. (NRC, 1996, p. 116).

The *Science and Decisions* report echoed the importance of planning and conducting the uncertainty assessment in support of discriminating among decision options. It also emphasized the point that there are many default assumptions within risk assessments, including those that are explicit (e.g., linear dose-response relationships for carcinogens in the absence of evidence to the contrary) and those that are implicit (including that nonlinear carcinogens and noncarcinogens act independently of background exposures and host susceptibility, contrary to the notions in cumulative risk assessment and the scientific evidence described above).

The *Improving Health in the United States* report similarly calls for the planning and management of uncertainty analysis in health impact assessment "to the extent possible and practicable" but cautioned "it should also not paralyze the decision process" (NRC, 2011, p. 97). Similar to the 1996 *Understanding Risk* report, it notes that characterization of uncertainty:

> will often need to go beyond quantitative methods to include other forms of information. Using a deliberative group process to arrive at judgments is a nonquantitative way to manage uncertainty and to moderate the effects of individual and organizational values and biases. (NRC, 2011, p. 99)

Approach to the Assessment

As noted in these various National Academies reports, risk or impact assessments are frequently a critical component of federal agency deliberations leading to a regulatory action. As a result, they receive considerable scrutiny from different "interest holders," defined as groups with legitimate interests in the issue under consideration (Akl et al., 2024). Complex assessments can be difficult if not impossible to understand by the public and can be costly to produce, and because they take years to complete, delay the regulatory actions predicated on their completion. While breadth is important for understanding cumulative impacts, the complexity may be heightened in cumulative assessments and challenging for all but a few risk analysts to fully comprehend either the findings or the underlying uncertainties. Another challenge is the fact that narrowly focused assessments can miss key and obvious aspects of the impact of a project or policy on the public and their quality of life. Several National Academies reports have provided advice on the scope of the assessment and process-related improvements.

Challenge posed by complexity

National Academies committees have cautioned about the potential intractability of cumulative assessments and the obstacles this poses for decision-making and have pointed to ways of moving forward. For example, the *Science for Environmental Protection: The Road Ahead* report notes "The broad challenge before the agency will involve developing tools and approaches to characterize cumulative effects in complex systems and harnessing insights from multi-stressor analyses without paralyzing decisions because of analytic complexities or missing data" (NRC, 2012b, p. 138). "Even as EPA seeks to improve its understanding of risks, some prevention-based decisions may need to be made in the face of uncertainty" (NRC, 2012b, p. 191). Similarly, the *Science and Decisions* report cautions:

> "Given the breadth of exposure pathways and types of stressors considered in cumulative risk assessment, there is a danger that it could become analytically intractable and therefore uninformative for making decisions in a timely fashion."

It then calls for:

> "increased reliance on relatively simple methods to determine whether more refined methods are required, or information is adequate to inform policy decisions. Developing simpler tools seems to contradict the complexity of cumulative risks, but methods can be developed that capture the breadth of chemical and nonchemical stressors with less computational burden." (NRC, 2009, p. 233)

In the ecological realm, the *Approaches to Understanding the Cumulative Effects of Stressors on Marine Mammals* report notes:

> Cumulative risk from exposure to multiple stressors cannot be predicted based on existing scientific theory and data for individual marine mammals or their populations. The Committee developed a ... model to provide a conceptual framework for ... assessing the risks associated with aggregate exposures to one kind of stressor, such as sound, and the cumulative exposure associated with sound and other stressors. (NASEM, 2017a, p. 1).

More generally, the *Understanding Risk* report provides precautionary guidance for analysis to reduce the complexity of risk (NRC, 1996, pp. 102–106).

Design of the assessment

Several NRC reports acknowledge the challenges introduced by uncertainty and the underlying scientific complexity facing those performing cumulative risk assessment, let alone CIA. The reports discuss a way forward in which more attention and analysis occur in the early phases of the assessment planning process, including consideration of simple tools and default assumptions in the face of uncertainty. The 1996 *Understanding Risk* report and the 2009 *Science and Decisions* report provided extensive advice on right-sizing the planning and conduct of the assessment, "specifically on planning, scoping and problem formulation, as articulated in EPA guidance for ecologic and cumulative risk assessment" (NRC, 2009, p. 5).

A key element under the 2009 framework is the "upfront identification of risk-management options, and the use of risk assessment to discriminate among these options." (NRC, 2009, p. 13). However, a key feature ahead of a planning and scoping exercise and identifying options is answering the question "Is risk assessment the appropriate decision support tool?" (NRC, 2009, p. 73). Similarly, the 1996 committee called for an early "diagnosis" of the situation, using an eight-step process, so that there can be a better match of "the analytic-deliberative process leading to the characterization to the needs of the decision, particularly in terms of level and intensity of effort" (NRC, 1996, p. 161). The NRC (2011a) HIA report is generally consistent with these approaches. The recommended six-step framework for the conduct of the HIA comprised screening, scoping, assessment, recommendations, reporting, and monitoring and evaluation. The initial screening step is to establish and determine the value, if any, of conducting an HIA. It lays out the most important factors to consider in the exercise, including among other factors the potential for substantial adverse or beneficial health effects; "the ability of information from the HIA to alter a decision or help a decisionmaker to discriminate among options; the ability of the HIA team to complete the assessment within the time and with the resources available" (NRC, 2011, p. 6). Similarly, *Constructing Valid Geospatial Tools for Environmental Justice* (NASEM, 2024), which advises on mapping approaches for identifying environmental justice disadvantage, recommends a rigorous, structured development process with elements tailored to the nature of the tool and context.

Participation of community and other interest holders

Understanding Risk (NRC, 1996) posed a participatory analytic-deliberative process to reach an understanding of a risk situation for decision-making, with a broad meaning of "risk" ("significant risk-related concerns of public officials and the spectrum of interested and affected parties, such as risks to health, economic well-being, and ecological and social values" [NRC, 1996, p. 7]). Particularly salient, the report identified objectives that could serve as criteria for judging success, which in the public participation realm included:

> Getting the right participation: The analytic-deliberative process has had sufficiently broad participation to ensure that the important, decision-relevant information enters the process, that all important perspectives are considered, and that the parties' legitimate concerns about inclusiveness and openness are met.
>
> Getting the participation right: The analytic-deliberative process satisfies the decision makers and interested and affected parties that it is responsive to their needs: that their information, viewpoints, and concerns have been adequately represented and taken into account; that they have been adequately consulted; and that their participation has been able to affect the way risk problems are defined and understood. (NRC, 1996, p. 7)

The 1996 report elevated the importance of public engagement of interested and affected parties at all phases of the risk-decision process. This criticality of robust public participation in the risk or impact characterization phase and other phases of the decision-making process is also emphasized in several subsequent National Academies reports (e.g., NRC, 2009, 2011a, 2013, 2014; NASEM TRB, 2012b).

In *Constructing Valid Geospatial Tools for Environmental Justice*, the committee considered the importance of community engagement in the construction of geospatial tools that measure cumulative impact:

> Choosing appropriate indicators, datasets, and integration approaches requires more than statistical robustness to achieve valid results. Community engagement validates the choices made in tool development as well as tool results and allows developers to understand the types of errors that are likely, why and where they occur, and how they might be overcome. (NASEM, 2024, p. 5)

The report provides detailed advice for interest-holder involvement in the tool development.

In the framework for conducting HIA (NRC, 2011), interest holders are actively engaged in the scoping, assessment, recommendations, and reporting steps of the process.

Tools and Methods for Conducting the Assessment

The National Academies has reviewed and/or commented on a variety of tools, and several emblematic assessment methods have been used to assess public health and environmental risks and impacts in support of decision-making.

Tools

NASEM (2017b), *Using 21st Century Science to Improve Risk-Related Evaluations,* discusses a number of scientific advances and tools in epidemiology, toxicology and exposure science that can be brought to bear in assessing cumulative risks and impacts. NASEM (2023), *Transforming EPA Science to Meet Today's and Tomorrow's Challenges,* provided examples of such tools that can be employed in analyzing the structural factors that contribute to cumulative risk, shown in Box 2-2.

BOX 2-2
Examples of Advanced Tools That Can Be Used in Cumulative Risk Assessment

Fundamental to the consideration of cumulative impacts is the need to incorporate structural factors into environmental health research and risk assessments, using multidisciplinary and holistic scientific methods. Some of the advanced tools and methods that could be used in pursuit of that objective include but are not limited to:

- Exposure sensors for multiple environmental stressors (e.g., fence-line or personal monitoring);
- Geospatial tools/analysis to link multiple place-based stressors and sources of exposure, including quantification of social stressors;
- Development and assessment of alternative metrics of exposure that cannot be measured directly or holistically characterized (e.g., proximity);
- Artificial intelligence and machine learning tools combined with extensive exposure testing across different stressors and concentrations to examine real-world risks from multiple stressors;
- Nontargeted analysis of chemicals linked to biomarkers of exposure and health outcomes;
- Exposure modeling; and
- Genetic and epigenetic analysis to understand exposure and effect biomarkers of toxicity.

SOURCE: Adapted from NASEM, 2023.

Geospatial Methods Measuring Cumulative Impacts

Assessment methods

A number of states and several federal agencies have developed and used mapping tools to geographically identify communities and regions overly burdened by pollution and with heightened vulnerability. These models use indicators of population-level pollutant exposures and indicators of various nonchemical stressors and score them for each administrative geographic unit (e.g., census tract). The indicators are categorized by type (e.g., exposure, vulnerability). Some tools provide composite indicators and final, integrated scores using a variety of weighting schemes. *Constructing Valid Geospatial Tools for Environmental Justice* (NASEM, 2024) provides detailed advice on many aspects of the development of geospatial tools used to characterize cumulative impacts. A few of these areas are briefly touched upon here.

The committee that authored *Constructing Valid Geospatial Tools* identified:

> The state of the art and practice in composite indicator and EJ tool construction:
> - Defining the concept to be measured and developing a description of its multiple facets or dimensions;
> - Selecting the indicators that measure each dimension;
> - Analyzing, treating, normalizing, and weighting the indicators as appropriate;
> - Integrating/aggregating the indicators;
> - Assessing statistical and conceptual robustness and coherence and determining the impact of uncertainties; and
> - Validating the results and presenting them visually (e.g., choice of category breaks and colors) (NASEM, 2024, p. 8).

The committee recommended that communities be identified "as disadvantaged based on cumulative impact scoring approaches that are informed by the state of science; the knowledge, needs, and experiences of agencies, tool developers, and users; and validation efforts conducted in partnership with affected communities." (NASEM, 2024, p. 11).

Health Impact Assessment

The NRC (2011a) report calls out HIA as a structured scientific approach to include health considerations in the decision-making process, often in the context of programs or policies that are not centered on health. The committee chose HIA as a tool over other options:

> because of its applicability to a broad array of policies, programs, plans, and projects; its consideration of adverse and beneficial health effects; its ability to consider and incorporate various types of evidence; and its engagement of communities and stakeholders in a deliberative process. (NRC, 2011, p. 5).

The assessment phase in the committee's six-step framework (see above) is a two-step process "that involves describing the baseline health status of the affected populations and then characterizing the expected effects on health (and its determinants) of the proposal and each alternative under consideration relative to the baseline and each other" (NRC, 2011, p. 6). After deliberating the pros and cons, the committee found that "quantitative estimates of health effects have value and should be provided when the data and resources allow and when they are responsive to decision-makers' and interest holders' information needs" (NRC, 2011, p. 10). Another issue is whether to provide summary measures of health effects.

> The most common approach in HIA is to describe and characterize each effect separately (see Chapter 3) and allow users to make judgments about the cumulative nature of the effects. The committee endorses that approach even if a summary measure of effects is used. Generally, decision-makers must balance multiple desirable and adverse effects related to a decision and will need to "weight" or assign values to them on the basis of institutional rules, constituent preferences, or some other approach. Keeping effects separate and assigning values allow decision-makers to consider tradeoffs among health and nonhealth effects clearly. (NRC, 2011, p. 101)

A number of reports by the National Academies review or comment on processes used to develop environmental impact statements and environmental assessments under NEPA. These assessments focus on the environmental impacts of the decision, and a criticism has been that the coverage of human impacts is often not adequate. The HIA committee noted the usefulness of HIA in NEPA assessments and that "recent efforts have successfully integrated the HIA framework into EIA" (NRC, 2011, p. 12).

Cumulative Risk Assessment

A number of technical points pertaining to cumulative risk assessment have been addressed in National Academies reports, including several discussed above and contained in Appendix D.

Guidance from some earlier reports focused on cumulative risk assessment for chemicals. For example, *Phthalates and Cumulative Risk Assessment: The Tasks Ahea*d was "not a comprehensive toxicologic profile or risk assessment" (NRC, 2008, p. 4) and the definition of cumulative risk used by the committee was confined to chemicals and did not include nonchemical stressors. The question was whether cumulative risk assessment of phthalates should be conducted. The committee found that it should and that the mixture effects were predicted well with the dose addition method, even though the chemicals (including nonphthalates) did not produce the effect by the same mechanism. The committee concluded that "[t]he current practice of restricting cumulative risk assessment to structurally or mechanistically related chemicals ignores the important fact that different chemical exposures may result in the same common adverse outcomes" (NRC, 2008, p. 10). The committee recommended that "the chemicals that should be considered for cumulative risk assessment should be ones that cause the same health outcomes or the same types of health outcomes" (NRC, 2008, p. 4). The 2004 *Review of the Army's Technical Guides on Assessing and Managing Chemical Hazards to Deployed Personnel* utilized the more restrictive approach and a correspondingly more restrictive definition of cumulative risk (NRC, 2004, p. 11), although it indicated that in practice a dose addition method (adding hazard indexes) could be used.

As noted above, the 2009 *Science and Decisions* report called for a more expansive definition of cumulative risk assessment. The committee noted, as is the case today:

> cumulative risk assessments have generally not yet reached the potential implied by the stated definition; there has been less than optimal formal consideration of nonchemical stressors, aspects of vulnerability, background processes, and other factors that could be of interest to stakeholders concerned about effects of cumulative exposures." (NRC, 2009, p. 219)

Taken with other recent reports calling for the inclusion of nonchemical stressors in cumulative risk assessment, National Academies committees' conceptualization of cumulative risk assessment has evolved over time.

DEVELOPMENTS BY EPA

In 1986, the Environmental Protection Agency published *Guidelines for the Health Risk Assessment of Chemical Mixtures.* In 1996, Congress enacted the Food Quality Protection Act (FQPA),[1] which required EPA to take into account when setting pesticide tolerances (maximum residue legally allowed on food) available evidence concerning the cumulative effects on infants and children of such residues that have common mechanisms of toxicity. It had its origins from numerous prior reports, including the National Research Council's *Pesticides in the Diets of Infants and Children* (NRC, 1993), *Science and Judgment in Risk Assessment* (NRC, 1994), the National Academy of Public Administration's *Setting Priorities, Getting Results* (NAPA, 1995), and the Commission on Risk Assessment and Risk Management's *Risk Assessment and Risk Management in Regulatory Decision-Making* (PCRARM, 1997). The FQPA directly stated that pesticide decision-making "shall consider …

[1] Pub. L. 104-170, 110 Stat. 1489. https://www.govinfo.gov/content/pkg/PLAW-104publ170/pdf/PLAW-104publ170.pdf.

available information concerning the cumulative effects of such residues and other substances that have a common mechanism of toxicity" (section 408(a)(4)(C)(i)(III)). One such example was dioxin-like compounds which were assigned dioxin-equivalent values for this purpose, and the requirement was particularly relevant for organophosphate pesticides.

This requirement initiated the planning and the development of guidance documents beginning in 2000 for internal review within EPA. At that time, cumulative risk was defined within the Framework for Cumulative Risk Assessment as "an analysis, characterization, and possible quantification of the combined risks to health or the environment from multiple agents or stressors" (EPA, 2003, p. xvii). One key aspect of this definition is that a cumulative risk assessment need not necessarily be quantitative, as long as it meets the other requirements. At that time, EPA noted:

> Because of the limitations of current science, cumulative risk assessments done in the near future will not be able to adequately answer all the questions posed by interest holders or interested parties. This does not mean, however, that they cannot answer some of the questions; in fact, cumulative risk assessment may be the best tool available to address certain questions dealing with multiple-stressor impacts. (EPA, 2003, p. xx)

The document also noted in response to inclusion of chemical and nonchemical stressors that: "Assessing the risk for these situations is considerably more complex methodologically and computationally than for the examples of aggregate risk assessments or single-effect cumulative risk assessments…." (EPA, 2003, p. 8). In 2004, EPA requested advice and recommendations from the National Environmental Justice Advisory Council regarding short-term and long-term actions to ensure environmental justice for all communities and tribes in proactively implementing the concepts contained in its Framework for Cumulative Risk Assessment.

By 2008, EPA was seeking further guidance on cumulative risk assessment, leading to the formation of multiple National Academies committees as described above. In the *Phthalates and Cumulative Risk Assessment* report, the committee recommended an approach to cumulative risk assessment based on inclusion of stressors with common adverse outcomes as a feasible and physiologically relevant approach, expanding beyond the earlier framework based on common mechanisms of toxicity (NRC, 2008). In *Science and Decisions*, the committee concluded that "EPA should draw on other approaches, including those from ecologic risk assessment and social epidemiology, to incorporate interactions between chemical and nonchemical stressors in assessments; increase the role of biomonitoring, epidemiologic, and surveillance data in cumulative risk assessments; and develop guidelines and methods for simpler analytical tools to support cumulative risk assessment and to provide for greater involvement of stakeholders."(NRC, 2009, p. 10). This represented an even more expansive view of cumulative risk assessment than in the *Phthalates and Cumulative Risk Assessment* report, including through the emphasis on nonchemical stressors and nontoxicological evidence. This framework informed an extramural grant program at EPA,[2] in which the funding opportunity emphasized understanding the role of nonchemical stressors in cumulative risk assessments (primarily but not exclusively psychosocial stress) and developing relevant analytical tools (EPA, 2009). A synthesis article published by grantees indicated the importance of understanding biological mechanisms, characterizing biomarkers of exposure and outcome, incorporating community insight, meaningfully characterizing exposures to nonchemical stressors, and utilizing interpretable statistical approaches to characterize the effects of multiple stressors (Payne-Sturges et al., 2018).

EPA continued to support extramural research related to questions of cumulative risks or cumulative impacts, including using a total-environment framework to evaluate health effects across the

[2] See https://cfpub.epa.gov/ncer_abstracts/index.cfm/fuseaction/display.rfatext/rfa_id/515 (accessed August 14, 2025).

life course[3] and on methods for cumulative health impacts considering how climate change could influence health risks from chemical exposures (EPA, 2021). A further publication by EPA staff addressed lessons learned with respect to attempts to undertake cumulative risk assessment (Gallagher et al., 2015).

The agency continued to work on the topic of cumulative risk assessment in subsequent years, though with inadequate advances in implementation or practice. For example, in 2010, the agency described tools to assess community-based cumulative risks and exposures (Barzyk et al., 2010). EPA also made regular presentations at various scientific meetings on cumulative risk assessment. One example that followed the paradigm of the 2009 extramural grant program mentioned above was the sponsorship of a workshop in 2011 at the annual Society of Toxicology meeting, entitled "Approaches for Incorporating Non-Chemical Stressors into Cumulative Risk Assessment." An overview of agency guidance, practice, and current major research activities in cumulative risk assessment was provided to EPA's Science Advisory Board in 2013. In January 2025, the Risk Assessment Forum of the EPA put forward updated guidelines for planning and problem formulation within cumulative risk assessment, building on their 2003 report as well as recommendations from multiple National Academies reports (EPA, 2025a). Other than reinforcing the importance of defining the intended purpose and context of use for cumulative risk assessment, this report included a timeline of publications on the topic that reinforced that relevant reports had been promulgated since the 1980s but that there had been only modest changes to agency guidance in recent decades. A review article summarized the 36 years from 1980 to 2016 to try to understand why little progress had been made up to that point in time, concluding that it was driven in part by the emphasis on toxicology in early agency decision-making and the mathematical complexity of mixtures in this context, along with the fact that existing regulations did not allow for mixtures to be considered in many settings (Sprinkle and Payne-Sturges, 2021).

In parallel to these efforts on more traditional cumulative risk assessment, EPA has made progress in thinking about other frameworks and strategies to address simultaneous exposure to multiple chemical and nonchemical stressors. For example, Tulve et al. (2016) emphasized a "total environment" framework that combines the built, natural, and social environment, which they used as a foundation for proposed work on CIA (Tulve et al., 2024). EPA has conducted numerous case studies using HIAs to evaluate impacts of community-level projects on multiple determinants of health and has also piloted CIAs in regulatory decision-making. Examples are provided in Box 2-3.

Building upon this work, in November 2024, EPA published its *Interim Framework for Advancing Consideration of Cumulative Impacts*. It represents a shift from earlier guidance in that it defines cumulative impacts as the totality of exposures to combinations of chemical and nonchemical stressors and their effects on health and quality-of-life outcomes. It does not require identification, measurement, and quantification of all such exposures and effects but rather an approach focused on exposures and effects of greatest relevance to a specific decision, that is, a decision context (place matters).

EPA's (2024) general approach to conducting a CIA, shown in Figure 2-2, emphasizes meaningful public engagement at all steps in the process and the importance of a fit-for-purpose analysis given the decision context and flexibility in application. "Determining which approaches and analytical methods to use in cumulative impacts assessment depends on factors such as statutory requirements, the scope of an assessment, types of data needed and available, and applicability for the evaluation and needs of the decision-maker" (EPA, 2024, p. 14). The *Interim Framework* further notes that "Approaches can be used in combination. Assessors need to exercise judgment in determining when to use cumulative risk assessment, cumulative impacts assessment, or another approach for evaluating exposures to multiple stressors for a specific purpose" (EPA, 2024, p. 15).

[3] See https://cfpub.epa.gov/ncer_abstracts/index.cfm/fuseaction/display.rfatext/rfa_id/630 (accessed August 14, 2025).

BOX 2-3

Examples of EPA Applied Health Impact and Cumulative Impact Assessments

- **Cumulative impact assessment (CIA) to evaluate a request for exemption, to allow the injection of oil and gas production waste into an aquifer (Fremont County, Wyoming).** EPA considered information from affected parties (the state, applicant, community, and tribal governments) and the analysis considered the aquifer's importance as a source of drinking water, in some cases, for water piped long distances to communities in rural areas. On the basis of the CIA deliberation the request was denied. (EPA, 2024)
- **Community risk assessment in proposing an air toxics rule.** The assessment examined the air toxics-related cancer impacts of a regulatory proposal for synthetic organic chemical manufacturers "from all large facilities in communities within about 6 miles of the plants—including facilities not covered by the rule." The rule would reduce by 96 percent the number of people with elevated risk. The racial make-up and low socioeconomic status of the community affected by the rule was analyzed and EPA indicated that it expected the rule "to reduce disproportionate harm to nearby communities often overburdened by pollution" (EPA, 2025b, p. 56).
- **Health impact assessment (HIA) to support decision-making in the revitalization of a brownfield neighborhood (Rockford, Illinois, South Main Corridor).** The outcome of the assessment was a suite of strategies to "maximize the potential health benefits and mitigate the potential adverse health impacts of neighborhood revitalization." The expedited assessment included, inter alia, mapping, qualitative and quantitative data analysis, and analytical input from interested parties. (EPA, 2022)

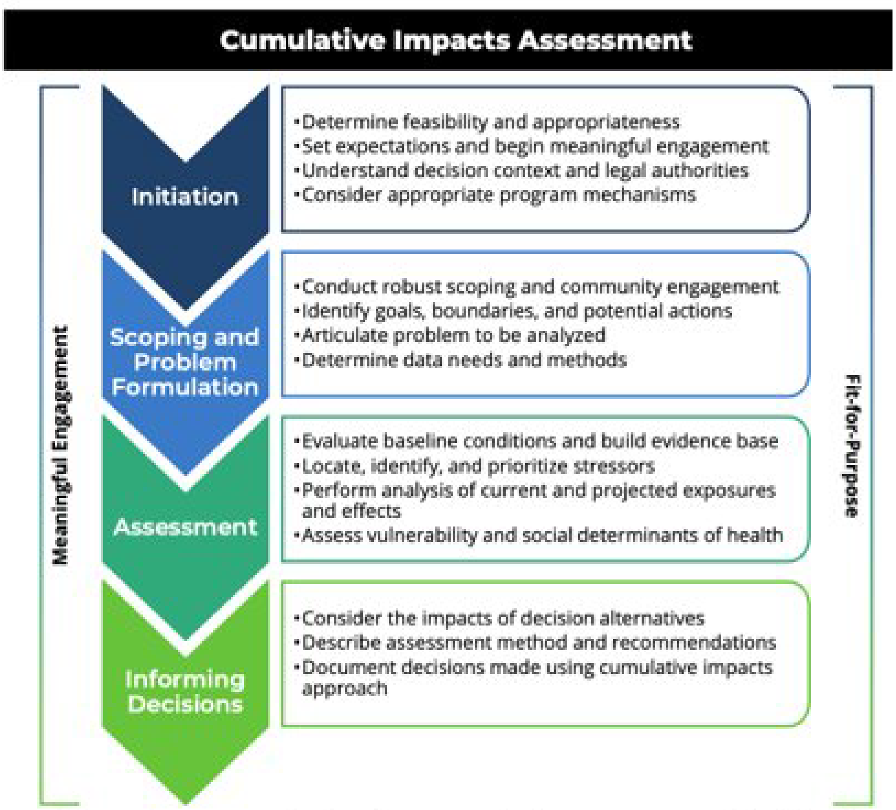

FIGURE 2-2 Proposed general structure for conducting cumulative impact assessment in EPA's *Interim Framework for Advancing Consideration of Cumulative Impacts.* SOURCE: EPA, 2024.

Within EPA's *Interim Framework*, the agency discussed some of the national-scale databases and related tools that could inform CIAs. This includes data as part of EJScreen, developed by EPA and available from non-EPA sites after February 2025[4] as well as data from outside of EPA.

DEVELOPMENTS BY OTHER FEDERAL AGENCIES

While considerable relevant activity has occurred at EPA, there have been efforts elsewhere in the federal government that inform CIA.

Geospatial tools that mapped nationwide socioeconomic, environmental, and health burdens were developed by the Council on Environmental Quality (CEQ), the Agency for Toxic Substances and Disease Registry of the Center for Disease Control and Prevention (CDC), the Department of Energy (DOE), and the Department of Transportation (DOT). Measures of climate vulnerability were included in the CEQ, DOE, and DOT tools. For further discussion see NASEM (2023).

Environmental assessments and impact statements required under NEPA are of particular interest because of the process steps used in their development and a previous requirement to characterize cumulative effects of the project in the assessment of impact. The term "cumulative effects" was not included in the original 1969 NEPA but was incorporated as a required element within NEPA regulations starting in 1978 (Schultz, 2012). It is defined in the regulation as follows:

> Cumulative effects, which are effects on the environment that result from the incremental effects of the action when added to the effects of other past, present, and reasonably foreseeable actions regardless of what agency (Federal or non-Federal) or person undertakes such other actions. Cumulative effects can result from actions with individually minor but collectively significant effects taking place over a period of time. (40 CFR § 1508.1, effective until March 27, 2025)

Effective March 27, 2025, the federal regulations covering the development of NEPA environmental impact statements and assessments were rescinded (40 CFR Parts 1500–1508).

Screening-level environmental assessments were used to determine if actions will be significant and environmental impact statements disclosed significant impacts to the public. The applications to date have been varied and wide ranging, for example, large transportation, urban redevelopment, and industrial farming projects (Bhatia and Wernham, 2008). Assessment of human health and welfare have been relatively limited in many applications in spite of the potential for substantial impacts (Bhatia and Wernham, 2008).

HIA is procedurally modeled after environmental impact assessments, which are used to determine any significant environmental impacts of a project or proposal. HIA has been widely used outside of NEPA but also has been integrated into NEPA impact assessments to consider social determinants of health that are not typically addressed. In this context, HIA shares many common features as in EPA's *Interim Framework*. The primary process distinction relates to the recommendation to have monitoring and evaluation as the final step within HIA.

STATE AND LOCAL EFFORTS

In parallel with the developments at EPA, CIA has been either required, utilized, or proposed in multiple states and communities. Examples of applications by state and local governments that have implemented some form of CIA are given in Table 2-1. In addition, as of July 2025, bills involving CIA had been proposed in 13 additional states plus the District of Columbia (NCEL, n.d.), with the form and nature of the requirements varying considerably across states.

[4] See, for example, https://dataverse.harvard.edu/dataset.xhtml?persistentId=doi:10.7910/DVN/RLR5AX.

TABLE 2-1 Use of Cumulative Impact Assessments by State and Local Governments

Method	Single Scoring	Matrix Approaches	Community-based Approaches	Epidemiological / Toxicological / Exposure Modeling Approaches
Description	Single scoring approaches combine values for environmental and social vulnerability indicators into a single score used for screening level assessment and categorization.	Matrix approaches evaluate environmental burdens and social vulnerability characteristics independently and apply separate thresholds or criteria to each to inform a regulatory or nonregulatory decision used for screening level assessment and categorization.	Health impact assessment and other structured processes used to develop community action plans or identify how a project, policy, or program might influence health, and produce recommendations to enhance the health benefits of the project/ policy/program and to mitigate potential harms.	Data analyses using epidemiological and toxicological data, exposure assessment and modeling, and site data to characterize the factors affecting risk and vulnerability or susceptibility of populations and population groups, including people at different lifestages. These analyses can include methods to characterize mixtures, including aggregate and cumulative exposures.
Examples	CalEnviroScreen; MiEJScreen[a]; MDE EJ Screening Tool[b]; Chicago EJ Index[c]; Washington Environmental Health Disparities Map[d]; ATSDR EJ Index[e]	New Jersey Method[f]; Massachusetts Method[g]; CEQ CEJST[h]	Health Impact Assessment[i]; Environmental Justice Collaborative Problem solving Program[j]; Environmental Benefits Districts[k]; Green Impact Zones[l]; Green Zones[m]	Identification of modifying factors in risk characterization documents such as the Integrated Science Assessments Community-level exposomics[n]. Epigenetic approaches to identifying and analyzing the impacts of chemical and nonchemical exposures (e.g., Martin et al., 2022).
Common Applications	• Inform decisions on siting, permitting, enforcement, and infrastructure improvements	• NJ: To decide whether to pose conditions on or deny permits for new sources • MA: Air quality permitting • CEQ: To identify communities that qualify for funding	• Community participatory place-based approaches for solutions-based planning to transform or revitalize communities • Identify how a project, policy, or program might influence health	• Risk assessment • Cumulative risk assessment

[a] See https://oehha.ca.gov/calenviroscreen.
[b] See https://mde.maryland.gov/Environmental_Justice/Pages/EJ-Screening-Tool.aspx.
[c] See https://www.chicago.gov/content/dam/city/depts/cdph/environment/CumulativeImpact/CIA_ChicagoEnvironmentalJusticeIndexMethodology_9.17.23.pdf.
[d] See https://doh.wa.gov/data-and-statistical-reports/washington-tracking-network-wtn/washington-environmental-health-disparities-map.
[e] See https://www.atsdr.cdc.gov/place-health/php/eji/?CDC_AAref_Val=https://www.atsdr.cdc.gov/placeandhealth/eji/index.html.
[f] See https://dep.nj.gov/ej/law/.
[g] See https://www.mass.gov/info-details/cumulative-impact-analysis-in-air-quality-permitting.
[h] See https://geoplatform.maps.arcgis.com/home/index.html.
[i] See https://hiasociety.org/.
[j] See https://www.epa.gov/inflation-reduction-act/collaborative-problem-solving-cooperative-agreement-program.
[k] See https://mde.maryland.gov/programs/ResearchCenter/eMDE/Pages/vol1no2/ebd.aspx.
[l] See https://archives.hud.gov/local/mo/goodstories/2009-09-30.cfm.
[m] See https://ceja.org/wp-content/uploads/2012/01/GZ_map_2pgrREVISED.pdf.
[n] See http://epa.gov/isa.
SOURCE: EPA, 2024.

For example, within California, a definition of cumulative impacts was formally adopted in 2005:

> exposures, public health or environmental effects from the combined emissions and discharges, in a geographic area, including environmental pollution from all sources, whether single or multi-media, routinely, accidentally, or otherwise released. Impacts will take into account sensitive populations and socioeconomic factors, where applicable and to the extent data are available. (CalEPA, 2021)

The CalEnviroScreen tool was developed to map cumulative impacts in census tracts across the state, including to inform the targeting of investments through the California Climate Investment Program as a part of Senate Bill 535 and connected with Senate Bill 673 to inform hazardous waste permitting. CalEnviroScreen incorporates a range of indicators and compiles them into an aggregate measure. Twenty-one different indicators are used to characterize pollution burden (divided into exposures such as air pollution concentrations, toxic releases, or Pb risks in housing; and environmental effects such as solid waste sites or hazardous waste sites) and population characteristics (divided into health outcome measures reflecting sensitive populations and socioeconomic factors). The score for each census tract is based on the product of the pollution burden score and the population characteristics score, where each is constructed as the average across percentile values for individual indicators. While the indicators were chosen through a systematic and interest-holder–engaged process and have been refined over time, concerns have been raised about the frequency of the updates and whether the indicators and the weighting scheme are sufficiently robust in identifying neighborhoods at risk from cumulative exposures (Huynh et al., 2024).

Within Massachusetts, CIA is used in a somewhat different context. It is now required as part of a comprehensive plan application for a facility emitting air pollution above a defined threshold in or near environmental justice populations (MassDEP, 2024a). The process in Massachusetts involves assessment of existing community conditions, air quality dispersion modeling that takes account of other sources as well as background conditions in the area, characterization of cumulative risks from air toxics emitted by the proposed project in the context of other sources in the area, and an overall evaluation of the cumulative impacts of the project. The effort therefore centers around cumulative impacts on air pollution rather than a broader multimedia perspective. Public outreach and involvement are required, and concerns raised by the public during the required public involvement are integrated into the CIA report submitted with the permit application (MassDEP, 2024a). The analytical process is informed by a set of exposure, facility, health, and socioeconomic and sensitive receptor indicators made available by the Massachusetts Department of Environmental Protection (MassDEP) at census block resolution.

As another example, in New Jersey, the decision context is somewhat different, as the evaluation of cumulative impacts is embedded in an environmental justice law[5] with application to eight different types of facilities (including sources of air pollution as in Massachusetts, but also incinerators of various types, large sewage treatment plants, transfer stations or solid waste facilities, and other categories). If one of these types of facilities is proposed within an overburdened community, an initial screening is conducted using information from a mapping tool developed by the New Jersey Department of Environmental Protection (NJDEP), which involves 26 stressors within the categories of concentrated areas of air pollution, mobile sources of air pollution, contaminated sites, transfer stations, point sources of water pollution, potential public health risk factors, proximity stressors, and social determinants of health. An environmental justice impact statement (EJIS) is required, which includes a systematic identification of existing cumulative stressors, the contribution from the proposed facility, whether it can avoid causing a disproportionate impact, and what measures could be taken to avoid or address any disproportionate impact. The analytical elements related to cumulative impacts principally center on comparing the levels of each of the stressors within the overburdened community of concern to levels in other comparator locations, summing the number of elevated stressors and determining if the sum exceeds

[5] See https://dep.nj.gov/ej/law/.

predefined thresholds that vary by county. The key decision point involves an assessment based on both the analysis within the EJIS and public input on whether a disproportionate impact can be avoided. In New Jersey, the CIA is therefore used in the specific context of environmental justice and at a defined step in the decision process for a range of new facility types.

CIA has also been enacted at the city level. For example, in Chicago, a CIA was developed to explicitly inform decisions related to environmental justice, with direct connection to multiple types of municipal decisions (City of Chicago, 2024). The process to develop the CIA relied heavily on community input from the outset, including engagement of multiple local community organizations, national nongovernmental organizations, and city agencies as voting members of a methodological working group. The ultimate product included an environmental justice index that was used to map cumulative burdens at census tract resolution, following a similar approach to CalEnviroScreen. Twenty-eight indicators were selected, intended to represent environmental exposures, environmental conditions, sensitive populations, or socioeconomic factors. These indicators were then combined into a score. In addition, Chicago included a number of additional “dashboard indicators,” which were not included in the aggregate score but were considered to provide additional contextual information.

Beyond federal, state, and local government, the use of CIA has been relatively modest. For example, a PubMed search for the phrase “cumulative impact assessment” in January 2025 found only 26 publications, most of which were using this phrase to describe a somewhat different methodology than is being considered in this report. Most of these studies were within the realm of ecological risk assessment, where for a number of years researchers have worked to characterize the combined effects of multiple types of stressors on marine and coastal ecosystems (Simeoni et al., 2023). Although the context is different from the realm of human health CIA, the general approach is similar—the use of mapping and the development of indexes based on individual indicators that are combined using some form of weighting scheme. Many of these CIAs are informed by conceptual models where impact scores relate in some manner to attributes such as intensity, exposure, and vulnerability (Halpern et al., 2008).

PERSPECTIVES OF COMMUNITIES

Community groups, especially those concerned with issues of environmental justice, have advocated for many years that assessments conducted by EPA needed to consider the combined exposures that overburdened communities have faced to both chemical and nonchemical stressors. Some of these concerns were expressed to the committee during its data-gathering process, as described in more detail in Chapter 3. Many critiques have been levied at risk assessment and related tools for not adequately reflecting conditions in overburdened communities and not allowing for community input into decision processes (Sadd et al., 2014). While cumulative risk assessment can in theory incorporate some of these elements, many of the applications to date have omitted many stressors and therefore systematically underestimated the health risks faced by these communities leading to increased interest within communities and community-based organizations in CIA (UCS, 2024).

Even if communities are supportive in theory, challenges can arise in the implementation of CIA, as illustrated in some of the public comments associated with the initial proposal for CIA in Massachusetts (MassDEP, 2024b). Various commenters were concerned about limited community engagement, the challenges in interpreting a wide range of disparate indicators in a manner that is interpretable and decision-relevant, and the lack of indication of how the cumulative impacts information should be formally incorporated into decisions. Broadly, MassDEP acknowledged that “additional guidance is needed on how cumulative impacts should be evaluated in the air permit decision-making context” (MassDEP, 2024b).

CONCLUSIONS AND RECOMMENDATIONS

Overall, the existing tools and methods applicable to CIA have evolved from three major “lineages” of assessment approaches, as depicted in Figure 2-3. Each lineage has been generally applied to different decision contexts, and each has evolved to better address cumulative impacts. While distinct in origin and application, these three lineages—impact assessment, community assessment, and risk assessment methods—each contribute essential concepts, tools, and practices to the current understanding of CIA. Environmental impact assessments, for instance, are used to determine any significant environmental impacts of a project or proposal, while regulatory impact assessments evaluate the impacts and benefits of a range of alternative options to inform policy decisions. Health impact assessments provide a structured scientific approach to include health considerations in the decision-making process, often in the context of programs or policies that are not centered on health. Community assessments use mapping and other geospatial tools, addressing environmental and social factors that impact health and well-being as well as identifying positive amenities within communities. Risk assessment, while focusing on quantifying the combined effects of chemical exposures on health, has increasingly recognized the potential contributions from nonchemical stressors. CIA can be considered an umbrella for these different lineages, and the committee's conclusions and recommendations aim to better integrate them into a common conceptual foundation applicable across diverse contexts of use.

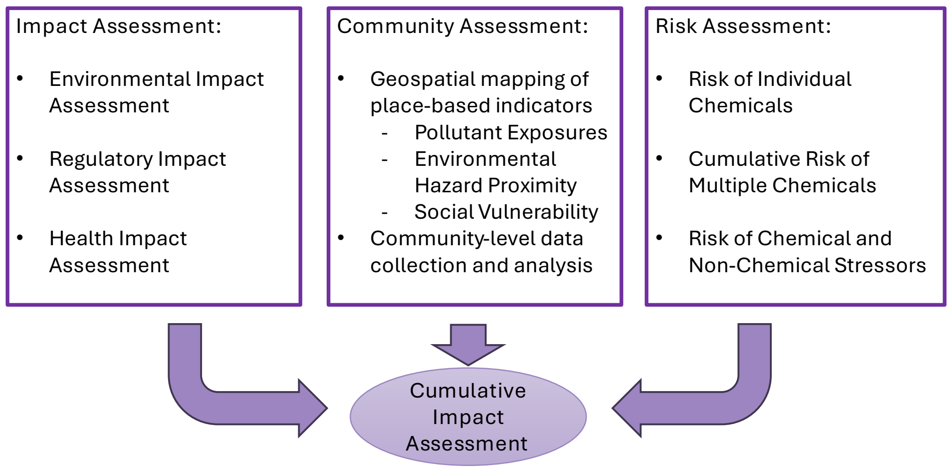

FIGURE 2-3 Overview of major lineages of assessments informing cumulative impact assessment.

Conclusion 2-1: The importance of evaluating exposures to combinations of chemical and nonchemical stressors, which can interact to affect health and well-being, has been widely recognized for decades. EPA has partially implemented aspects of cumulative risk assessment, with uneven implementation across offices and programs. However, EPA has not generally moved beyond combining related chemicals that have a common mechanism of action or that affect the same general system (e.g., kidney). Nonchemical stressors are generally not addressed, and EPA has not fully acted upon prior National Academies recommendations or in a manner that is concordant with their definition of cumulative risk assessment.

Conclusion 2-2: Future applications of cumulative impact assessment (CIA) can draw from the wide range of datasets and insights available from the scientific literature and communities and from approaches of impact, community, and risk assessments. Central to CIA are the broad scope, decision-focused orientation, and methods to incorporate qualitative evidence used in impact assessments. Also important to CIA are the geospatial analysis methods within community assessments that support rapid comparisons of locations and populations, along with the tools associated with risk assessment that quantify exposure and health risk with characterization of uncertainty.

Conclusion 2-3: EPA's interim framework, including its definitions of key terms, provides a useful starting point for conceptualizing cumulative impacts. It reflects lessons learned from assessment practices and facilitates the development and improvement of decision-relevant tools. However, the interim framework lacks key steps such as monitoring and evaluation (whether of process, impact, or outcome) and does not provide sufficient information on implementation. Advancing cumulative impact assessment will require multidisciplinary approaches for various environmental decision-making contexts, and implementation will vary due to jurisdictional limitations and resources.

Recommendation 2-1: EPA should update and expeditiously finalize its cumulative impact assessment framework to include a multistep process that is driven by ongoing meaningful engagement and includes monitoring and evaluation of decisions implemented. Specifically, the recommended steps for the practice of cumulative impact assessment are: (1) initiate with meaningful engagement; (2) define scope and formulate problem; (3) assess health and well-being, stressors, and resources; (4) inform planning, policy, and/or decisions; and (5) undertake monitoring and evaluation of process, impact, or outcomes.

The recommended steps of CIA are elaborated in Figure 2-4. Ongoing meaningful engagement with interest holders, defined as groups with legitimate interests in the issue under consideration, is an essential aspect of the recommended process. Through this process, CIA can help build and strengthen relationships, support transparency, and reflect the full scope of what affects community health and well-being. This recommended process, applicable to a broad range of actors and interest holders, is designed to be both structured and flexible, reflecting advice from National Academies reports and lessons learned from risk, community, and impact assessment practices.

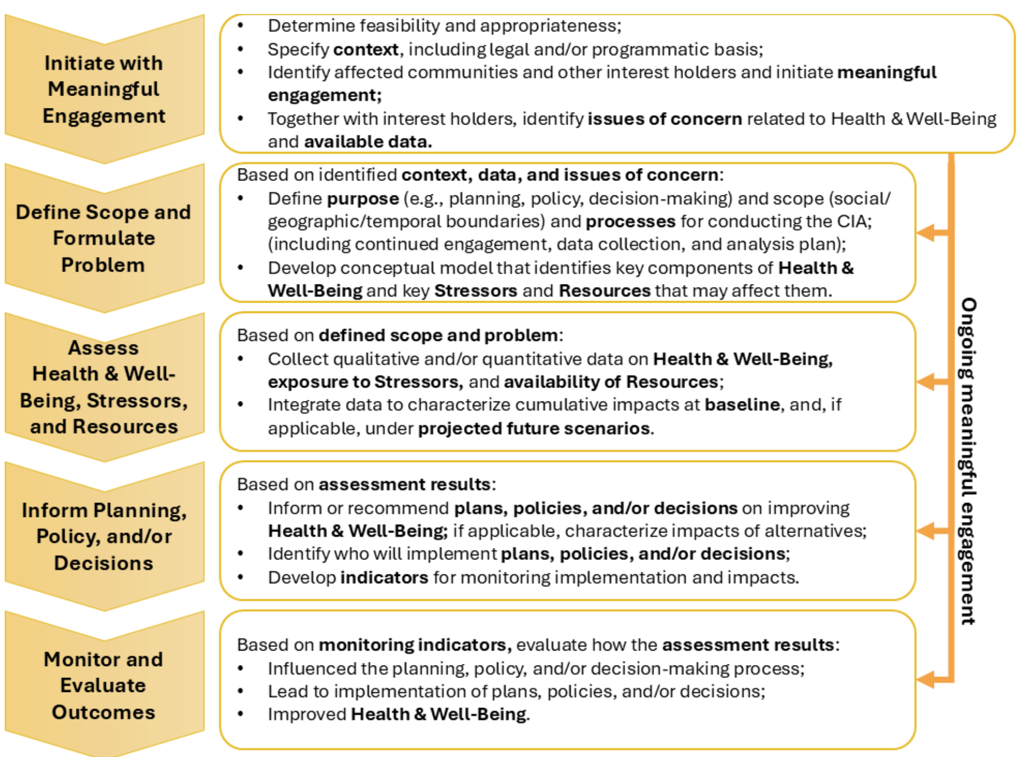

FIGURE 2-4 Five-step process for cumulative impact assessment recommended by the committee.

The chapters that follow address these five steps of CIA in further detail. Specifically, Chapter 3 focuses on the second step of the process by describing the data and knowledge for CIA, including the insights gained through the committee's information-gathering sessions. Chapter 4 then addresses the third step of the CIA process by presenting the methods and approaches. The final chapter, Chapter 5, provides example applications at different levels of implementation, to guide use of the proposed framework. Among other topics, Chapter 5 provides recommendations specifically relevant to the second and fifth steps of the committee's recommended process (i.e., CIA design as well as monitoring and evaluation).

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3
Data and Knowledge for Cumulative Impact Assessment

The knowledge is in the community . . . . The cumulative impacts exist in the stories that people know—how many relatives they lost to cancer, what kinds of cancer, and how quickly it came and where they live and where they work. You can draw out this kind of information by talking to the communities that have been impacted by it.

- Justin Kray (Hidden Landscape Consulting)

INTRODUCTION

As part of its statement of task (see Chapter 1), the committee was asked to address the following charge questions:

- *What types of stressors, both now and anticipated in the future, should be prioritized, characterized, and considered in combination in a cumulative impact assessment to best reflect overall burdens facing diverse communities and populations?*
- *How can cumulative impact assessment consider issues such as factors that may make a community more vulnerable to stressors, barriers to strengthening a community's ability to respond to stressors, and critical paths to improved community health and well-being in the future?*
- *How can community and tribal data and knowledge be incorporated into cumulative impact assessment?*

This chapter addresses the charge questions in the context of the committee's recommended approach to cumulative impact assessment (CIA; see Figure 3-1) by describing the key sources of data and knowledge for assessing health and well-being, stressors, and resources. The discussion encompasses consideration of the types of stressors to include, as well as community resources in addition to the overlapping influences that may make a community more vulnerable to these stressors and affect their ability to respond to them. In addition, the chapter addresses the incorporation of community and tribal data and knowledge in the CIA process. While methodological issues are largely addressed separately in Chapter 4, this chapter outlines how key sources of data and knowledge are incorporated into CIAs to advance critical paths to improved community health and well-being. Overall, it aims to provide a conceptual paradigm to characterize and address stressors and resources that affect individual- and community-level health and well-being.

The chapter is divided into seven sections. The first section centers on community health and well-being in the context of CIAs and discusses the value of using qualitative approaches and data to highlight known barriers, data gaps, and potential challenges for decision-making. The second section provides a summary of the committee's community-engaged activities and selected takeaways from those events that are relevant to the committee's charge questions. The third and fourth sections, respectively, focus on types of current and future stressors to prioritize and characterize in CIA and factors that can make a community more vulnerable to stressors, including barriers to strengthening a community's ability to respond to stressors. Section five discusses the role of community and tribal data and knowledge in the context of CIAs, including issues of data sovereignty and examples of community-led tribal data initiatives. That section primarily focuses on tribal communities; however, the committee recognizes that issues in this section could also pertain to Black, Hispanic, Asian, and other communities of color. The sixth section highlights key challenges of addressing cumulative impacts. The final section provides the committee's conclusions and recommendations.

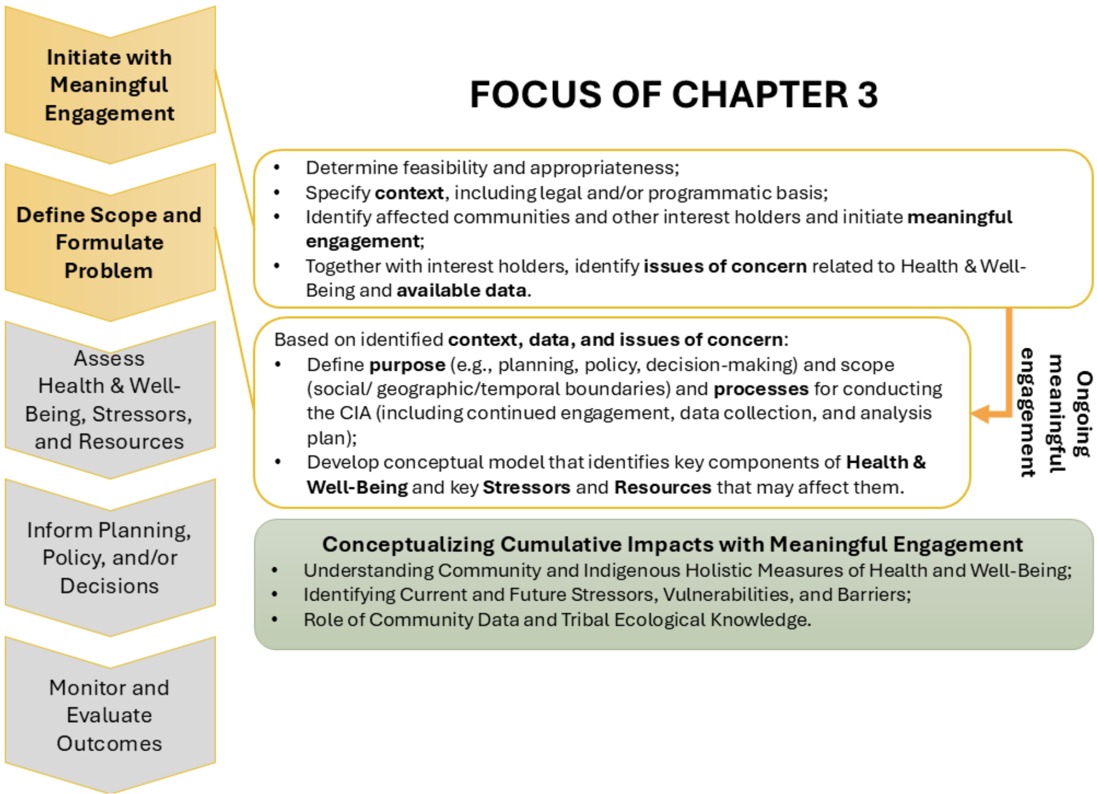

FIGURE 3-1 Chapter 3 addresses the first and second steps within the recommended process for cumulative impact assessment, focusing specifically on conceptualizing cumulative impacts with meaningful engagement.

COMMUNITY HEALTH AND WELL-BEING

The overall goal of developing and implementing a CIA approach is to support decisions by federal, state, and local policymakers and community members, among other relevant entities, who achieve results that ultimately improve the health and quality of life of communities.[1] Community health is not defined simply by the absence of disease (WHO, 1946; see Chapter 1). Community health is also a balance between the physical, mental, emotional, material, social, and spiritual well-being of people. Neglecting any one dimension can adversely affect others, leading to an imbalance that negatively impacts overall health and quality of life (Greenwood et al., 2018). This balance has been a long-standing worldview of Indigenous people whose teachings recognize the deep connection between people, animals, and the land (Kahn-John and Koithan, 2015). In recent years, this balance has also been acknowledged with the emergence of "planetary health" and "One Health" (de Castañeda et al., 2023).

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[1] As described in the National Academies report *Constructing Valid Geospatial Tools for Environmental Justice*, "community" is defined as "a group of people who share common experiences and interactions. While traditionally associated with specific places (i.e., geographic communities)—such as a neighborhood, town, city, or region—more general definitions decouple community from geography. Communities can exist at multiple scales—from local to global—and places can exist without community (Bradshaw, 2008)" NASEM (2024a, p. 23).

Value of Qualitative Data in CIAs

Documenting cumulative impacts is inherently a people-centered process. While much of the data that have gone into CIAs are quantitative data (e.g., number of industrial facilities located in a community, amount and access to green space, and health metrics), utilizing qualitative methods in CIAs can support an increased understanding of the lived experiences of individuals, communities, and tribes. For example, qualitative methods that have been used to identify social, economic, cultural, and political stressors and conceptualizations of cumulative impacts include individual and focus group interviews (Lightner et al., 2025), surveys (Chiger et al., 2025), key informant interviews, long-term participant observation, and content analysis (Payne-Sturges et al., 2021; Scammell, 2010;). Insights gathered through qualitative methods are especially important to ensure that the lived experience of impacted communities is appropriately captured through established community-engagement approaches (Payne-Sturges et al., 2018). Importantly, there is a need to define the goal and scale of the analysis upfront to ensure the utility of the information gained. As such, generating qualitative data by engaging communities can produce CIAs that more accurately reflect the needs and experiences of the people who are impacted. Additionally, engaging communities ensures that community strengths and resources that might be vulnerable to impacts are also appropriately captured. Such data offer a nuanced understanding of the stressors and how they may interact with one another to create aggregate or cumulative impacts.

Qualitative data collection can also help with prioritization (i.e., ranking) and highlight known barriers, data gaps, and potential challenges for decision-making that are not always apparent when using quantitative methods alone (van Roode et al., 2020). Integrating qualitative data into public health research enriches the understanding of complex health issues and supports more informed decision-making. By identifying barriers, data gaps, and contextual factors, qualitative research complements quantitative findings and contributes to the development of effective, equitable health interventions (see Chapter 4). The lack of awareness of qualitative data, such as lived experience, for example, can reduce the efficacy of decision-making by not identifying important unintended consequences or unintentionally exacerbating disparities across groups. Further, when exploring geospatial data, the administrative boundaries that define neighborhoods and how people interact in spaces and places over time are often different than those used for delivering mail (e.g., zip codes) or for census data collection, and therefore, aggregation methods based on these administrative boundaries can lead to misclassification or can dilute or conceal finer spatial gradients in risk factors (Kinnee et al., 2020). Not only can qualitative methods be used to identify individual stressors, but they can also be used to develop a qualitative causal theory linking multiple stressors that impact health and well-being (Payne-Sturges et al., 2023). One such approach is qualitative system dynamics methodology, where researchers use a group model-building approach to develop a “stock and flow diagram” that incorporates the multiple stressors that impact health (Siokou et al., 2014).

> *[Our communities] feel like they don't have a voice; they don't feel like they can stop these plants; they feel like it’s a done deal. They don't know where to go, who to talk to [in order to] stop these plants from being built in their communities. There's a need to help them advocate for themselves.*
>
> \- Shamell Lavigne (Rise St. James, Louisiana)

Engaging a community can take many forms and is best viewed as a continuum: on one end, this spectrum involves inviting the community to share information; on the other, it is an iterative process where the community is a co-creator (González, 2019; Williamson et al., 2020), and this form of community engagement can be applied to CIAs. The precise nature of the community engagement will depend on factors that include the decision context, timing, and resources (e.g., funds for facilitation services, language interpretation, and related relationship- and trust-building tools). The federal government can play an important role in promoting meaningful community engagement by providing such resources and funding and implementing the appropriate ecosystem for collaborative problem solving. This ecosystem includes community members, academic researchers, and public agency staff, among others specific to the context (MacIver et al., 2022).

Meaningfully engaging the community in the CIA process can improve the data and knowledge that can ultimately affect the specific decision to be made. The knowledge and data provided can range from historical, to lived experience, to firsthand accounts of local conditions. Community members can also provide data on existing conditions, areas of concern, stressors, and resources that might not be readily available in the peer-reviewed literature or white papers. Engaging the community can improve the CIA through the following actions:

- Identifying stressors and resources that impact community health and well-being that may not be captured in official or administrative data sources;
- Providing “ground-truthing” (i.e., validating data with real-world observations) to validate inputs and outcomes of CIA with the lived experience;
- Providing historical perspectives about efforts that, from the community viewpoint, have failed or succeeded;
- Highlighting the implications and impacts of the specific decision to be made; and
- Centering the desired outcomes on community priorities and solutions.

The next section provides examples of the outcomes of these actions from community engagement activities undertaken by the committee through the course of the study.

COMMITTEE’S INFORMATION-GATHERING ACTIVITIES FROM TRIBES AND COMMUNITIES

To answer the charge questions focused on data and knowledge for CIAs that are addressed in this chapter, the committee designed and carried out several in-person and virtual information-gathering activities in consultation with their community and tribal liaison group (see Chapter 1, Figure 1-1 and Table 1-1). These activities specifically sought to capture both the lived experiences and intergenerational transmission of historical experiences of community members through dialogues in the format of the World Café methodology, which consists of a series of small-group conversations about specific discussion questions. The table below summarizes the committee's three information-gathering engagements, which are also summarized in a separate Proceedings (NASEM, 2025a). These three events complemented the other public sessions conducted by the committee, including a virtual workshop (see NASEM, 2025b), an open session with practitioners (see Chapter 1, Box 1-2), and an open session with liaisons during the committee’s first public meeting in July 2024. Overall, the committee gathered input from more than 100 individuals through their six public workshops and open sessions.

TABLE 3-1 Information-Gathering Engagements Using the World Café Method

Event	Date	Location	Participants
Community-engaged workshop and site visit	Nov 20, 2024	New Orleans, LA	Local community members, liaisons
Virtual Town Hall during eighth meeting	Dec 12, 2024	Virtual	Liaisons
Colorado tribal engagement during tenth meeting	Feb 12, 2025	Aurora, CO	Local tribal members

The committee, in consultation with the community and tribal liaison group, developed discussion questions to gather information relevant to the committee’s charge questions. The questions they developed are detailed in Box 3-1.

BOX 3-1
World Café Discussion Questions Developed to Address the Study Charge Questions

1. What are the main stressors experienced in your community now?
2. What will be the main stressors in the future—in the next 10–20 years?
3. What makes your community more vulnerable to stressors?
4. What are the barriers to strengthening your community's ability to respond to stressors?
5. What is your future vision of improved community health and well-being?
6. What is the most important aspect for our committee to consider?
7. What are special considerations or concerns that should be highlighted to ensure children are properly included in cumulative impact assessments?[a]
8. What are the opportunities to improve decision-making tools by incorporating tribal knowledge and data?[b]

[a] Only during the virtual liaison Town Hall.
[b] Only used during the Colorado tribal engagement.

An overview of the topics raised by participants and highlighted by the committee during the three events is provided below in Boxes 3-2, 3-3, and 3-4. A full summary is presented in the published *Proceedings* (NASEM, 2025a).

The first of these events, summarized in Box 3-2, provided a forum for in-person engagement with local community members from the greater New Orleans area and River Parishes. The day before the workshop, the committee took a tour of the Mississippi River Parishes, including a visit to the Whitney Plantation in Edgard, Louisiana, to gain perspective on the community and its history. Committee member Yoshi Van Horne drew the committee's attention to a brochure entitled "Plantations to Petrochemicals" that was created by a local community-based organization, The Descendants Project, to highlight the issues of concern to local communities.[2]

The committee also conducted a virtual Town Hall that was open to members of the committee's community and tribal liaison group. An overview of the Town Hall is provided in Box 3-3.

During the Town Hall, the committee also heard presentations from liaisons from Houston, Texas, and Portland, Oregon. Liaisons from Houston presented on the cumulative and intergenerational impacts of pollution and juxtaposition of industrial facilities and residential areas, including schools. Challenges included extreme weather, an unreliable electric grid, urban sprawl, and issues with zoning, public transit, insufficient safe housing, and barriers to accessing health care. Historically marginalized populations subjected to redlining and community disinvestment were also emphasized. "*I have often called the Houston area … the perfect storm of cumulative impacts and stressors*," said Jennifer Hadayia (Air Alliance Houston), who is from a third-generation Houston Ship Channel family.

Cassie Cohen (Portland Harbor Community Coalition) highlighted the proximity of industrial installations to houses and schools. Residents face a broad range of environmental exposures across the lifespan, as well as intergenerational and systemic impacts. Institutional racism and layers of oppression—shaped by policy and power structures—contribute to long-term health outcomes, Cohen said. She described a Superfund site and a critical energy infrastructure hub near houses and schools. It stores 90 percent of Oregon's oil, fuels, and gas and sits on liquefiable sediment along the banks of the Willamette River, raising concerns about major economic and environmental impacts of an earthquake.

The third and final event, detailed in Box 3-4, took place in Aurora, Colorado, as a focused engagement with tribal communities living in the Greater Denver area.

[2] More information about The Descendants Project is available at https://www.thedescendantsproject.org/about.

BOX 3-2
Overview of Community-Engaged Workshop in New Orleans, Louisiana
November 20, 2024

Topics raised regarding stressors included:

- *Stressors experienced now*: Structural racism, chemical industry entrenchment, abandonment, disenfranchisement, lack of data and decision transparency, housing costs, climate impacts—including flooding, poor infrastructure, industrial and infrastructure system failures during storms, and the mental stress caused by the inability to recover between storms;
- *Stressors anticipated in the future*: Population out-migration driven by pollution and gentrification, climate impacts, lack of adequate and affordable housing, insurance, poor education, failing infrastructure (e.g., roads, sewers, water treatment, energy), rising costs of utilities and insurance, data gaps, lack of resources for cleanup and remediation of polluted sites;
- *Factors making communities more vulnerable to stressors*: Gaps in pollution monitoring and enforcement; inadequate zoning laws; juxtaposition of high concentration of industrial sites and communities and schools; racial- and class-based segregation; economic disempowerment; low or limited political influence (compared to industry) to prevent industrial development; lack of: employment opportunities, health care access, full-service food markets, and other amenities; climate impacts (e.g., pollution from industry sites, flooding, saltwater intrusion); lack of social capital; financial vulnerability (e.g., rising cost of homeowner insurance);
- *Barriers to strengthening community response to stressors*: Political disenfranchisement, gaps in regulatory accountability and enforcement, lack of investment, poverty, racism, sexism, social barriers to resilience, unemployment, accessible education, lack of social connectivity.

Topics raised regarding visions for the future included:

- *Future vision of improved community health and well-being:* More impactful regulations; restrictions on existing industry and expansion; balancing economic interests and public health; prioritized community engagement, education, and empowerment; improved health access and outreach; investment of tax revenue in communities (e.g., green infrastructure, resilient housing);
- *Most important aspect for the committee to consider:* Being responsive to and representative of the most vulnerable communities and giving them a voice; value of balancing quantitative data with narratives and qualitative data; central role of intergenerational relationship building in communities.

TYPES OF CURRENT AND FUTURE STRESSORS

> *I don't know if this "Cancer Alley" is duplicated anywhere else, where you have 224 industries stacked on top of each other.*
>
> \- Verdell Banner (The Descendants Project)

Stressors or exposures, experiences, and conditions with adverse impacts on health and well-being to consider in CIAs are vast and encompass multiple domains. There are many classification schemes and terms used to group or categorize stressors across the cumulative risk and CIA literature; overarching themes include environmental, socioeconomic, political, and cultural stressors (Archer and Payne-Sturges, 2024).

Traditionally, environmental stressors have been commonly grouped as chemical versus nonchemical, and in most EPA decision contexts reducing or eliminating chemical stressors is at the core of the debate (e.g., expansion of a refinery or placement of a new toxic release facility). However, the committee identified a need to move away from this binary definition because it places a disproportionate importance on chemicals and their risks and an underappreciation of the complexity and diversity of nonchemical stressors, their direct risks, and how they might modify the effects of chemical stressors.

BOX 3-3
Overview of Virtual Town Hall, December 12, 2024

Topics raised regarding stressors included:

- *Stressors experienced now*: Children's health, asthma, and school performance; low life expectancy, mid-adulthood cardiovascular issues and other chronic health conditions; lack of access to health care, transportation, and affordable housing; poor water quality; low food security; active and legacy pollution;
- *Stressors anticipated in the future*: Climate change in areas with heavy industry; increases in housing costs and unhoused populations; increase in substance use; lack of planning for emergency disaster situations;
- *Factors making communities more vulnerable to stressors:* Legacy of government and regulatory neglect; racism and segregation; lack of educational opportunities and effective community empowerment; inadequate housing; uneven distribution of wealth; people being constantly in "survival mode";
- *Barriers to strengthening community response to stressors:* Lack of empowerment from lack of meaningful local representation and the exclusion of community voices; fundamental inequalities by gender, race, immigration status, and income; community divisiveness and gender inequalities that trickle down from the national scale; negative impacts on the natural world/environment.

Topics raised regarding visions for the future included:

- *Future vision of improved community health and well-being:* Clean rivers to fish and swim; green industry; stronger collaboration with community members; lead remediation; improved regulatory oversight; integration of community input in decision-making processes; strengthened infrastructure, including improved housing, expanded public transportation, and health care access;
- *Most important aspect for the committee to consider:* Accounting for lived experiences; low-income communities suffer the most from environmental and climate hazards; community-driven research empowers communities; more transparent, comprehensive, and understandable information is needed; the interconnectedness of air, water, soil, land, and housing issues; incentives for industry to improve; interactions among different stressors;
- *Special considerations regarding children:* The need for better data, including on air monitoring at school, blood lead levels, and school days missed; consider children in a different category (more vulnerable and higher exposures relative to their body weight); unique exposure pathways; consider proximity of schools to industrial sites in regulations/permitting.

Going forward, stressors can be generally separated into environmental (e.g., chemical, physical, biological, natural, infrastructural, or built-environment related), social (e.g., racial and ethnic discrimination, violence), economic (e.g., lack of affordable housing, access to healthy and affordable food), political (e.g., disenfranchisement), and cultural (e.g., language barriers, identity misrepresentation). The impacts of these stressors can be considered in the context of the interconnectedness of air, water, soil, land, and housing issues, as was reflected in the committee's tribal engagement (see Box 3-3) and as also recognized by the concept of "One Health" (de Castañeda et al., 2023).

The lack of positive features in the environment is also sometimes referred to as a stressor; for example, the lack of quality accessible green space in a neighborhood could diminish opportunities for physical activity or socialization and community building. The concept of salutogenesis allows positive features to be considered distinctly from negative ones, or as buffering factors of negative features (Burwell-Naney et al., 2019; von Lindern et al., 2022). The concept of salutogenesis encompasses ways to promote health, wellness, and well-being across many dimensions, including the built, natural, economic, political, and spiritual environments. It also lends itself to the concepts of resiliency and resilience (see NASEM, 2025b, for further discussion of these concepts).

> *Social vulnerability is not the opposite side of the coin as resilience. You can be both very socially vulnerable and very resilient to disasters.*
>
> \- Christopher Emrich, University of Central Florida (NASEM, 2025b)

BOX 3-4
Overview of Tribal Engagement Event in Aurora, Colorado, February 12, 2025

Topics raised regarding stressors included:

- *Stressors experienced now*: Limited availability of holistic and culturally relevant healthcare; affordable housing, housing security, and access to transportation, including between the city and tribal reservations; access to healthy and affordable food options; loss of cultural identity, language, and spirituality; lack of educational curricula that affirm Indigenous history and culture;
- *Stressors anticipated in the future*: Climate change driving extreme events and the loss of biodiversity; environmental challenges to self-sustaining off the land;
- *Factors making communities more vulnerable to stressors:* History of settler colonialism, land dispossession, and cultural genocide (e.g., forced removal, colonization, boarding schools), leading to intergenerational trauma; inaccurate and underrepresentation of Indigenous people in educational curricula and mainstream media; isolation (e.g., distance of reservation to resources, and isolation within urban areas); disconnection from tribal languages, traditions, and cultural practices;
- *Barriers to strengthening community response to stressors:* Lack of Indigenous community-support resources and institutions for urban-dwelling Indigenous people; invisibility of tribal communities, including tribal entrepreneurial capacity and an underappreciation of the successful business culture in Tribal communities.

Topics raised regarding visions for the future included:

- *A future vision of improved community health and well-being:* Improved public transportation and the associated environmental and infrastructure benefits;
- *Opportunities to improve decision-making tools by incorporating tribal knowledge and data:* A regulatory decision-making process that integrates and acknowledges community input before permits are approved;
- *The most important aspect for the committee to consider:* Integrating the interconnectedness of air, water, soil, land, and housing issues in cumulative impact assessments; incorporating community voices into the policymaking process; facilitating equitable access to health and health-promoting conditions.

Although the magnitude, relevance, and prioritization of specific stressors may vary from one community or group to another, the committee identified consistently reported stressors to prioritize for inclusion and characterization in CIA, at present and in the future, based on the literature and on knowledge gained during committee information-gathering activities. It is also worth noting that across different disciplines or literature, stressors and their impacts may be described as primary versus secondary (or cascading), hazards versus exposures, and direct versus indirect, but for the sake of clarity we summarize stressors into two major categories: environmental; and social, economic, and political. In the sections that follow, we describe these stressors and the resources that counter them.

Environmental Stressors

Environmental stressors are often described as chemical, physical, biological, natural, and infrastructural or built-environment related. They can be encountered in various settings such as residential, occupational, or community-wide. Below, we provide examples of each of these subcategories, drawing from the committee's information-gathering activities and the environmental health and risk assessment literature (Johnston and Cushing, 2020; Thakali and MacRae, 2021; Wei et al., 2022). These myriad examples are not exhaustive lists, and it is important to note that across disciplines or application areas, different terminology or ways to classify these stressors in the following subcategories may be used.

- Chemical stressors include contaminants present in air, water, soil, dust, food, consumer products, and other exposure media. These include air pollutants such as particulate matter

(PM), gases (e.g., ozone, nitrogen dioxide, hydrogen sulfide), volatile and semi-volatile organics (e.g., benzene, toluene, polyaromatic hydrocarbons, and trihalomethanes) in ambient and indoor air, coming from specific point or diffuse area sources (e.g., traffic, industry, indoor consumer products and building materials, wildfires, agricultural fields). Chemical pollutants in water include disinfection byproducts, PFAS (per- and polyfluoroalkyl substances), heavy metals, microplastics, drugs, nitrates, and pesticides, among others. Chemical food contaminants include pesticides and heavy metals, among others.

- Physical stressors include noise (e.g., from construction, traffic, occupational sources), pressure fields such as vibration (e.g., from construction sites or nearby railway systems), electromagnetic fields (e.g., from high-energy power lines) and radiation (e.g., ionizing such as x rays, gamma rays, and radon gas, and non-ionizing such as ultraviolet light and radio waves or microwaves).
- Biological stressors include pathogens such as bacteria, fungi, and viruses present in drinking or recreational water (e.g., fecal coliforms from wastewater or hog farms), in food items (e.g., mold or bacteria), pollen in ambient air, fungi and spores in soil and air, mold and viruses in indoor air.
- Natural stressors include disasters such as earthquakes, extreme weather events such as tornadoes and hurricanes, extreme temperatures, and volcanoes. Some of these stressors may also include increased frequency and severity of extreme weather events (e.g., hurricanes, storms, tornadoes) and loss of biodiversity (e.g., traditional medicinal plants no longer growing).
- Infrastructure or built-environment-related stressors include poorly designed or maintained, failing, or aging transportation systems (e.g., roads, public transit), wastewater and drinking water systems (e.g., sewers, drinking water networks), power distribution systems, and buildings or structures. Built-environment stressors may limit mobility or use of different modes of travel, including public transit, affecting connectedness and access to essential services, community gathering spaces, and disaster response (e.g., evacuation routes). Other examples include increased urbanization and loss of natural spaces, which can lead to increased erosion.

We know from public health data that a couple of hours of very heavy particulates can be really bad for heart health and lung health . . . .These short-term events happen like clockwork.

- Scott Eustis (Healthy Gulf)

These environmental stressors may be countered by resources that minimize pollution from chemical, physical, and biological agents; strengthen infrastructure; and enhance response and adaptation to extreme weather events. Increased access to health care is another example of a resource. Other types of resources may also enhance access to nature that has direct mental health benefits but also provides opportunities for physical activity, such as urban vegetation, green or blue space including parks, forests, coastal, or natural recreational areas (Jimenez et al., 2021). Oftentimes, some of these same factors are described as buffers—not exactly resources but serving in similar positive ways—because their presence may also mitigate pollution directly (e.g., some types of vegetation may enhance PM removal from air) or indirectly (e.g., the mere presence of a large park in an urban city equates to the absence of a polluting road of facility in that same location, or removes the opportunity for a polluting source to be placed there).

. . .green spaces, a reintroduced wetland buffer, … and residential homes that are built to withstand severe weather events, and the community enjoys clean air and water.

- Jacqueline Baham (Water Wise Gulf South and New Orleans East Green Infrastructure Collective)

Social, Economic, Political, and Cultural Stressors

Social, economic, political, and cultural stressors are often due to nonphysical forces, processes, policies, or norms in contrast with most environmental stressors described above. A strong body of evidence and literature to date indicates that these socioeconomic, political, and cultural stressors can similarly exert measurable impacts on biology and negatively affect health, most commonly through chronic stress and trauma-related pathways. They may be tightly interconnected (e.g., living in extreme poverty can also increase exposure to social stressors such as discrimination). Additionally, repeated cumulative traumas also lower the "starting point" for overcoming social, economic, political, and/or cultural stressors and thus can also contribute to vulnerability or lead to barriers as described below.

- Social stressors include experiencing racism, violence, crime, aggression or harassment, excessive policing, drug and alcohol abuse, discrimination, and social isolation. Social stressors could also be particularly connected to, or exacerbated by, transitional (e.g., losing housing security, homelessness) or traumatic events.
- Economic stressors include factors related to income and purchasing power such as financial hardship and poverty, unemployment, inability to afford adequate housing and insurance, and energy and food insecurity. Uneven distribution or inequalities in these stressors are often estimated or measured using dissimilarity indexes within defined geographic areas, such as the Gini Index of Income Inequality, or based on relative advantage or privilege in a local context.
- Political stressors often result from power dynamics and structural factors that affect policymaking and governance, among others. Examples include redlining (i.e., exclusionary housing policies); marginalization, exclusion or disempowerment of certain individuals or groups from voting, political decision-making processes, and business ownership opportunities; targeted divestment in neighborhoods and job opportunities or educational programs (e.g., closure of schools, recruitment of teachers); lack of resource allocation for cleanup and remediation of polluted sites; policies and processes that undermine Indigenous sovereignty; lack of workplace protections; and more.
- Cultural stressors can result from expectations, stereotypes, or roles assigned to individuals or groups based on their identity, often connected to language, origin or nationality, immigration status, and more. Examples include linguistic and social isolation, lack of culturally sensitive and linguistically capable health care providers serving a certain community, acculturation stress from adapting to new cultures or navigating across original and new culture, and loss of community traditions, among others.

Particularly in the river parishes …I feel like there's a lack of public commons.

- Justin Kray (Hidden Landscape Consulting)

The costs of housing are unbelievable, and Native families have always congregated and lived together; that's how we survived a lot of the trials and tribulation.

- Beverly Castaneda (Community Elder)

These stressors may be countered by resources such as economic assistance programs; tax policies that promote local investment; and enhancement of social capital, community connection, purchasing power, organizing power, voting turnout, and political representation. Other resources include bilingual tribally run school programs. A further example is building the evidence base to provide insurance coverage for culturally adapted interventions or cultural practices (e.g., using a traditional healer for post-traumatic stress disorder being paid for by the Veteran's Administration). Additional resources include laws such as the Indian Child Welfare Act, and economic benefits of the Alaska Native Claims Settlement Act.

VULNERABILITY FACTORS AND BARRIERS

> *Something that makes our community uniquely vulnerable is a spiritual disconnection. Before colonization, we had tribal methods for healthcare, mental wellness, community organization, people management, cultural education, all of those pieces. And through colonization, lots of disconnection has happened through boarding schools, through termination, through reservation, through allotments, through relocation, through all of those mechanisms. There is a large population of tribal folks who have been spiritually disconnected from their homelands [and] home cultures.*
>
> \- Sena Harjo, Seminole, Choctaw and Creek

While definitions of susceptibility and vulnerability have been offered in previous National Academies reports (NRC, 2009), the committee refers to the following definitions.

> ***Susceptibility*** is the presence of intrinsic biological factors that make a person more likely to experience adverse outcomes from an exposure.
>
> ***Vulnerability*** includes both the presence of intrinsic (i.e., biological) factors that influence susceptibility to experience adverse outcomes from exposure and the presence of extrinsic factors, both contemporary and historical, that make a person more likely to be exposed and/or to experience adverse outcomes from an exposure, such as reduced capacity to tolerate or recover from a harmful exposure.

Expanding on these concepts, intrinsic factors that underly susceptibility such as chronological age, life stage, body composition, physical condition, underlying disease and genetics can alter one's biological response to chemical and nonchemical stressors. Extrinsic factors, that compound with susceptibility to increase one's vulnerability, include individual and place-based structural factors that undermine population health and shape one's access to "healthy behaviors" and resources. Thus, vulnerability can arise from (1) excessive or chronic exposure to chemical and nonchemical stressors; (2) underlying health conditions resulting from adverse exposures; or (3) limited access to resources required to prevent an exposure, be unaffected by an exposure, or adequately recover from an exposure.

It is also important to consider the various historical and contemporary processes and structural factors that can exacerbate social, economic, or cultural stressors and/or serve as barriers to access to important resources for certain populations. These include, but are not limited to settler colonialism, slavery, laws and policies that enforce discrimination or that encourage segregation or displacement, and the role of industry and commercial interests (Gilmore et al., 2023). These processes can act as barriers to positive change and contribute to intergenerational trauma (e.g., the lasting psychological and emotional harm passed down through generations due to historical injustices), thus shaping cumulative impacts within key populations (Bailey et al., 2017; Morello-Frosch et al., 2011; Varshavsky et al., 2023).

Quantitative indicators across multiple stressor domains include the Centers for Disease Control and Prevention's (CDC's) Social Vulnerability Index (SVI),[3] the Area Deprivation Index (ADI),[4], and the Environmental Justice Index (EJI).[5] Other indexes have been developed for specific contexts or applications. Data on rates of, for example, frequency of extreme weather events and quality of critical infrastructure/systems can also inform an assessment of vulnerability. Although these may be useful for a general or rapid assessment of vulnerability, community engagement will likely provide deeper and more specific insights and allow for qualitative assessment of many of the social, political, and cultural stressors for which publicly available data do not exist. Community engagement can also illuminate which data should be included or prioritized when assessing community/population vulnerability. For example, during the committee's information gathering, several themes arose when asked about barriers to strengthening community response to stressors and community vulnerability, including gaps in pollution monitoring and enforcement; juxtaposition of industrial sites, communities, and schools; legacy of neglect, racism, and segregation leading to intergenerational trauma; economic disempowerment; lack of education and employment opportunities; lack of social capital; financial vulnerability (e.g., lack of affordable housing); isolation and disconnection from traditional and cultural practices (see Boxes 3-2, 3-3, and 3-4, above).

One common theme that the committee perceived as a strong driver of vulnerability was political disenfranchisement and low political capital. Both lead to exclusion from meaningful engagement in decision processes. Indeed, exclusion from the procedures and process that inform policymaking, development projects, permitting, investment, and other decisions disproportionately affects communities that also experience poverty, racial discrimination, and linguistic isolation and are outside of urban centers, and serves as an important source of vulnerability. Underbounding and gerrymandering are examples of political exclusion by design, in which political boundaries are drawn to intentionally minimize the influence of specific populations in municipal or state decision processes. Exclusion can also occur through less explicit means. Over time, the lack of representation contributes to the neglect of certain communities' needs in other areas beyond environmental protection and regulation, including availability of quality education, health care, housing, and infrastructure, thus leading to adverse cumulative impacts. The resulting disparities can compound across generations, reinforcing cycles of poverty, marginalization, and political powerlessness. As these communities continue to be excluded, their ability to influence change diminishes (as does their sense of agency in affecting change), thus perpetuating a feedback loop and serving as a significant barrier to accessing resources and opening critical paths forward that can promote well-being and a high quality of life.

Community assets or resources can break these feedback loops and enable critical paths forward for improved health and well-being (Flora et al., 2012), including:

- *Human*: Skills and abilities of individuals within a community;
- *Social*: Networks, organizations, and institutions, including norms of reciprocity and the mutual trust that exists among and within groups and communities;
- *Political*: Ability of a group to influence the distribution of resources, financial and otherwise;
- *Financial*: Money or other investments that can be used for wealth accumulation rather than consumption;
- *Cultural*: Values and approaches to life that have both economic and non-economic benefits;
- *Built*: Anything physically made by humans, including housing, factories, schools, roads, community centers, power systems, water and sewer systems, telecommunications infrastructure, recreation facilities, and transportation systems;
- *Natural*: Landscape, air, water, wind, soil, and biodiversity of plants and animals.

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[3] More information about the CDC's SVI is available at https://www.atsdr.cdc.gov/place-health/php/svi/index.html.
[4] More information about the ADI is available at https://www.neighborhoodatlas.medicine.wisc.edu/.
[5] More information about the EJI is available at https://www.atsdr.cdc.gov/place-health/php/eji/index.html.

ROLE OF COMMUNITY AND TRIBAL DATA AND KNOWLEDGE

Data and knowledge originating from community and tribal nations are as valuable and important for conducting CIA as data curated from academia, government agencies, or private institutions.[6] Incorporating data and knowledge originating from affected communities through mixed methods and scientifically rigorous approaches (Davis and Ramírez-Andreotta, 2021) can be integrated seamlessly into CIAs.

Through a community participatory approach, researchers from the University of California at Davis Center for Regional Change (London et al., 2011) and the San Joaquin Valley Cumulative Health Impacts Project (SJVCHIP), sought to collaboratively identify stressors for a CIA in California's San Joaquin Valley and Eastern Coachella Valley (Huang and London, 2016). The team was able to integrate data and knowledge from SJVCHIP through a two-step process. First, the academic team identified stressors in publicly available datasets, such as point-source pollution sites through the U.S. EPA's Toxics Release Inventory, pesticides through the California Department of Pesticide Use Registry, and sociocultural factors, such as the percentage of the population that is linguistically isolated, through census data. Next, the academic team gathered with members of the SJVCHIP to host an in-person workshop where the academic team engaged the attendees in a participatory mapping activity. Through this activity, the community attendees were able to add other pollution sources not included in the publicly available data by noting the location sites on the map, which improves public agency staff understanding of community members' hyperlocal pollution source concerns. The academic team then digitized this information and incorporated it into their CIA. Another example is the Washington Environmental Health Disparities Map project which utilized a community-driven approach to develop a cumulative environmental health impacts assessment tool (Min et al., 2019). Over a 2-year period, the team conducted 11 community listening sessions, where common themes that emerged from these sessions were used to inform the stressors and develop the indicators for the tool. The Washington Environmental Health Disparities Map project also utilized participatory mapping, and through an iterative process reached consensus on the stressors to include in their cumulative impacts assessment.[7]

Similarly, mixed methods and community participatory approaches have been used to conduct cumulative risk assessment with Indigenous communities (Van Horne et al., 2021). Through a multidisciplinary collaboration, a team of Navajo-centered researchers and community leaders demonstrated that risk assessments that only incorporate data originating from non-Indigenous sources do not accurately capture exposures in Native communities (Van Horne et al., 2024). These Western-centric assessments often overlook unique cultural factors, deep environmental relationships, and unique community activities (e.g., subsistence fishing) that can significantly influence exposure levels.

Indigenous communities such as the Akwesasne Mohawk Nation, the Navajo Nation (Hoover, 2017), the Standing Rock Sioux Tribe (Whyte, 2018), as well as Alaska Natives face environmental impacts from the cumulative effects of oil pipelines, mining activities, and water contamination (NRC, 2003). It is critical to note that these environmental impacts are a direct or an indirect result of federal policies such as the Indian Removal Act, the Trail of Tears, and The Long Walk (Denetdale, 2011), which forced the removal of Indigenous people from their homelands. Furthermore, relocation programs implemented by the U.S. Bureau of Indian Affairs during the 1950s, which sought to move Indigenous individuals from reservations to major urban centers (Cobb and Fowler, 2007) also had negative effects not only on the generation that experienced relocation but also on the subsequent generations. For

[6] In November 2021, the White House Office of Science and Technology Policy and the Council on Environmental Quality issued a memorandum identifying the relevance and importance of Indigenous traditional ecological knowledge (ITEK) to federal decision-making and committed to elevate the role of ITEK in federal scientific and policy processes (Lander and Mallory, 2021).

[7] More information about the Washington Environmental Health Disparities Map project is available at https://doh.wa.gov/data-and-statistical-reports/washington-tracking-network-wtn/washington-environmental-health-disparities-map.

example, using life-course perspective concepts and drawing from data collected from a longitudinal study of four American Indian reservations in the northern Midwest and four Canadian First Nation reserves, Walls and Whitbeck (2012) assert that the trauma and psychosocial stress initiated by the relocation experience did not end with those moved—but instead cast long shadows over subsequent generations, shaping health and emotional outcomes even among descendants. Participation of the grandparent generation in government relocation programs was found to have both direct and indirect negative effects on their own welfare and also to ripple across generations, contributing to increased substance use, negative affective states, and behavioral problems in their children and grandchildren. As such, CIAs are crucial for ensuring that the multiple and compounding stressors impacting Indigenous communities are accurately captured.

Inclusion of tribal data and knowledge in these assessments is vital to ensure that the inherent rights of Indigenous groups as sovereign nations are included in decision-making processes (United Nations, 2007). Historically, Indigenous peoples have relied on their traditional knowledge to govern their lands, protect ecosystems, and maintain cultural practices, knowledge that is often intertwined with the land they occupy (Berkes, 2012; Gómez-Baggethun et al., 2013; Simpson, 2004). The role of data sovereignty in CIAs is therefore essential for Indigenous peoples to assert their rights, protect their resources, and maintain their cultures (KukuTai and Taylor, 2016).

The Importance of Traditional Ecological Knowledge

TEK encompasses the collective knowledge and practices developed over generations by traditional communities, such as Indigenous peoples, in relation to their environment (Berkes et al., 2000). TEK can include observations of natural phenomena, seasonal cycles, animal migrations, plant growth, and other ecological patterns essential for the sustainable management of natural resources (Berkes, 2012; Whyte, 2013). It also encompasses spiritual and cultural practices tied to the land. Integrating TEK into CIAs provides a more holistic view of the environmental effects of polluting industrial projects and allows Indigenous communities to convey their deep connection to the land in ways that are often overlooked by conventional scientific methods and assessments. TEK serves as a counterbalance to the limitations of scientific data, providing a more comprehensive, Indigenous-centered approach to environmental monitoring (Simpson, 2004; Turner and Berkes, 2006).

Tribal Data Democratization

On a structural level … there needs to be a guarantee of data sovereignty and data privacy.

- Spencer Green (County & Tribal Liaison, Colorado).

Data democratization refers to the process of making data, and that the benefits derived from the data are accessible to all, particularly historically marginalized groups. For Indigenous communities, the potential of data democratization is particularly significant. Much TEK—concerning ecosystems, land management, cultural practices, and health—has been passed down through generations, often through oral traditions and tightly knit community networks (Berkes et al., 2000; Murray and Benitez 2020). Historically, such knowledge has been marginalized or misinterpreted by external researchers and institutions, contributing to mistrust between peoples and leading to policies and practices that have harmed Indigenous peoples and their lands. Additionally, extractive approaches to data collection, for example, without fair compensation, consent, control, or benefit to communities, can lead to the misrepresentation of Indigenous knowledge and, in many cases, the exploitation of that knowledge for external profit or control (Schnarch, 2004). Furthermore, the failure to include Indigenous knowledge in conventional data systems has contributed to the erasure of valuable ecological insights and cultural wisdom.

However, while data democratization offers numerous opportunities, it also raises critical questions about data governance, ownership, and benefit sharing. For Indigenous communities, the challenge is not only about gaining access to data but also about asserting their rights over how data are collected, stored, shared, and applied. The application of frameworks such as the First Nations principles of OCAP® (Ownership, Control, Access, and Possession)[8] and the CARE Principles for Indigenous Data Governance (Collective Benefit, Authority to Control, Responsibility, Ethics) provides valuable guidance for ensuring that data democratization efforts respect Indigenous rights and knowledge systems (Schnarch, 2004). Together, OCAP® and CARE provide essential frameworks for advancing Indigenous data sovereignty by promoting ethical standards that respect Indigenous governance systems. These frameworks offer tools for resisting exploitative research practices and creating pathways for Indigenous peoples to assert control over their data. As the importance of data sovereignty continues to gain recognition, these principles are increasingly being integrated into research, policy, and advocacy efforts aimed at supporting Indigenous rights and knowledge systems.

Community-Led Tribal Data Initiatives

A fundamental aspect of data democratization for Indigenous communities is the establishment of systems that empower communities to collect, manage, and govern their own data. Today, Indigenous communities are actively reclaiming their data sovereignty by developing community-led data initiatives that prioritize their self-determination, cultural integrity, and social justice (Carroll et al., 2019). The capacity, bandwidth, and interest of each community is accounted for in self-determination to set the requirements, procedures, and specific protocols relevant to each community.

Indigenous data sovereignty initiatives often incorporate a blend of traditional knowledge systems and modern technologies to ensure that data collection and management are conducted on the community's terms. Tools such as geographic information systems, drones, mobile applications, and community-managed databases are increasingly being employed to document ecological knowledge, map traditional territories, monitor environmental changes, and protect cultural resources (Corbett and Keller, 2006). For Indigenous communities, data are not just information—they are living entities intertwined with cultural teachings, histories, and responsibilities to the land and future generations (Carroll et al., 2020).

A noteworthy example is the Akwesasne Mohawk Nation's efforts to establish greater control over their environmental data and cultural resources through the Akwesasne Environmental Management Program (AEMP). Launched in the 1990s, the AEMP is a community-driven initiative focusing on monitoring air quality, water quality, and land use. Localized control over environmental data has been pivotal in safeguarding their lands from industrial pollution and other environmental threats.[9] By utilizing culturally relevant methodologies and traditional TEK alongside scientific practices, the AEMP exemplifies how Indigenous communities can assert agency over data governance to enhance environmental health and promote economic resilience. Community-led data democratization provides numerous critical benefits to Indigenous communities:

1. *Cultural Preservation*: Ensuring that TEK and cultural practices are documented and stored in culturally appropriate ways to safeguard Indigenous worldviews from being misrepresented or lost (Carroll et al., 2025);
2. *Local Empowerment*: Providing communities with the tools and authority to collect, manage, and analyze data strengthens their capacity for self-determination. This empowerment allows Indigenous peoples to make informed decisions about natural resource management, health, education, community development, and land rights, while also promoting resilience in the

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[8] More information about OCAP® is available at https://fnigc.ca/ocap-training/.
[9] More information about the Akwesasne Environment Program is available at https://www.akwesasne.ca/dihe/environment/.

face of climate change and other external threats (Rainie et al., 2017; Whyte et al., 2023, pp. 14-15);

3. *Research Inclusion*: Community-driven initiatives promote a more inclusive research ecosystem where Indigenous perspectives and knowledge systems are regarded as legitimate sources of information. This paradigm shift challenges the dominance of Western scientific methodologies and advocates for collaborative research practices that respect Indigenous governance and decision-making processes (Schnarch, 2004);
4. *Sustainable Development*: Combining traditional knowledge with modern technologies enables communities to develop innovative strategies for managing natural resources, adapt to environmental changes, and enhance economic opportunities. This integration acknowledges the deep interconnections between cultural heritage, environmental stewardship, and well-being (Johnson et al., 2016);
5. *Data Governance and Sovereignty*: By asserting control over data processes, Indigenous communities can establish frameworks that align with their cultural values and political priorities.

Ultimately, community-led data initiatives are not just about making data accessible; they are about reclaiming power, asserting sovereignty, and ensuring that Indigenous knowledge systems are recognized and valued on their own terms. The continued growth of these initiatives holds the potential to transform how data are collected, shared, and utilized, paving the way for more just and equitable data governance systems, and the incorporation of these into CIAs.

Moving Forward: Enabling Tribal Data Sovereignty and Knowledge Preservation

Addressing the challenges facing tribal data sovereignty requires concerted efforts across multiple areas.

1. *Developing Indigenous Data Governance Frameworks:* Tribal communities must lead the creation of governance structures for managing their data. This includes establishing protocols for data collection, distribution, storage, and enforcement mechanisms that reflect community values and priorities (Kukutai and Taylor, 2016).
2. *Building Data Literacy and Capacity:* Providing training in data collection techniques, ethics, and digital tools empowers Indigenous communities to autonomously manage their data. Developing educational resources and increasing accessibility to technological tools are essential for enhancing data sovereignty (Walter and Suina, 2018).
3. *Collaborative Partnerships:* Building mutually beneficial partnerships with researchers, technology companies, and governments can foster transparent and respectful relationships. Such partnerships must be based on trust, with clearly defined agreements on data ownership, access, and usage (Smith, 2012).
4. *Advocating for Legal Protections:* Evolving legal frameworks to recognize Indigenous data sovereignty is essential. This includes advocating for national and international policies that protect Indigenous data and affirm communities' rights to control their knowledge (Kukutai and Taylor, 2016).

The intersection of community-driven data practices, data sovereignty, and democratization is pivotal for empowering Indigenous communities. Ensuring that tribal knowledge is preserved and protected through culturally sensitive data practices offers a path forward where Indigenous peoples can govern their resources, traditions, and intellectual property. Data sovereignty allows these communities to assert control over their data and ensures that their cultural heritage is respected and preserved in the digital age. By fostering community-led initiatives, advocating for legal protections, and promoting education and capacity-building, a future where Indigenous communities control their data and benefit equitably from the digital transformation is achievable.

Tribal data sovereignty not only empowers Indigenous communities to protect their lands and cultures but also enriches the CIA process, providing a more complete, and accurate, picture of the environmental and health challenges facing these communities. As Indigenous nations continue to assert their data sovereignty, they are shaping a future where their knowledge and voices are central to the governance of their lands and the protection of their peoples.

KEY CHALLENGES FOR ASSESSING CUMULATIVE IMPACTS

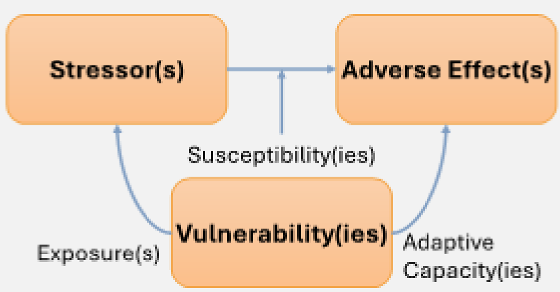
As described above and elsewhere in the report, the Committee's information-gathering sessions, particularly those with state agencies, community members, and tribal representatives, have revealed a marked breadth and variety of factors, concepts, and concerns that fall under CIA, from stressors to resources, barriers, and vulnerabilities, as described in this chapter. Even concepts of health and well-being may encompass a wide array of constituents beyond commonly considered physical and mental health.

> *Models should conceptualize well-being as a holistic interplay of physical, mental, social, and spiritual domains and recognize how the health of humans, animals, and the environment are interrelated.*
>
> \- Denise Dillard (NASEM, 2025b).

Furthermore, while there has historically been an emphasis on "negative" impacts that are detrimental to health and well-being, previous National Academies reports, HIA frameworks, researchers, and interest holders have also highlighted the need to consider "positive" factors in CIAs that promote health and well-being, posing challenges for a traditional risk assessment paradigm (see Box 3-5).

BOX 3-5
Challenges of Risk Assessment-Based Paradigm for Addressing Cumulative Impacts

The basic risk assessment paradigm of hazard identification, exposure assessment, dose-response assessment, and risk characterization has remained unchanged since it was introduced over 40 years ago (NRC, 1983). Over time, what started as chemical risk assessment has been generalized to encompass some of the elements of cumulative impacts (see Diagram below). For instance, chemical hazards have been expanded to include "nonchemical stressors"; however, there are numerous limitations to adapting these approaches to CIA, including that traditional risk assessment.



- Emphasizes the quantification of dose-response relationships between chemical exposures and health outcomes using toxicological and human evidence. Yet, the *health risks of exposures to many nonchemical stressors often cannot be quantified* in ways that are amendable to traditional risk assessment methods;

continued

BOX 3-5 *continued*

- *Does not consider outcomes related to improved health and well-being* and is not conducive to the integration of salutogenic factors that can promote health and well-being;
- Often *excludes local data, traditional environmental knowledge, lived experiences, and other data sources* that can facilitate more holistic approaches to characterizing cumulative impacts;
- *Does not include nonhealth outcomes* that are important to understand the impact of decisions on a community, such as land dispossession, impairment of human–natural world connection, loss of cultural heritage, displacement and gentrification, disempowerment and disenfranchisement, and lack of economic opportunities and other salutogenic amenities; and
- The quantitative data inputs required often delay or *paralyze already lengthy regulatory and standard-setting processes*. Yet often there is sufficient existing human and/or toxicological evidence linking environmental hazard exposures with adverse health effects, making exposure characterization or the application of hazard-based triggers sufficient to inform decision-making and action without the need for additional risk assessments.

Therefore, cumulative impacts assessment should transcend a narrow "healthy/diseased" dichotomy to include a broader continuum that augments "stressors" with positive factors and resources that promote health and well-being, and that leans toward a bias for regulatory action (NASEM, 2025b).

CONCLUSIONS AND RECOMMENDATIONS

Conclusion 3-1: EPA's interim framework provides a starting point for conceptualizing cumulative impacts, but there is a need for expansion to account for the multiple dimensions of health and well-being for individuals and communities. To address key issues identified and discussed during the committee's information-gathering process, cumulative impact assessment (CIA) would benefit from conceptually separating biological and structural factors into those that promote disease and distress (stressors) from those that promote health and well-being and decrease vulnerability to stressors (resources). Additionally, CIA can be broadened to reflect the deep interconnection between people, animals, and the natural environment and enrich concepts of health and well-being to include physical, mental, emotional, material, social, and spiritual components. Finally, it is necessary to highlight the critical importance of the context of decision-making and provide consideration for different spatial and temporal scales, including past, present, and future.

Recommendation 3-1: In EPA's final framework, and in the practice of cumulative impact assessment, the conceptual paradigm for cumulative impacts should be expanded to encompass the following three concepts:

- **Health and well-being: A broad umbrella encompassing multiple dimensions—including physical, mental, emotional, material, social, and spiritual aspects;**
- **Stressors: Factors that undermine health and well-being; and**
- **Resources: Factors that promote health and well-being.**

Figure 3-2 elaborates on the committee's recommended cumulative impacts paradigm (CIP) to characterize and address both stressors and resources. These operate at multiple levels to affect individual and community health and well-being. The CIP respects tribal sovereignty and American Indian and Alaska Native legal self-governance as a critical aspect of understanding local context and the role of data democratization for CIA. The CIP can be applied throughout the committee's recommended steps of CIA (see Chapter 2, Figure 2-4). The CIP provides a broad basis for developing an inventory of data, indicators, and metrics for use in CIA. Additionally, the CIP highlights the need for and challenges of combining environmental with socioeconomic stressors and resources within communities, addressing potential complex relationships within and across factors, and ultimately translating them to measure and improve overall health and well-being.

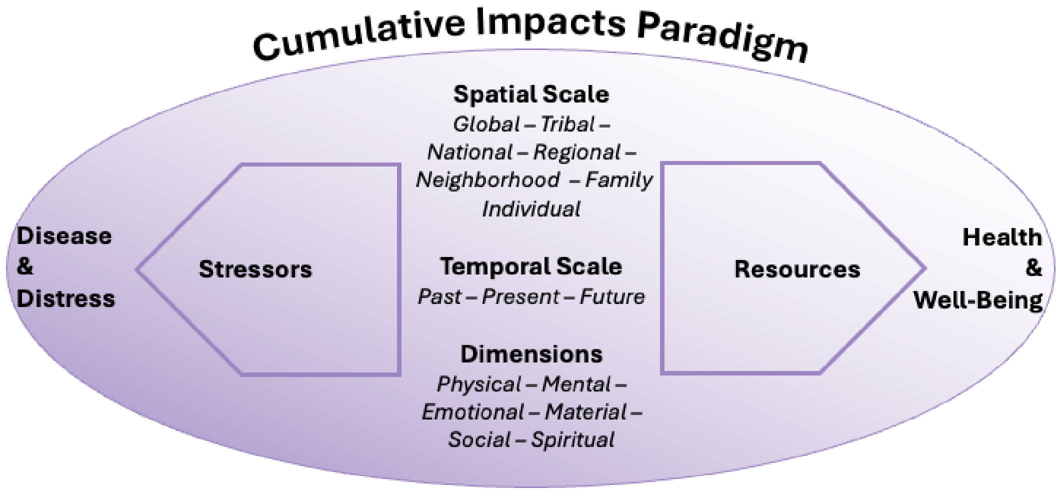


FIGURE 3-2 Cumulative impacts paradigm (CIP) to characterize and address stressors and resources that affect individual- and community-level health and well-being.

Conclusion 3-2: The types of stressors to prioritize, characterize, and consider in combination in a cumulative impact assessment to best reflect overall burdens facing diverse communities and populations may encompass a range of environmental, political, economic, historical, and cultural factors. Similarly, types of resources may vary, including across spatial and temporal scales. A broad consideration of the different stressors faced by and resources available to communities, tribes, and other interest holders can help to facilitate meaningful engagement.

Recommendation 3-2: EPA and other entities should implement existing best practices for meaningful engagement in the context of cumulative impact assessments. Through this process, they should gather and incorporate data and knowledge originating from communities and tribal nations, including traditional ecological knowledge.

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4
Methodological Approaches to, Frameworks for, and Uncertainties in Assessing Overall Health and Well-Being

As part of its statement of task (see Chapter 1), the committee was asked to address the following charge questions:

- *What approaches for assessing overall health and well-being are most useful for incorporating into cumulative impact assessment?*
- *How can uncertainty in cumulative impact assessments be characterized?*

This chapter addresses these charge questions by describing available methods and approaches to collect and synthesize qualitative and quantitative data on health and well-being, stressors, and resources. It builds from the identification of key sources of data and knowledge for assessing health and well-being, stressors, and resources outlined in Chapter 3 and describes how this evidence can be integrated and analyzed to characterize cumulative impacts or to support advancement of cumulative impact assessment (CIA).

Figure 4-1 summarizes how the methods and approaches described below fit into Step 3, Assess Health & Well-Being, Stressors, and Resources, of the process for CIA recommended in Chapter 2 (See Figure 2-4). This step is informed by the decision context, understanding that CIA can be used across a range of interest holders and communities, and at multiple scales—national, regional, state, local, and individual. The focus of the tasks within Step 3 are to:

- Collect, evaluate, and synthesize evidence; and
- Analyze and integrate evidence to characterize cumulative impacts.

This general approach is informed by ongoing meaningful engagement with communities and tribes, as further discussed in Chapter 3. It also necessitates using the multidisciplinary approaches described in this chapter, as well as the availability of authoritative data sources and reviews[1] (and systematic reviews). Further, it relies on qualitative information on lived experiences and addressing uncertainty while maintaining timeliness.

The chapter is organized based on different methodological approaches for integrating data and evidence to assess health and well-being in a CIA. These resources and methods each present unique sources of uncertainty associated with data completeness, precision of measurement across space and time, and design limitations. Strengths of the approach and gaps in generating evidence are identified for each method. Also discussed are emerging evidence, new scientific tools, and data needed to address major sources of uncertainties. The chapter concludes with the committee's relevant findings, conclusions, and recommendations.

METHODOLOGICAL APPROACHES

CIAs rely on integration and analysis of data gathered from numerous resources to characterize the unique combination of stressors and resources that influence health and well-being within a particular

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[1] Reviews produced by governmental agencies and international agencies (i.e., EPA, National Toxicology Program, U.S. state agencies, foreign governmental agencies, the European Union, and the International Agency for Research on Cancer/World Health Organization, etc.).

decision context and geographic scale. Examples of assessment and evaluation methods used to conduct a CIA are provided in the EPA's *Interim Framework for Advancing Consideration of Cumulative Impacts*, including single scoring and matrix approaches (for assessments of geospatial data and indicators), community-based approaches, and combined aspects of epidemiological, toxicological, and exposure modeling approaches (EPA, 2024). The committee's methodological recommendations support the use of approaches outlined by EPA for implementing CIA and also describe additional sources of evidence needed to better understand how stressors and resources impact health and well-being within a CIA. This additional evidence can be drawn from the fields of toxicology, epidemiology, exposure science and exposomics, life-course approaches, and economics.

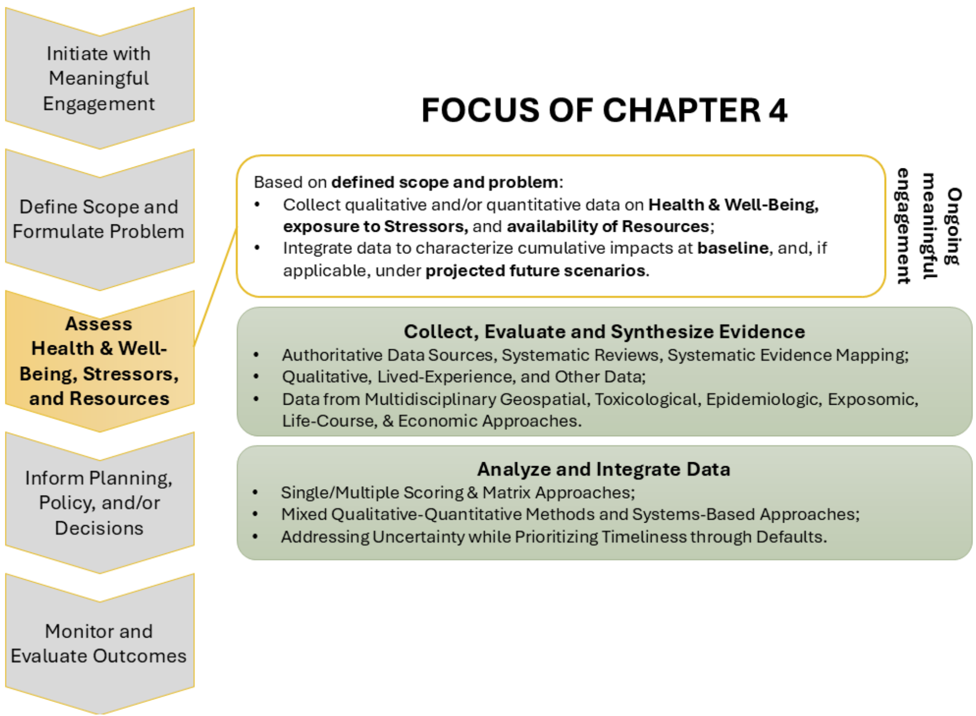

FIGURE 4-1. Approaches to assessing health and well-being within the recommended Process for Cumulative Impact Assessment from Chapter 2.

Each method or approach offers a unique contribution to the advancement of CIA. Composite indexes and matrix-based approaches are important tools in CIAs for interpreting complex data and can help identify where mitigation and intervention are most needed. Integrating community participatory approaches is important for identifying gaps in CIA and helps validate the tools that are intended to reflect the lived experiences of communities. Toxicology, epidemiology, and exposure science form the basis of authoritative or systematic evidence reviews supporting hazard and risk assessments of chemicals and complex mixtures. Life-course approaches inform understanding of the temporal accumulation of exposures across developmental stages and generations as well as the important role of timing such as critical and sensitive periods. Economic methods and studies also provide evidence of the impact of stressors on health and well-being, leveraging natural experiments and administrative dataset(s). This chapter outlines the following:

- Existing methods for addressing cumulative impacts;
- Strengths of the approach in advancing CIA;

- Gaps and barriers in generating relevant evidence;
- Major sources of uncertainty; and
- New opportunities or avenues needed to advance the field.

Composite Indexes or Matrix-Based Approaches

Existing methods and opportunities for addressing cumulative impacts

Implementing CIA often includes a comparative analysis of indicators that may impact health across geographically defined spaces. This work is facilitated by either composite indexes derived from single scoring or matrix-based approaches considering additive and comparative methods for considering community burden using multiple indicators. Composite indicators compare populations defined by geographic boundaries using a single index representing the combination of environmental and social factors, usually selected to represent a given domain of interest such as pollution burden or socioeconomic deprivation. Within each domain, data on several variables or elements are usually collected, integrated, and aggregated to obtain domain scores, which may also be further combined into a single overall score. The National Academies recently published a consensus report, *Constructing Valid Geospatial Tools for Environmental Justice* (NASEM, 2024), which compiles a variety of composite indexes from governmental institutions at the federal, state, and local levels, and from nongovernmental organizations. That report also outlines important considerations for selecting and integrating indicators in the creation of a composite index.

The number of indicators used to calculate indexes may vary substantially depending on the tool or domain. The analytical approaches used to combine indicators can also vary in complexity from assigning differing scores or weights to each indicator and summing across (where weights can be derived by expert opinion or ideally through community-engaged processes) to utilizing more complex multivariate dimension reduction methods such as principal components analysis (PCA), especially because many of the these indicators can be highly correlated with each other (Giordano et al., 2025; Roland et al., 2023). Other related approaches that consider both quantitative and qualitative data in ranking and scoring indicators have been developed and are evolving, including the analytic hierarchy process (AHP; Kurek et al., 2022). For decision-making, all geographically defined units are often ranked, and a cut point (e.g., 75th percentile) might be used to define communities that experience more burden. Decision-bodies can then prioritize communities at or above these thresholds in deciding on future regulation and permitting decisions.

As an example, CalEnviroScreen (CES), developed by the California Office of Environmental Health Hazard Assessment (OEHHA), is a policy screening tool to assess cumulative impacts and identify communities (defined by census tracts in this case) in California that are most affected by these impacts. The tool has seen a variety of uses, including targeting investments to areas identified as disadvantaged based on its composite score (OEHHA, 2025). See Figure 4-2 for an example of how CalEnviroScreen calculates its composite “CalEnviroScreen Score.”

CES 4.0 defines the overall cumulative impact score as the product (multiplication) of a pollution burden score and a population characteristics score—the pollution burden score was calculated based on 13 indicators of environmental exposures (8 indicators) and environmental effects (5 indicators) within a census tract, and the population characteristics score was calculated based on 8 indicators of sensitive populations (3 indicators) and socioeconomic factors (5 indicators). Census tracts are identified as disadvantaged if they have composite scores at or greater than the 75th percentile, are lands under the control of federally recognized tribes, or lack overall scores due to data gaps but are in the highest 5 percentile of pollution burden (OEHHA, 2024).

Single-scoring methods can be challenging to understand in terms of the contributors to overall vulnerability, especially when combining indicators from disparate categories of stressors, resources, and health and well-being. To address inherent heterogeneity and spatial clustering of environmental and

FIGURE 4-2 Example of a composite index, or single-scoring approach, used by the California EPA for the CalEnviroScreen (OEHHA, n.d.).

social indicators, the Climate Vulnerability Index (CVI) uses hierarchical scoring (Tee Lewis et al., 2023). The index includes consideration of both climate risk (probability and severity of events) and vulnerability (increased likelihood of exposure and impact). Box 4-1 describes the range of indicators and scoring methods used to generate the CVI and its ability to integrate multiple metrics at different levels of aggregation. By mapping all these levels at the census tract level, the CVI aims to help communities and policymakers:

- Identify where mitigation and intervention are most needed;
- Ascertain the most critical factors that cumulatively impact health and well-being; and
- Develop targeted strategies to reduce stressors and increase resources so as to improve overall health and well-being.

In contrast to single scoring, matrix approaches first use indicators of social conditions (percent minority, percent low income, percent lower educational attainment) and then develop a mathematical approach to identify the number of environmental stressors in communities experiencing more burden relative to other geographically defined communities. For example, in New Jersey, three social indicators are used to determine communities experiencing more burden. These indicators are census block groups where at least 35 percent of households have low income; 40 percent of residents identify as minority or members of state-recognized tribes; or 40 percent of households have limited English proficiency (NJOEJ, 2025). A comparative analysis is then conducted to determine if cumulative burden exists by comparing the total number of environmental and public health stressors in the identified community to the state or other relative geographic regions. This is facilitated through use of New Jersey's online mapping tool, EJMAP (NJDEP, 2025). The number of environmental factors is largely tied to facilities and air pollution sites, not necessarily the amount or magnitude of releases. New Jersey uses this matrix-based approach to support regulation and siting decisions.

In all these approaches, spatial linkages to assign attributes to locations (points such as residences, or administrative units such as census tracts) in geographic information systems (GIS) can be used to generate indicators needed for integration into a composite score. Similar spatial linkages in GIS may be used to estimate or assess exposures to environmental contaminants or social factors in epidemiological analyses described in later sections. Spatial interpolation methods to predict environmental or social features at unmeasured locations can also be used to impute missing data in single-score or matrix approaches or for predicting air pollution concentrations, for example, based on discrete measurements at monitoring stations for use in epidemiological studies. Various spatial analysis techniques can also be used to downscale or aggregate existing data to the desired resolution to be able to combine or integrate multiple data indicators using the same reference.

BOX 4-1
Example of Hierarchical Scoring: The U.S. Climate Vulnerability Index

The U.S. Climate Vulnerability Index (CVI) uses a hierarchical scoring approach (Figure 4-a), where 184 indicators at the census tract level were combined at five different levels of aggregation, each of which can be separately visualized (Figure 4-b; Tee Lewis et al., 2023).

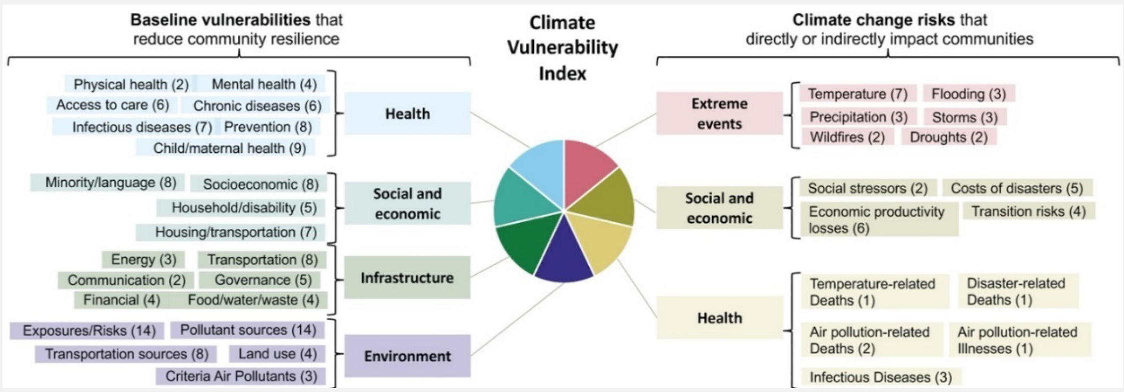

FIGURE 4-a. Hierarchical structure of CVI indicators.
SOURCE: Environmental Defense Fund, 2025.

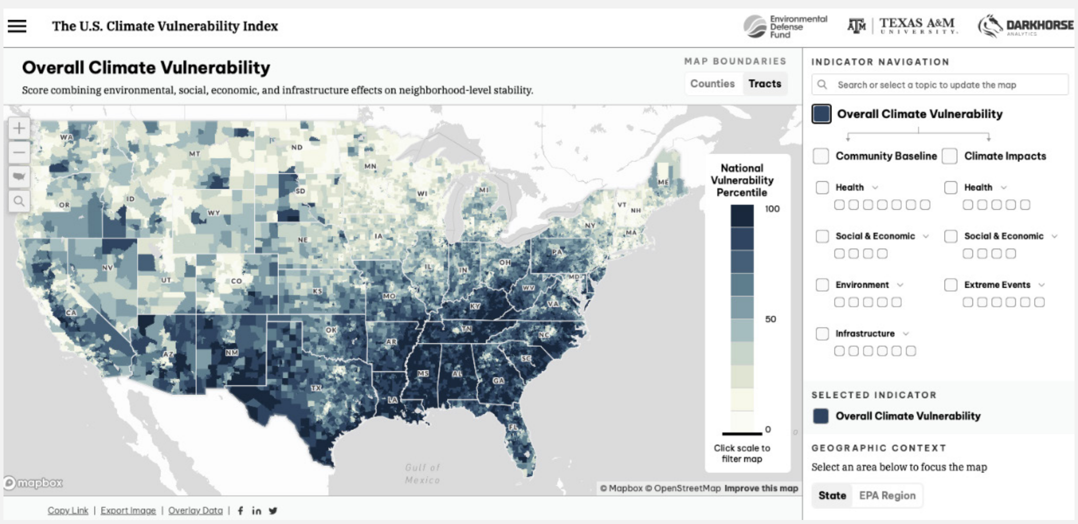

FIGURE 4-b Online mapping tool allowing visualization at different levels of aggregation.
SOURCE: Environmental Defense Fund, 2025.

Strengths of the approaches in advancing CIA

Single-score and hierarchical approaches combine values for environmental and social indicators into one score that is easy to digest and compare across regions, making initial prioritization in decision-making fairly straightforward. Additionally, impacted communities can access, visualize, and describe disparities in their communities and use the data to advocate with policymakers. Matrix approaches keep these domains explicitly distinct from one another, limiting their ability to identify interactions amongst indicators. At the same time, matrix approaches' detailed accounting and inventory of environmental and other stressors allows for more targeted approaches to decision-making. Both methods can be modified using different cut points by domain to support decision-making.

Gaps and barriers in generating relevant evidence

There are significant data gaps in measuring relevant stressors in the social and built environment at spatial and temporal scales that reflect real-world scenarios. For example, community boundaries may not align with administrative boundaries, and thus data organized in this manner may misrepresent the lived experiences of communities. Further, methods are limited for considering interactions among indicators and potential synergies between stressors. Coverage may also be incomplete, as in the case of air monitoring data; or reporting may be inaccurate or incomplete, as in the case of emission inventories. Although EPA maintains a national regulatory monitoring network for criteria air pollutants and the speciation trends network, the density of monitors is still highly uneven across the country, with some areas having a single monitor to represent an entire state. Emissions of hazardous air pollutants or air toxics in particular (not concentrations) are of great relevance and concern for CIA, and despite requirements for reporting under the National Air Toxics Assessment, emission data are still very limited in coverage and in accuracy. This heterogeneity in data coverage is often addressed with model predictions in assessments. However, such models also have uncertainties linked to integration of multiple sources and the often limited spatial and temporal coverage of existing monitoring data or gaps and uncertainties in emissions inventories. Additionally, model performance and the validity of modeled data are largely driven by the availability of high-quality training data inputs (i.e., areas with sparse monitoring data are also the areas with low model-prediction performance).

Similarly, national water quality monitoring networks and the availability of these data can vary because of national security concerns about the location of infrastructure or certain types of pollutants. Under the Safe Drinking Water Act, owners and operators of public water systems are required to monitor and treat drinking water at the point of distribution and throughout the system (depending on the chemical of concern). For example, Wisconsin makes these data widely available on a public website, while other states require detailed Freedom of Information Act requests for access. Other sources of environmental hazard and potential exposure data such as emission inventories are limited in how data are collected, by whom, and for what purpose (e.g., Toxic Release Inventory facilities) and may suffer from reporting biases (e.g., all releases of the year reported in the last reporting period or month, or releases under certain quantities only recommended but not required to be reported).

The available indicators miss some important stressors, for instance, due to inconsistent reporting requirements for certain data used in developing indicators such as drinking water quality, maternal and child health data, and neighborhood safety. Pollution due to odor, light, and noise may also be missed because of limited regulatory considerations. Urban noise in particular has been associated with and known to exacerbate numerous health impacts related to sleep, mental well-being, and cognition (Mucci et al., 2020). Like many other stressors, noise is more common in highly industrial areas with greater truck traffic but often not included as one of the multiple stressors in CIAs. Because modeled noise data are derived and maintained outside of regulatory environmental or health agencies in the United States (unlike in the European Union), exposure often is estimated as proximity to major sources including airports, railways, and major roadways. Moreover, data are often aggregated (e.g., as annual averages) to reflect the longer-term, which can mask more episodic or recurrent spikes in air pollution occurring in different seasons, such as wildfire smoke impacts. Some data may also be missed if meaningful engagement is not undertaken to gather community input in the development of these tools, especially in the selection of relevant indicators.

Major sources of uncertainty

Because their underlying data were designed for different purposes, the application of composite and matrix-based tools in CIA can introduce uncertainties. As discussed in the NASEM (2024a) report on geospatial tools, integration, weighting, indicator selection, normalization, and thresholding are all major sources of uncertainty in composite indicators and matrix-based schemes. Composite- and matrix-scoring approaches are also prone to bias related to uncertainties about availability and concerns about validity of the indicators themselves and whether they are measuring the true exposure to the complex mixtures of stressors being assessed. These tools are dependent on data that are already available and being monitored.

Variability in data across urban and rural contexts can also introduce uncertainty related to data availability. Rural communities face different hazards (e.g., proximity to large industrial farming facilities, agricultural runoff and compromised water supplies) which are not often included in the existing CIA methods. This issue arose in discussing how to measure stressors within Indigenous communities as there are stark differences in environmental stressors captured for urban tribal members compared to those living on more remote reservations. Highly spatially and temporally resolved data, as well as current health outcome data, are also difficult to obtain for issues of confidentiality. As such, composite indexes that include health outcome data such as asthma cases, emergency room visits, and accidents and injuries are more limited, and datasets such as the Centers for Disease Control and Prevention's (CDC's) PLACES[2] utilizes modeling to fill data gaps.

Inherent in development and use of composite tools are issues of multicollinearity. Spatial data used in CIA are often highly correlated, especially when aggregated to a larger spatial unit such as a census tract. This results in the need for data dimension reduction tools such as PCA to generate single composite measures, which creates a challenge in identifying or conveying those indicators that provide the greatest influence. Collinearity, where multiple measures are correlated with each other in space, is distinct from spatial autocorrelation in values of any single measure (or similarity in values of the same measure for locations that are closer [in distance] to each other). In many cases, common underlying processes or reasons (e.g., historical race-based redlining) have resulted over time in strong spatial clustering of exposures or risk factors in space. These result in "hot spots" of concern, where, for example, the placement of polluting facilities is not randomly distributed in space (Brousmiche, 2023; Osiecki et al., 2013; Ozdenerol, 2015). In such cases, care should be taken in a CIA to not overlook these hot spots with aggregation or other dimension reduction or spatial smoothing techniques. CIA aims to inherently identify clusters and geographically defined populations with greater burden of stressors, and thus common smoothing or aggregate methods, although used to advance exposure measurement, may not be appropriate for CIA.

New opportunities or avenues needed to advance the field.

There are numerous opportunities to advance the field based on the gaps and uncertainties outlined above. For example, newer mixture approaches and methods and machine learning are available to address issues of data complexity. Further, many of the indexes already include salutogenic aspects of the environment such as green space, but there is an opportunity for advancing how access to and quality of green, blue, natural, or vegetated spaces are assessed. This is particularly important in conjunction with meaningful engagement with communities to reflect their lived experiences. There are also many opportunities for further incorporation of community assets in these measures similarly to that in the Healthy Places Index (HPI),[3] or more comprehensively assessing both risk and vulnerability as shown in the CVI (See Box 4-1).

Additional opportunities are available for integrating estimates of exposure or hazards with existing foundational knowledge derived from toxicology and epidemiology to further translate into health burden, including assessments of both risk and vulnerability as shown in the CVI (See Box 4-1). Gathering more granular and localized environmental monitoring (ground or remote sensing), social and built-environment data, paired with human behavioral, mobility, and time-activity data, also provides important opportunities for validating the indicators and providing more accurate exposure data that mirror the lived experiences and match individual-level exposures and variability across real-life activity spaces (NASEM, 2022). Additional work on how to support integration of indicators and weighting of

[2] See https://www.cdc.gov/places/about/index.html.
[3] See Healthy Places Index, https://www.healthyplacesindex.org/

indicators in ways that better reflect health burden and validation of these approaches is needed. Much of this was discussed during the committee's October 15 workshop (NASEM, 2025a).

Finally, many of the existing approaches could be expanded by considering the ecosystem services and application of One Health and Planetary Health approaches that acknowledge the intersection of not only humans in the context of social and built environments, but also how the multitude of humans, plants, and animals intersect within social and built environments to influence health and well-being of humans and ecosystems (NASEM, 2023a; Talukder et al., 2024). This balance has been a long-standing worldview of Indigenous people whose teachings recognize the deep connection between people, animals, and the land (Kahn-John and Koithan, 2015). Decision-making tools similar to the HPI and CVI that explicitly consider community context and are more reflective of population-based lived experiences or explicitly support use of both quantitative and qualitative information in their development represent a unique opportunity for advancing the utility of these tools for decision-making (Roland et al., 2023).

Toxicology

Existing methods and opportunities for addressing cumulative impacts

Toxicology approaches focused on toxicity testing of chemicals have been in use for more than a century. This information has been foundational in assessing hazards and risks of chemicals in scope of Title 21 of the Code of Federal Regulations (CFR) (drugs) and Title 40 of the CFR (pesticides), which require a specific battery of animal-based toxicity tests before being marketed, in contrast to chemicals registered under the Toxic Substances Control Act, other commodity chemicals, and environmental pollutants. Important databases of toxicological assessments that to the extent available also integrate epidemiological data include federal (EPA's Integrated Risk Information System, the Agency for Toxic Substances and Disease Registry of the CDC, and the National Toxicology Program of the Department of Health and Human Services), state (e.g., California, Minnesota, New York), and international (e.g., the International Agency for Research on Cancer (IARC), International Programme on Chemical Safety, World Health Organization and Food and Agriculture Organization Joint Meeting on Pesticide Residues, European Commission, European Chemicals Agency, and others). These assessments support a range of decisions, including regulation, exposure reduction, or occupational health monitoring. Such decisions can be made based on varying degrees of certainty of evidence identified in the assessments, with different actions implemented, for instance, for agents classified by IARC as possibly carcinogenic, probably carcinogenic, or carcinogenic to humans (IARC, 2019).

Opportunities for addressing cumulative impacts include the advent of population-based models encompassing genetic diversity, both in vitro and in vivo. Although biological variation in toxic response (e.g., encompassing susceptibility due to life stage, sex, strain, or genetic polymorphisms) has been more widely explored, more recently, experimental approaches to incorporate some of the nonchemical stressors relevant in CIA have also been advanced (Fiamingo et al., 2024; Harmon et al., 2024). Further, methods and approaches have moved away from frank effects (i.e., signs of toxicity) to examine perturbations that may be more subtle as well as more relevant and more important to public health. Another important opportunity is to leverage and combine information from the range of available computational approaches and shorter-term toxicology assays to provide timely and relevant information for assessing and managing risks (see Figure 4-3).

In line with these developments, evidence integration paradigms used in authoritative and systematic reviews have evolved to formally permit hazard classification solely based on evidence besides traditional toxicology studies in experimental animals or human epidemiological studies. One example is the IARC Monographs Preamble for carcinogen classification, under which hazard conclusions are possible based on mechanistic information even when data from studies in humans or experimental animals are sparse (IARC, 2019). Fundamental to advances in IARC's approach to cancer hazard identification is the advent of the "key characteristics of carcinogens" paradigm (Smith et al., 2016), which provides a uniform, objective approach for identifying and evaluating mechanistic evidence pertinent to identifying cancer hazards. Using the key characteristics approach, evidence from the different computational and experimental approaches, as shown in Figure 4-3, can be comprehensively identified, evaluated, and integrated to provide more robust evidence-based classifications. Thus, this approach can take advantage of toxicology and molecular epidemiological studies and databases, including important short-term endpoints (e.g., damage to DNA, epigenetic effects), to support more timely decisions that are supported by evidence. The approach has been extended beyond carcinogens to a range of other toxicants including those that are endocrine disruptors (La Merrill et al., 2020), metabolic disruptors (La Merrill et al., 2025), hepatotoxicants (Rusyn et al., 2021), or cardiovascular toxicants (Lind et al., 2021).

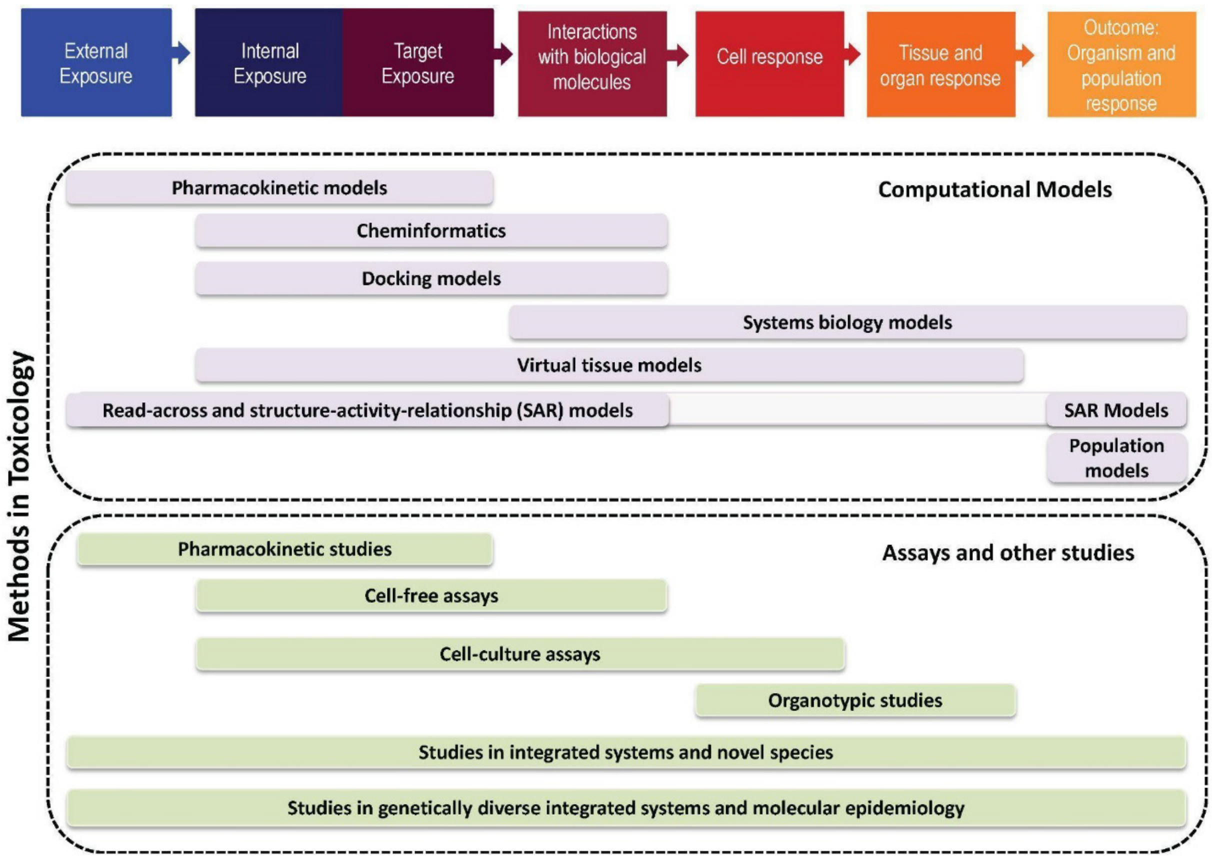

FIGURE 4-3 Continuum of computational models and biological assays in toxicology can inform impacts.
SOURCE: Reproduced from (NASEM, 2017, Fig. 3-1).

In addition to high-quality systematic reviews and authoritative reviews, systematic methods are available to expedite decision-making (e.g., rapid reviews) or assemble and display current knowledge and gaps in evidence (e.g., systematic evidence maps[4]). Other currently available methods can help to rapidly assemble and assess available evidence and computational models, predict hazards, estimate quantitative risk, and identify gaps limiting confidence (Wignall et al., 2018).

[4] https://assessments.epa.gov/risk/document/&deid=364489

Strengths of the approach in advancing CIA

The main strengths of toxicology in advancing CIA include the fact that it is an accepted method that has been traditionally used to explore hazards as well as characterize and rank risks. Accordingly, there are established methods for conducting testing, interpreting results, and applying them in a transparent manner to inform risk management decisions. Assessments based on toxicology have been the subject of consensus advice from the National Academies and others over the past 40+ years (e.g., NRC, 1983, 2009). As detailed in Chapter 2, these reports highlight the use of default assumptions to allow for analyses to be conducted and decisions to be made even when the ideal empirical information is lacking (NRC, 1983). Shifts in the evidence available since the landmark NRC (2007) report *Toxicity Testing in the 21st Century* have made testing more comprehensive as well as timely, and experience and confidence in integrating and applying novel types of evidence to decision-making continues to build (see NASEM, 2017, 2023a).

Gaps and barriers in generating relevant evidence

While computational modeling and testing of single chemicals and related classes of chemicals have advanced significantly, toxicology approaches that encompass a broader range of stressors beyond biological factors are more limited. Examples in the literature include examination of the role of factors in combination with toxicant exposure such as diet, co-morbidities, or animal husbandry conditions to mimic stress (e.g., from overcrowding) or alterations in circadian rhythm (see Chapter 2, Scientific Underpinning of Cumulative Impacts on Health). However, routine exploration of these factors in the context of toxicant effects remains nascent. Further, significant gaps in coverage remain in the testing and evaluation by authoritative bodies of the vast number of individual chemicals already in commerce (Guyton et al., 2009).

Major sources of uncertainty

Sources of uncertainty in toxicology have been extensively addressed in previous National Academies reports and include technical characterization of assays, data limitations, human relevance, reproducibility and validity, and context relevance (e.g., NASEM, 2023b). Quantitative methods to address uncertainty include applying default assumptions in the form of numerical "uncertainty" factors to address data limitations, including when there is a lack of information on variability in susceptibility across the human population. However, as discussed in Chapter 2, previous National Academies reports have noted that current approaches do not explicitly consider nonchemical stressors, aspects of vulnerability, background processes, and other factors that may be important for assessing cumulative impacts. When conducting risk assessments to account for multiple chemical exposures, one proposed approach is to introduce an additional "mixture assessment factor" or "mixture allocation factor" (Backhaus, 2024), and a similar approach could be applied to nonchemical stressors in the context of CIAs.

New opportunities or avenues needed to advance the field

Despite current limitations, new technological advances and testing strategies continue to progress that will afford greater insight into how cumulative stressors combine to affect toxicant response. These avenues will provide evidence if the experimental conditions that are used are more relevant to the lived experience of populations exposed to environmental stressors. In addition, the use of shorter-term molecular endpoints can provide more timely information that is also more relevant.

Other avenues involve modernizing decision-making paradigms and building confidence in the use of new approach methods (NAMs). In this vein, the key characteristics approach (Smith et al., 2016) can help to promote transparency and reproducibility by ensuring broad consideration of existing evidence as well as identification of gaps in understanding. Nonetheless, safeguarding against the elimination of traditional toxicology tests with no adequate replacement will be important for addressing human variability in CIA. By adopting approaches that more clearly specify the purpose and context of use of NAMs in toxicology, as recommended in the NASEM report *Building Confidence in New Evidence Streams for Human Health Risk Assessment*, the application of NAMs to cumulative impact assessments can be facilitated (NASEM, 2023a).

Epidemiology and Exposure Science

Existing methods and opportunities for addressing cumulative impacts

Existing epidemiological studies provide important support for conclusions on the strength of cause-and-effect relationships in the identification of hazards and classification of agents for their carcinogenicity and toxicity. As noted in the preceding section, *Toxicology*, authoritative evidence reviews at the federal, state, and international levels have relied on epidemiological evidence, with examples encompassing occupational exposures, environmental pollutants, lifestyle factors, and drugs. The field of epidemiology, like toxicology, offers critical foundational evidence to advance CIA. Epidemiology provides information on the magnitude of exposure and response effects in relation to complex observed mixtures of exposures and real-life vulnerability and susceptibility factors that can drive regulatory decision-making. Many such examples were presented in Chapter 2.

Advances in molecular epidemiology and in targeted and untargeted analytical capabilities have significantly accelerated the study of human biomarkers of single exposures, exposure mixtures, and response, which has in turn increased our understanding of susceptibility and vulnerability to combined effects of environmental and social stressors. New methods for integrating chemical mixtures and integration of social and environmental factors, such as PCA, Bayesian kernel machine regression, weighted quantile sum, regression, G-computation, and advanced Bayesian modeling and machine learning methods have been developed to advance our understanding of mixture effects (Joubert et al., 2022).

Many environmental exposures act through mechanisms linked to chronic conditions, affecting immune function, inflammation, gene regulation, DNA damage and repair, and mitochondrial function (Wu et al., 2023). Biological weathering, first coined by Nancy Krieger, describes the concept that cumulative exposure to adverse social and environmental stressors can “get under the skin” to increase susceptibility to environmental exposures and advance chronic disease and aging. Numerous markers of environmental exposures and biological aging in relation to cumulative impacts have been examined, including epigenetics through the use of DNA methylation and epigenome-wide association studies (Galkin et al., 2023; Kuznetsov et al., 2025). The growing body of studies of accelerated biological aging and allostatic load demonstrate that exposure to cumulative impacts can lead to early biological changes that can increase susceptibility and accelerate aging and disease processes including cancer, cardiovascular disease, metabolic dysregulation, diabetes, and respiratory outcomes (Lichtveld et al., 2018; Martin et al., 2021, 2022). Paired with these advances, exposome-wide association studies are expanding knowledge beyond traditional gene–environment interactions to advance CIA by moving beyond single exposures and responses while shedding light on pathways of response, at both the population and individual levels. Other work has provided new insights into novel pathways influenced by multiple stressors (nutrition and environmental factors), including the gut microbiome (Gama et al., 2022).

The potential for epidemiology to advance CIA has also grown through long-standing cohort studies as well as national research consortia that invest in pooling multidisciplinary teams of researchers together to advance more integrative and impactful research to understand health determinants and support CIA. Examples of existing longitudinal cohort studies, including the Framingham Heart Study, Women's Health Initiative, Nurses' Health Study, Atherosclerosis Risk in Communities, and the Multi-Ethnic Study of Atherosclerosis, have provided important opportunities to advance cumulative impacts research. Other foundational research to support CIA includes the All of Us initiative, the Adolescent Brain Cognitive Development Study (Abad et al., 2024), and the Environmental Influences on Child Health Outcomes Program[5]. This latter study examines how early life exposures at preconception, postnatally, and through childhood affect adverse health outcomes, including respiratory, metabolic, neurodevelopmental outcomes, as well as well-being or positive health (e.g., happiness and sense of well-being). In all, these studies are important for understanding health impacts of multiple stressors simultaneously (e.g., mixtures) but also in identifying factors in the pathway between exposure and outcome (mediation).

Exposure science advances have contributed significantly to enhancing the value of longitudinal epidemiological cohort studies and the ability to conduct foundational research that supports CIA. For example, air pollution epidemiology has seen dramatic advances in exposure modeling over the last several decades. EPA and others have developed newer spatiotemporal modeling using analytical approaches to address data gaps, improve spatial resolution, and provide longer temporal trends that can be used in longitudinal cohort studies (Li et al., 2017). They can also support better integration of environmental features, including those of the social and built environments, to changes in population-level vulnerability over time. These advances have improved exposure measurement and advanced understanding of the complex interactions and collinearity that often exist with air pollution and other stressors.

Additional advances in mobile and wearable sensing technologies, paired with geolocation technologies, are also significantly improving capacity to capture more highly spatiotemporally resolved, localized, and personalized exposure, activity, behavior, and contextual data, often in real time (within seconds from when it occurs). This includes exposure of children and adults to various air pollutants, noise, light, as well as behaviors and activities (physical activity, sleep patterns, circadian alterations, heart rate, etc.), medication use, health and symptom reports, and geolocation (NASEM, 2023c). These data can be combined with questionnaires, other administrative or contextual geospatial data, and analysis of geolocation and mobility, allowing more nuanced analysis of cumulative impacts and finer understanding of personal- to group-level vulnerability. Other opportunities include constructing and geocoding lifetime residential histories allowing for spatial and temporal linkages to occur efficiently to as many datasets and exposure models with the desired spatiotemporal resolution as possible (Miller, R. et al., 2025; Wang et al., 2024). Examples include linking predicted or reconstructed exposure surfaces (e.g., daily fine particulate matter concentration predictions from a gridded model covering the continental United States) to participants' locations and calculating relevant exposure metrics (e.g., Wang et al., 2024).

Strengths of the approach in advancing CIA

Epidemiological studies of populations in real-world settings can provide critical empirical evidence for CIAs, as foundational support for authoritative and/or systematic evidence reviews. The integration of newer statistical modeling techniques and data science can also play an important role in determining population risk. These studies provide important empirical evidence to demonstrate that exposure to multiple mixtures of chemicals along with other social and individual-level factors can shape and change risk of adverse events in the population as well as identifying vulnerable and sensitive populations. As an example, Morello-Frosch and colleagues (2001) mapped sources of air pollutants with cancer risk, finding that smaller-scale pollutant sources and traffic contribute most to subgroup differences in population risks.

[5] See https://www.nih.gov/echo.

Gaps and barriers in generating relevant evidence

Epidemiological investigations are time and resource intensive and are not suited to many types of investigations. Near-term decisions, such as regarding new chemicals introduced into commerce or the environment, are poorly suited to epidemiological methods, which can take decades. Further, very few longitudinal cohort studies have been designed with the aim of measuring cumulative impacts. This has made it difficult to integrate and harmonize data on environmental and social stressors, as well as the range of intrinsic susceptibility and extrinsic vulnerability factors across the life course. The bulk of epidemiological research to date has been developed with specific disease (cancer or cardiovascular disease) or life stages (e.g., prenatal) in mind, rather than more holistic indicators of health and well-being. Decision-makers including regulators, communities, and scientists need additional longitudinal data and integrated methods to support advancing foundational knowledge from real-world settings to support policy development.

Major sources of uncertainty

Major sources of uncertainty in epidemiological studies include emerging hazards and concerns facing communities that have not yet been fully investigated. Further, U.S. laws do not require comprehensive reporting on thousands of chemicals already on the market, nor is there a requirement for industry to provide analytical standards for chemicals they use or release to support human biomonitoring needs and accurate identification (Kannan, 2025). This lack of knowledge, largely driven by data limitations, introduces substantial uncertainty into epidemiological studies. Although much effort has been made in the last two decades, epidemiological studies need to consider multiple sources of environmental pollutants, including air, drinking water, household and individual indoor exposures, extreme heat or cold, diet and food quality, as well as other social and emotional stressors simultaneously. Few if any studies are designed to capture this breadth of information and may underestimate the effects of nonchemical stressors (e.g., stress, diet, and poverty). In addition, many of these factors are often highly correlated, making identification of priority factors driving risk challenging. Simple models of additivity also do not allow for identification of key drivers of risk needed for prevention strategies. Although significant progress has been made, exposure assessment and existing external sources of data used for spatial and temporal linkages often lack the appropriate resolution or coverage necessary to address policy-relevant questions. Observational studies comparing correlations between group-level exposures and outcomes by geographic location are also prone to classic issues of ecological fallacy in considering group exposure and extrapolating to individual differences (Hubbell et al., 2009), and spatial analyses based on defined administrative boundaries are often plagued by the modifiable areal unit problem where conclusions might change depending on the unit used (NASEM, 2024).

New opportunities or avenues needed to advance the field

New statistical approaches for chemical mixtures and use of big data, machine learning, and artificial intelligence are being rapidly developed to support integrated analyses of multiple stressors and protective factors in a single study. The last two decades have seen increasing methodological advances in mixture methods (Gibson et al., 2019). Many of these newer methods and systems-thinking approaches are now being applied to epidemiological studies to generate new policy-relevant evidence (Chen et al., 2023), to prospectively evaluate the complexity of policy decisions inherent in CIA as well as to address challenges in geospatial heterogeneity, exposure to numerous social and environmental stressors, complex and heterogeneous disease outcomes and interactions over time (Huang et al., 2018; Niamir et al., 2018).

The exposome was first defined in 2005 by Christopher Wild as the totality of exposures throughout the life course (Wild, 2005; see also Wild, 2025). National and global efforts to characterize the human exposome for individuals and across populations are applying big data, artificial intelligence, and emerging technologies to advance the assessment of the totality of external factors that shape health and well-being, including physical, built, and social environments at multiple scales (Anderer, 2025; Miller, G., et al., 2025). Research on exposomics—defined as the integrated compilation of all physical, chemical, biological, and (psycho)social influences that impact biology, and thus impact health, disease, and well-being (Miller, G., et al., 2025)—can provide critical information on how stressors intersect to drive health and disease relevant to CIA. Other areas of advanced research include consideration of early biomarkers of enhanced vulnerability and disease risk. Similarly to modeling of allostatic load and biological weathering, newer technologies can provide insights into common biological mechanisms that capture systemic changes from cumulative impacts.

As previously discussed with respect to air pollution modeling and exposure assessment, newer, more cost-effective and scalable technology for understanding variability in human exposure in real-world settings (neighborhood or fence-line monitoring, accelerometry, other wearables) can be capitalized on to advance CIA. As with all measurement technologies, these low-cost sensors and wearables have specific data quality assurance requirements that need to be applied to minimize uncertainty in their measurements. These measurements can also be integrated with other data resources to build models, including data on ecosystem services to demonstrate where solutions for combatting exposures and policy-relevant levers exist. In addition, CIAs need to address significant gaps that exist in capturing how individual-level well-being, population culture, and spirituality can support new opportunities to mitigate adverse cumulative impacts across the life course, the ultimate goal of CIA.

There are also many opportunities to accelerate epidemiological research findings to advance and support CIA through long-term investment in multiple-scale investigations, including investments in local and state efforts, as well as large national cohorts and consortia (Hubbell et al., 2009; Malecki et al., 2022; Xu et al., 2024). These initiatives aim to create national-level, generalizable population-based studies and data platforms that can advance increased understanding of how multiple stressors intersect with one another across one's lifetime. These are only a few of the numerous longitudinal cohorts that support integration of key elements of a life-course approach to advance CIA as described in the next section.

Life-Course Approaches

Existing methods and opportunities for addressing cumulative impacts

Life-course approaches, with their theoretical foundation deeply rooted in the life-course perspective, are intertwined with other approaches in guiding the methods of conducting CIA (Dannefer, 2003; Elder, 1998; Giele and Elder, 1998; Hertzman et al., 2001; Kuh and Ben-Shlomo, 2004). These approaches are most prominent in characterizing the time dimension in CIA, especially the temporal accumulation of exposures across developmental stages and generations as well as the important role of timing such as critical and sensitive periods (Dilworth-Bart et al., 2024). In addition, these approaches are intertwined with other approaches that emphasize the importance of multilevel structural and contextual factors and their interactions. Thus, they provide a solid foundation for policy intervention, such as addressing stressors during critical periods to mitigate the cumulative effects with multilevel interventions.

The life-course perspective is a multidisciplinary framework that examines how biological, psychological, and social factors across an individual's lifespan influence health and well-being outcomes (Dannefer, 2003; Elder, 1998). Six principles underlie this perspective:

- *Lifespan development*: Human development and aging are lifelong processes. Experiences at one stage of life can affect outcomes in later stages. For example, early exposure to poverty can have lasting effects on health and well-being (see additional examples in the Economics section below).
- *Agency*: Individuals shape their own life paths through choices and actions, despite social structures and historical contexts. This principle highlights how people can navigate or resist

disadvantages, though fundamentally constrained and contextualized by structural contexts discussed below.

- *Time and place*: The historical, cultural, and structural contexts related to time and place influence people's life trajectories. For example, changes in socioeconomic or environmental factors, such as policy reforms or pollution levels, affect individuals differently depending on when and where they occur. This principle aligns with and is more fully developed in recent concepts of social and community vulnerability, which emphasize the critical influence of multilevel structural contexts on individual behaviors, choices, and outcomes (Cutter et al., 2003).
- *Timing*: The effects of life events or transitions depend on when they happen in a person's life. Critical periods, such as childhood or adolescence, are especially influential for long-term outcomes.
- *Linked lives*: People's lives are interconnected through social relationships. For instance, a parent's socioeconomic status can affect their children's experiences across generations.
- *Cumulative advantage or disadvantage*: Over time, advantages or disadvantages build up, leading to increasing inequity. Repeated exposure to stressors, such as discrimination or pollution, can amplify disparities.

Correspondingly, life-course approaches are especially useful in examining how social and environmental exposures and experiences during early life stages—such as gestation, infancy, childhood, adolescence, and early adulthood—cumulatively shape physiological systems and influence the risk of developing chronic diseases and aggravated social and health disparities in later life, contextualized by systemic inequalities associated with race, class, time, place, and their interactions (Dannefer, 2003; Giele and Elder, 1998; Hertzman et al., 2001; Kuh and Ben-Shlomo, 2004). For example, Ben-Shlomo and Kuh (2002) introduced a framework of how biological and social exposures from fetal development through adulthood interact across multiple pathways—biological, social, sociobiological, and biosocial—to influence adult respiratory health and disease risk (Ben-Shlomo and Kuh, 2002). Lynch and Smith (2005) summarized evidence of life-course processes related to birth cohort, place of birth, early childhood events, etc., and demonstrating how biological, behavioral, and socioenvironmental exposures—shaped by timing, accumulation, and intergenerational transmission—interact across the lifespan to influence chronic disease risk and population health disparities (Lynch and Smith, 2005). Recent CIAs have incorporated concepts and components of life-course approaches (City of Chicago, 2023; MassDEP, 2024).

Strengths of the approach in advancing CIA

Life-course approaches offer significant strengths for advancing the scope, capacity, and accuracy of CIAs. These approaches capture the interplay of biological, social, and environmental factors over time across multiple levels, providing a comprehensive view of cumulative impacts, particularly for chronic diseases influenced by lifelong exposures (Kuh and Ben-Shlomo, 2004). Their longitudinal perspective enables comprehensive tracking of exposures, especially in linking early-life exposures (e.g., poor childhood socioeconomic status and infant respiratory infections) to adult health outcomes (e.g., adult lung disease and later-life chronic diseases) (Ben-Shlomo and Kuh, 2002; Lynch and Smith, 2005). Their multilevel perspective facilitates integration of ecological and place-based approaches and data into comprehensive assessments (Cong and Feng, 2022; Cong et al., 2023).

By identifying critical and sensitive periods (e.g., in utero, adolescence), the life-course perspective enables CIA to prioritize interventions at critical and sensitive periods to mitigate cumulative risks, such as implementing full-day kindergarten to promote high school graduation and early intervention on trauma to reduce later depression (Colman and Ataullahjan, 2010; Pharr et al., 2017). In addition, life-course approaches recognize that exposures in one generation (e.g., a mother's exposure to toxins) can affect the health of future generations through epigenetic or socioeconomic pathways

(Dilworth-Bart et al., 2024). Further, life-course approaches enable linking of historical and cumulative exposures to pollutants with current health and well-being, highlighting how stressors can compound across vulnerable populations' life stages and through generations (Buse et al., 2019; Morello-Frosch et al., 2011). Intergenerational trauma—the lasting psychological and emotional harm passed down through generations due to historical injustices—was emphasized in the committee's community and tribal engagements (NASEM, 2025b). Incorporating this into CIA ensures that assessments consider long-term, intergenerational consequences, leading to more comprehensive and accurate impact evaluations.

Gaps and barriers in generating relevant evidence

While a life-course perspective is aligned with CIA in its consideration of stressors, assessing cumulative impacts with life-course approaches would require complex longitudinal data spanning across the life course and even generations. These data are scarce and prone to recall bias when collected retrospectively. Additional data limitations include validating exposure histories and capturing dynamic, lifelong exposures and their complex interactions (Ben-Shlomo and Kuh, 2002; Lynch and Smith, 2005).

Although current CIAs have integrated components of life-course approaches, such as exposure at different life stages and contextual factors, a consistent framework to guide the assessment is generally lacking (MassDEP, 2024). This leads to a missed opportunity for full integration and comparisons across time and places. In addition, differing terminologies (e.g., exposome, social determinants of health) across disciplines and quantitative estimation methods complicates comparisons (Bhatia and Seto, 2011; Buse et al., 2019; Lynch and Smith, 2005). Additionally, tracking policy changes and long-term outcomes in life-course studies requires substantial funding and meticulous cohort management. Leveraging larger research infrastructures, such as biobanks and multigenerational studies, can help address these challenges.

Translating life-course insights into practical CIA tools, such as intervention at critical and sensitive periods, intergenerational intervention programs, and community-based health programs, remains underdeveloped (Ashton et al., 2020; Dilworth-Bart et al., 2024). Challenges inherent in applying a whole-of-government approach—a collaborative strategy where multiple government agencies and levels coordinate resources and expertise to address complex issues holistically—may present barriers to developing CIA tools based on life-course approaches (Danaa, 2022; Tulve et al., 2024).

Major sources of uncertainty

Data limitations create uncertainty, particularly for long-term exposures. Incomplete longitudinal data, small sample size, and low-quality data, particularly in tribal communities and Indigenous populations and for early-life exposures, undermine reliable CIA (Hertzman et al., 2001; Lynch and Smith, 2005). In addition, uncertainties in community-level data, where local exposure patterns may not be fully captured, affect CIA reliability (Morello-Frosch et al., 2011; Sexton and Linder, 2011).

Social, economic, and environmental contexts vary across populations, complicating generalizable CIA findings, especially for susceptible groups (Varshavsky et al., 2023). The complexity of exposure interactions introduces uncertainty (Ben-Shlomo and Kuh, 2002; Bhatia and Seto, 2011). For example, synergistic effects between chemical pollutants and social stressors are difficult to quantify, limiting predictive models.

Choosing between life-course approach models and pathways (e.g., biological programming, accumulation) introduces uncertainty, as each implies different causal pathways. Distinguishing direct from indirect effects of exposures is complex, especially when early exposures influence later ones (Varshavsky et al., 2023). In addition, life-course approach models often assume irreversible impacts, but some processes (e.g., socioeconomic mobility) may be reversible, introducing uncertainty in predicting outcomes (Dannefer, 2003).

New opportunities or avenues needed to advance the field

Leveraging big data and advanced tools can address data gaps and improve modeling of lifelong exposures, particularly for chemical and nonchemical stressor interactions (Varshavsky et al., 2023). Increased access to big data, longitudinal data, data warehouses, and biobanks, which has been inspired and substantiated by theoretical innovations (including but not limited to the life-course perspective and exposome), provides empirical foundations for applying life-course approaches in CIA (Wild, 2025). In addition, integrating advanced analytical tools, such as machine learning and deep learning, could address complex dynamic exposure interactions and their cumulative impact without explicitly hypothesized pathways (Huang et al., 2018).

Interdisciplinary collaboration with life-course approaches could bridge health and environmental sciences, fostering integrated CIA frameworks (Graham, 2002; Halfon and Hochstein, 2002). For example, combining life-course epidemiology with environmental modeling could improve assessments of cumulative impacts (Lynch and Smith, 2005). Bridging epidemiology, sociology, and environmental science through shared nomenclature and collaborative platforms can reduce fragmentation, a priority for EPA's research agenda (Tulve et al., 2024). The National Institute of Environmental Health Sciences Environmental Health Language Collaborative is one initiative aiming to reduce this fragmentation (NIEHS, 2025).

Translating life-course approaches into actionable CIA interventions, such as multigenerational health programs, requires more applied studies, as seen in social value assessments (Ashton et al., 2020; Dilworth-Bart et al., 2024). Aligning life-course approaches in CIA research with policy frameworks such as the UN's whole-of-the government approach (Danaa, 2022) can overcome barriers related to fragmented integration of life-course approaches, thus enhancing their impact on welfare, public health, and environmental policies (Meers, 2022; Tulve et al., 2024). Investigating the reversibility of cumulative impacts (e.g., through environmental remediation) can refine intervention strategies (Buse et al., 2019).

Developing consistent methodologies and guidelines, including universal indicators for cumulative exposures, would enhance comparability and applicability. This will promote comprehensive integration and overcome barriers to comparisons across different assessments (City of Chicago, 2023; MassDEP, 2024).

Prioritizing studies with diverse populations will strengthen evidence on cumulative impacts in marginalized communities (Tulve et al., 2024). Expanding longitudinal datasets, particularly for underrepresented populations, with community-driven data collection is critical to fill gaps in research on health disparities (Jones et al., 2019; Morello-Frosch et al., 2011).

Economics

Existing methods and opportunities for addressing cumulative impacts

Cumulative impact assessment can extrapolate from the findings from the economics literature, including both economic theory and econometrics. This body of work uses a wide variety of econometric techniques, including causal inference methods (natural experiments, instrumental variables, difference-in-differences, and regression discontinuity, etc.), as identification strategies, establishing plausible counterfactuals for affected groups. Strategies including finding arbitrary cutoffs below which a policy does not apply, or areas that unpredictably received substantially more exposure than others, or states or regions that for idiosyncratic reasons did not enact or implement a policy or program. These methods are crucial as many experiments cannot be run at the scale necessary to have sufficient statistical power for reasons of cost, feasibility, or ethics. This "credibility revolution" in economics (Angrist and Pischke, 2010), which has also occurred in other fields such as psychology (Vazire, 2018; Joel et al., 2025), has greatly expanded what information can be used for CIA beyond that of randomized controlled trials or descriptive correlational studies. These quantitative components would complement qualitative ones from other disciplines as described elsewhere in this report.

Examples of policies studied using these methods include the cleanup of Superfund sites (Currie et al., 2011), the introduction of automatic toll booths (e.g., EZPass; Currie and Walker, 2011), and the Clean Air Act (Currie and Walker, 2019). These studies follow a similar formula: they combine some kind of variation in policy or exposure, a counterfactual group that was not affected (or was at least less affected), and quantitative data on outcome variables of interest. These examples would enable accurate projections for future CIA of new analogous projects.

Strengths of the approach in advancing CIA

These outcome variables of interest are often beyond direct morbidity (i.e., per National Cancer Institute (n.d.), "having a disease or a symptom of disease, or . . . medical problems caused by a treatment") and mortality. For example, studies have examined indirect effects including the impact of drinking water contamination on test scores (Marcus, 2025), or lead exposure on school behavior (Sauve-Syed, 2024), test scores (Aizer et al., 2018), or criminal activity later in life (Grönqvist et al., 2020).

Many of these studies make use of large, previously existing datasets, and in many cases manage to individually link those datasets. These include economic, social, and demographic data from the U.S. Census; vital statistics (i.e., birth and death records); inpatient, emergency, outpatient, and ambulatory surgery discharge records, public and private insurance claims, and electronic medical records.

These *administrative data linkages* support opportunities to estimate exposure to stressors (including nonchemical stressors, as described elsewhere in this report) across the life course including over long periods of time and can show how reductions in sources of environmental exposures can improve outcomes, particularly in more vulnerable communities facing numerous environmental and social (economic, food access, housing) stressors. This issue was highlighted by Janet Currie in the committee's virtual workshop (NASEM, 2025a).

Gaps and barriers in generating relevant evidence

A major gap in these observational analyses is lack of data. Unlike in randomized controlled trials where the investigators can choose the ideal data to gather, observational researchers are limited to data that already exists, is accessible, can be linked to the variation of interest, and has sufficient sample size to statistically significantly detect an effect.

Additionally, it is often difficult to link restricted or confidential administrative datasets at the individual level. The owners of these datasets normally do not want to release their individual-level identifying information to another organization for linking purposes, given their ethical obligation to maintain the security of the data. At best, researchers need to find a dataset of interest whose identifiers are not confidential or use simulated microdata. Or at times researchers hide the dataset of interest within a larger set of similar individuals before linking. Alternatively (or in addition), the dataset must be split among three parties in a complicated "double blind" manner to ensure that no one has access to a merged identifiable individual version. (Miller et al., 2023) Further challenges when linking administrative data include both spatial and temporal discordance of the data, and masking of aggregate data to protect individual privacy if there are too few observations.

Major sources of uncertainty

It is important to mention that these studies do not just produce point estimates of the effects of a particular policy or exposure on outcomes of interest. Each result also has a corresponding standard error. The magnitudes of these standard errors can help convey the scale of the uncertainty in CIA. In the future, this measure of variability in the estimated quantities (and the associated confidence intervals) could be reflected in cumulative impact assessment by extrapolating from the point estimates, whereby the variation in the upper and lower bounds of the estimates are incorporated to demonstrate the precision of measures of associations with risk within a CIA.

Another potential source of uncertainty (but also an opportunity) is new working papers from the economics field. The economics publication process is extremely drawn out, with often several years elapsing between initial submission and acceptance at a peer reviewed journal. While other fields suffer from drawn-out review processes, the time from submission to acceptance (even at the 75th percentile) is twice as long in economics as in other social sciences and four times as long as in journals such as *Nature* and *Proceedings of the National Academy of Sciences* (Hadavand et al., 2024).

Waiting for work to be accepted for publication before incorporating it into a CIA will likely result in suboptimal assessments as key results from new economics working papers (disseminated in parallel to the peer-review process) are excluded. These working papers could instead be included, albeit with additional uncertainty. This inclusion could also be asymmetric, consistent with the precautionary principle, with results showing harm being incorporated whereas results that do not show harm being downweighted until peer review is complete.

New opportunities or avenues needed to advance the field.

One additional opportunity is the use of machine learning to interpolate data that are otherwise insufficient due to incomplete collection. For example, one recent study uses newly combined data from pollution monitors, satellites, chemical airflow models, and land use details to produce 1-km-square gridded ambient pollution data for the whole United States. The study then combines these data with neighbor characteristics drawn from individual-level survey microdata to study disparities in pollution reduction efforts (Currie et al., 2023). CIA could make use of both of these newer, granular pollution data, and then use outcomes of economics papers to build on it.

Integrating Community Participatory Approaches

As discussed in Chapter 3, the community participatory approach (CPA) actively engages diverse community members as equal partners in co-creating context-specific, equitable, and sustainable solutions, leveraging local knowledge to enhance relevance, trust, empowerment, and outcomes in areas such as health and urban planning. Closely aligning with this approach, EPA's vision for participatory science prioritizes empowering communities to co-create knowledge, collect actionable data, and meaningfully contribute to environmental decision-making through meaningful engagement (EPA, 2022; Tulve et al., 2024). While many of the above methodologies can employ a CPA in quantitative data collection, this approach lends itself well to gathering qualitative data. Chapter 3 further discusses the value of qualitative data in CIAs and the importance of community engagement. The use of CPA was also strongly echoed and emphasized in the committee's community workshops (NASEM, 2025b). For example, Na'Taki Osborne Jelks emphasized the importance of participatory science and community-generated data in capturing nonchemical stressors that are often overlooked in traditional assessments. Jelks advocated for identifying community assets, honoring diverse ways of knowing, and authentically engaging communities to uncover root causes of environmental and health challenges. Similarly, Shirlee Tan highlighted the need for communities to reflect their burdens in decision-making processes and lived experiences in discussions, especially in areas heavily affected by environmental exposures. Janet Currie underscored the value of local knowledge and inexpensive monitoring tools to fill data gaps, while William Boyd stressed the integration of community voices to address compounding impacts.

MAJOR SOURCES OF UNCERTAINTY ACROSS METHODS

The major sources of uncertainty common across the methods discussed in this chapter include:

- Data quality and availability,
- Gaps in the foundational knowledge on emerging exposures and stressors,

- Spatial and temporal heterogeneity of data at multiple scales and decision contexts (national, state, local, and individual),
- Limited integration and use of mixed-method approaches to integrate quantitative research with qualitative data to support contextualization of research findings and address data gaps.

CONCLUSIONS AND RECOMMENDATIONS

Conclusion 4-1: EPA provides examples of methods for assessing cumulative impacts, but information is lacking on how to select, apply, and integrate them. The most commonly applied methods are composite-index- or matrix-based approaches in a geospatial context, which have been used at national, state, and local levels and in a range of contexts.

Conclusion 4-2: There is a need to implement cumulative impact assessments (CIAs) that consider multiple chemical and social stressors and resources simultaneously through spatial and temporal dimensions without paralyzing decisions because of uncertainties due to analytical complexity or missing data. Approaches are needed to facilitate evidence-based CIAs while prioritizing timely decisions to support future protection of health and well-being, using rapid methods as appropriate, leveraging existing authoritative or systematic reviews, and applying default assumptions to account for uncertainty.

Recommendation 4-1: In their final framework and their practice of cumulative impact assessment (CIA), EPA should specify how to select and apply appropriate approaches for CIA to assess overall health and well-being based on decision context, engaging with affected populations in the process. Key issues the framework should address include how to:

- **Integrate comprehensive perspectives (e.g., life-course approach, systems thinking, One Health) into CIA;**
- **Integrate both qualitative and quantitative data that allow for identification, prioritization, and characterization of health and well-being, stressors, resources, and metrics that best reflect the overall cumulative impacts that communities face; and**
- **Prioritize timely decision-making using existing tools, data, and evidence syntheses even when there is limited knowledge and data gaps and uncertainties exist by:**
    - **Applying composite-index- or matrix-based methods for rapid CIA, when appropriate;**
    - **Utilizing existing authoritative or systematic reviews, when available; and**
    - **Delineating and justifying "default" assumptions to account for uncertainty associated with data and knowledge gaps with a bias toward action and against underestimation of cumulative impacts. At minimum, EPA should develop a "default" factor for quantifying measures of risk and hazard when formal methods are lacking to account for enhancement of chemical effects from concomitant exposures to other stressors.**

Conclusion 4-3: Advancing cumulative impact assessment relies on maintenance and expansion of authoritative data and databases that document impacts of a wide range of stressors, resources, and multiple aspects of health and well-being and how their combined effects are also impactful. Existing authoritative information sources include EPA's CompTox databases, Chemical and Products database, the Toxic Release Inventory database, Risk-Screening Environmental Indicators, as well as other federal (Centers for Disease Control and Prevention, Bureau of Labor Statistics, U.S. Census Bureau, Department of Transportation, National Aeronautics and Space Administration, National Oceanic and Atmospheric Administration, U.S.

Geological Survey, Food and Drug Administration, U.S. Department of Agriculture, U.S. Department of Housing and Urban Development, and Federal Bureau of Investigation), state, and international data resources.

Recommendation 4-2: Government entities responsible for collection and curation of data related to stressors, resources, and health and well-being—including but not limited to EPA, the Centers for Disease Control and Prevention, Bureau of Labor Statistics, U.S. Census Bureau, U.S. Department of Transportation, National Aeronautics and Space Administration, National Oceanic and Atmospheric Administration, U.S. Geological Survey, Food and Drug Administration, U.S. Department of Agriculture, and state and local health and environmental agencies—should maintain, update, and expand datasets and infrastructure for public access and crosswalks across agencies.

Conclusion 4-4: Advancing cumulative impact assessment also requires synthesizing and integrating existing evidence on how health and well-being are affected by exposure to stressors and access to or availability of resources. Existing authoritative syntheses of evidence include federal (by EPA Integrated Risk Information System, Agency for Toxic Substances and Disease Registry, and National Toxicology Program), state (e.g., California, Minnesota, New York) and international (e.g., International Agency for Research on Cancer (for carcinogens), International Programme on Chemical Safety, World Health Organization and Food and Agricultural Organization Joint Meeting on Pesticide Residues, European Commission, European Chemicals Agency, and others) sources. Such authoritative syntheses are compilations of the most up-to-date data available at the time of their development and provide concise summaries of how stressors affect health and well-being. However, these authoritative sources have focused mainly on individual agents, the majority of which are chemicals or lifestyle/behavioral factors.

Recommendation 4-3: EPA, National Institutes of Health, National Science Foundation, National Aeronautics and Space Administration, and other government research funding agencies should support the numerous opportunities available to advance analysis and integration of existing multidisciplinary research into cumulative impact assessment, including:

- **Maintaining and enhancing authoritative resources generated by EPA (e.g., Integrated Risk Information System) and other federal and international bodies (e.g., Centers for Disease Control and Prevention, International Agency for Research on Cancer);**
- **Synthesizing the current knowledge base across the domains of (1) health and well-being, (2) stressors, and (3) resources, to the extent feasible developing systematic scoping reviews, systematic evidence maps, or systematic reviews to inventory factors and indicators; and**
- **Communicating results of authoritative and systematic reviews for use by the general public and identifying potential actions that arise from findings.**

Conclusion 4-5: Continued research on and development of data and methods to support interdisciplinary approaches and integration across methods would support more informative cumulative impact assessments. Opportunities to advance these methods draw from an array of fields, including toxicology, epidemiology, exposure science, statistics and data science, economics, human ecology, demography, and Indigenous knowledge systems.

Recommendation 4-4: Federal agencies and other funding bodies (e.g., EPA, National Institutes of Health, foundations) should advance new research that fills data and

methodological gaps needed to address existing uncertainties and improve assessment of health and well-being in cumulative impact assessment.

With respect to recommended research, priorities for expanding relevant data include increasing meaningful engagement with affected groups, with the aim of ensuring that the resultant data benefit (rather than harm) communities and are publicly available. Also important is improving geospatial data availability, harmonization, and relevance through ground truthing (i.e., verifying data and model accuracy) as well as meaningful community engagement. A further priority is improving accessibility and accelerating use of more scalable and more cost-effective technology for understanding variability in human exposures in real-world settings (such as personal monitoring, accelerometry, and other wearables) and within communities (e.g., lower-cost air monitoring networks). In addition, it will be important to improve access to, and advance the use of, existing well-characterized longitudinal epidemiological cohort data that include biospecimens for biomarkers of exposure, vulnerability and response reflective of cumulative impacts and trajectories of susceptibility.

Priorities for advancing methods include use of best available evidence (indicators, cross-sectional and/or longitudinal) to support timely decision-making regarding cumulative impacts. In addition, it is important to support generation of new biological, statistical, and data science approaches for toxicological evaluation of chemical mixtures to reduce uncertainties. A further priority is application of econometrics and causal inference approaches to generate evidence from existing natural experiments. New exposomic approaches that consider multiple stressors and resources simultaneously can also support improved risk quantification, and identification of the most pressing modifying and mediating factors. Other priorities include supporting use of mixed-method approaches for integration of quantitative and qualitative data. Indigenous approaches for integrating holistic measures of health, life-course and intergenerational and One Health perspectives also remain paramount. Finally, improving translation and risk communication of evidence are essential to support effective decision-making in multiple contexts.

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5
The Path Forward: Practical Applications for Cumulative Impact Assessment

In this final chapter of the report, the committee provides practical applications of its framework for cumulative impact assessment at varying geographic scales to address different decision-making contexts and specific needs. It provides guidance for implementation and examples for conducting cumulative impact assessment (CIA) in a range of settings to address the following charge question to the committee:

> *How can cumulative impact assessment be adapted to different communities, generalized to regional or national scale, and remain flexible for EPA's different programmatic needs?*

The committee identified several challenges of the risk-assessment-based paradigm for assessing cumulative impacts, as outlined previously in Chapter 3, Box 3-6. Specifically, the quantitative focus of risk-based approaches limits or even bars consideration of the health risks posed by exposures to many nonchemical stressors that often cannot be quantified. In addition, outcomes related to improved health and well-being are not considered in traditional risk assessment, and important information sources, such as local and tribal ecological knowledge, data collected and analyzed by communities, and lived experiences, are excluded. Moreover, the lengthy risk assessment process frequently delays or can paralyze decision-making, instead of expediting regulatory action. As noted during the committee's virtual workshop, a bias for action is essential for CIA (see NASEM, 2025).

> *When we think about the conceptual architecture of cumulative impact assessment, we should be thinking about alternatives to the basic risk assessment framework that have …a bias for action."*
>
> \- William Boyd, UCLA

ASPECTS OF CUMULATIVE IMPACT ASSESSMENT

Steps of Cumulative Impact Assessment

The steps of CIA introduced in Chapter 2 include (1) initiate meaningful engagement; (2) define scope and formulate problem; (3) assess health and well-being, stressors, and resources; (4) inform planning, policy, and/or decisions; and (5) monitor and evaluate outcomes. This process builds on the strong elements outlined in the proposed general structure for EPA's (2024) *Interim Framework for Advancing Consideration of Cumulative Impacts*. In line with the National Academies recommendations for health impact assessment (HIA), the process is expanded to include monitoring and evaluation. Once implemented, a CIA process and framework can be used for ongoing monitoring and evaluation to track intended improvements in health, social, and economic well-being over time and uncover any unintended consequences of decisions and policies implemented.

Diverse Contexts of Use for CIAs

CIA can be applied in different regulatory, policy, and decision-making contexts. For example, CIA is applicable to national regulations, including standard-setting, to target enforcement and compliance activities, and for permitting and siting, land use planning and zoning, as well as distribution of resources and funding to mitigate environmental hazards (e.g., pollution emission reduction incentives, reduction of greenhouse gas emissions) to address structural vulnerability factors (e.g., affordable and quality housing and economic development initiatives). CIA can also entail application of spatial screening methods, such as those undertaken in New Jersey, California, and other states, which have developed well-vetted methodologies that are integrated with public policies and are used to guide regulatory decision-making including permitting decisions, the allocation of investments in pollution abatement, and investment of resources to mitigate and adapt to climate change. The degree of community engagement and its input into the CIA is often shaped by the decision-making context and the scale of the analysis (e.g., national, state, regional, tribal nation, local).

Spatial Scale

Spatial scale is relevant to CIA in its variety of applications at different granular levels. For instance, federal and state governments may implement CIA using spatial screening and mapping tools to direct programmatic benefits or funding to disadvantaged communities (e.g., the former federal Climate and Economic Justice Screening Tool or California Environmental Protection Agency's (CalEPA's) CalEnviroScreen or to inform regulatory decision-making. State and local governments may use CIA for program implementation to prioritize areas for improving community health (identifying and mitigating pollution burdens in their communities) or in permitting decisions. Communities may use CIAs to inform their policy engagement, land use planning, and advocacy efforts. Data availability may vary across spatial and temporal scales, making integration more challenging, for instance, if data are collected at various spatial resolutions and granularity (i.e., census tract, block group, county, region).

Temporal Scale

Temporal scale is important to consider because burdens and resources may change or accumulate over time, as may a community's overall health and well-being. Additionally, data availability may change over time in a given area, as can the temporal resolution or frequency at which data are collected. The temporal scale may pose challenges for measuring the performance of interventions or policy changes, such as improvements in reducing exposures or adverse health outcomes in a community. Baseline CIAs may be especially helpful in projecting impacts of future disasters in consideration of a community's vulnerability and the barriers to recovery or responding to stressors.

APPLICATION OF THE CUMULATIVE IMPACT ASSESSMENT FRAMEWORK

Prior chapters of this report discuss existing and robust CIA approaches developed by governments and other entities, including HIAs undertaken by cities to guide decision-making and online mapping tools that integrate environmental, health, and socioeconomic information to identify overburdened communities (e.g., CalEPA's CalEnviroScreen discussed in Chapters 2 and 4). In this chapter we present retrospective and future-oriented case studies that elevate how the committee's recommended CIA process and framework can be applied in different contexts. The committee also acknowledges that in limited circumstances there may be some decision-making contexts with rapid time frames in which a CIA may not be feasible or appropriate. Nevertheless, the case studies, summarized in Table 5-1, and discussed in detail below, cover the following topical categories: place-based; population-based; disaster response; anticipatory and retrospective assessments of regulations, standards, and policies; interventions to reduce harmful exposures; and assessments of chemical classes and mixtures. Additionally, these case studies aim to demonstrate how the committee's recommended process and framework bring greater coherence to assessing cumulative impacts across settings. By integrating environmental, social, and health stressors, the approach is designed to support a wide range of users—from technical experts to on-the-ground planners—working within varied constraints. Together, they offer a practical starting point for informing permitting, planning, standard-setting (e.g., for National Ambient Air Quality Standards) and policy decisions, especially where overlapping mandates or limited data have historically hindered progress.

TABLE 5-1 Overview of Case Studies

Case Study	Initiation	Scope & Problem	Approaches to Assess Impacts, Inform Action, and Monitor and Evaluate Outcomes	Examples of Relevant EPA Programs
Place-based—Cancer Alley in Louisiana	• **Context:** Permitting & enforcement of emissions from multiple sources • **Affected:** Residents • **Concerns:** Health effects due to emissions, climate change, social & economic decline	• **Purpose:** Influencing future decisions on permitting enforcement • **Processes:** Document concurrent increases in stressors, decline in available resources, and deterioration of health and well-being over time	• **Assess:** Holistic (e.g., index-based) approach to integrate data on stressors, resources, and health & well-being to demonstrate disproportionate burden. • **Inform:** Advocate for stricter enforcement of emissions standards, restricting new permits for industrial sources, building resilience to flooding, investing in services and education. • **Monitor/evaluate:** Track individual and integrated indicators, and decisions/actions.	• **Chemical Safety** • **Clean Air Act** • **Clean Water Act** • **Environmental Justice**
Population-based— Urban and rural tribal members in Colorado	• **Context:** Lived experience of dispersed tribal communities • **Affected:** Tribal members outside of sovereign reservations • **Concerns:** Housing, jobs, political decision-making, environmental conditions, health care access	• **Purpose:** Identify fair solutions that uphold tribal sovereignty across diverse tribal geographies • **Processes:** Compare challenges and assets in rural and urban contexts	• **Assess:** Evaluate housing, health, environmental, and political stressors. • **Inform:** Support policies tailored to distinct tribal community needs. • **Monitor/evaluate:** Track tribal health, services, and governance inclusion efforts.	• **Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA)** • **Waste Management** • **Clean Air Act** • **Clean Water Act** • **Environmental Justice**
Anthropogenic disaster—East Palestine, OH train derailment	• **Context:** Train derailment with chemical spill and fire • **Affected:** Residents of East Palestine and surrounding communities • **Concerns:** Physical, emotional, social impacts of train derailment	• **Purpose:** Address community concerns about the multiple impacts from the derailment • **Processes:** Identify preexisting vulnerabilities and those likely exacerbated by derailment	• **Assess:** Baseline assessment to identify pre-existing physical, mental, and children's health issues, as well as current stressors and resources/lack thereof. • **Inform:** Prioritize areas of vulnerability to address through increased resource commitment and accessibility. • **Monitor/evaluate:** Track health (physical, mental), and children's health; stressor exposure; and resource availability.	• **Emergency Response** • **Environmental Justice**
Natural disaster—Community and worker impacts of Los Angeles wildfires	• **Context:** Recurring wildfires affecting residents and frontline workers in Los Angeles. • **Affected:** Low-income communities, firefighters, transit staff, outdoor laborers. • **Concerns:** Smoke exposure, displacement, mental health, service disruption, worker safety.	• **Purpose:** Improve resilience to wildfires through integrated community and worker protections • **Processes:** Assess vulnerabilities; engage workers, unions, residents; map resources	• **Assess:** Evaluate cumulative stressors and health risks across populations. • **Inform:** Target investments in shelter, healthcare, labor protections, communication. • **Monitor/evaluate:** Track myriad health outcomes, characterize exposures to multiple compounds, service use, and feedback for improvement.	• **Clean Air Act** • **Clean Water Act** • **Emergency Response** • **Environmental Justice**

Case Study	Initiation	Scope & Problem	Approaches to Assess Impacts, Inform Action, and Monitor and Evaluate Outcomes	Examples of Relevant EPA Programs
Anticipatory and retrospective assessments of regulations & policies—Changes in air pollution exposures due to regulatory activities	• **Context:** Assessing the effectiveness of air quality regulations by assessing temporal changes in air pollution exposures and their distributions in population groups • **Affected:** Residents • **Concerns:** Short- and long-term effects of air pollution and differential exposure burdens across different populations.	• **Purpose:** improve the effectiveness of regulatory programs and standards to optimally reduce exposures and address disproportionate impacts on more vulnerable population groups • **Processes:** Assess predicted impacts of proposed regulations and programs; and temporal changes in air quality due to regulations or policies	• **Assess**: Use modeling data to predict changes in air quality and the distribution of air pollution exposures under different emission reduction scenarios (e.g., targeting specific sectors, emission sources, geographic areas, etc.) to visualize the exposure and health impacts across different population groups and overall. • **Inform:** Ensure that distributional impacts of proposed and future regulations and programs are elevated in deliberations about the effectiveness of regulatory standards and their implementation. • **Monitor/evaluate:** Embed anticipatory and retrospective assessments of air quality regulations and programs at national, state, and regional scales to elucidate impacts among different population groups.	• **Clean Air Act** • **Environmental Justice**
Assessment of co-benefits of climate change policies	• **Context:** Climate change policies in California can provide short-term environmental and socioeconomic co-benefits to communities. • **Affected**: Disadvantaged and marginalized communities co-located with greenhouse gas and co-pollutant emissions. • **Concerns:** To what extent have climate change policies amplified or decreased environmental disparities in air quality improvements and mitigation/adaptation investments?	• **Purpose:** Characterize co-benefits of climate policies on health and well-being • **Processes:** Evaluate whether/how greenhouse gas reduction strategies are also yielding short- and long-term co-benefits and improving outcomes	• **Assess:** Use emissions and air quality modeling data to examine the relationship between greenhouse gas reductions and reductions in co-pollutants such as air toxics and fine particulate matter ($PM_{2.5}$) from mobile and stationary sources. Assess the extent to which these potential air quality co-benefits reduce differences in pollution burdens across myriad communities. Track the distribution as well as environmental, health and socioeconomic impacts of investments in climate change mitigation and in adaption. • **Inform:** Develop protocols and online tools to track co-benefits and investments in ways that are accessible to myriad end users. • **Monitor/evaluate:** Assess distributional trends and impacts, particularly in disadvantaged and marginalized communities, over time.	• **Clean Air Act** • **Environmental Justice**
Regulatory implementation – Lead service line replacement (LSLR)	• **Context:** Reducing disparities and maximizing impact in LSLR • **Affected**: Populations exposed to lead through lead service lines • **Concerns:** Disparities in burdens of lead exposure and implementation of mitigation	• **Purpose:** Ensure that LSLR prioritizes most highly impacted populations • **Processes:** Identify exposed populations with greatest cumulative burdens; reduce barriers and negative secondary impacts of LSLR implementation	• **Assess:** Baseline assessment of cumulative burdens most relevant to LSL-related lead exposure (e.g., other source of lead, poor nutrition, vulnerable life stages, other neurotoxic stressors, social and economic stressors, low health care access, poor baseline health); assessment of barriers to implementation (economic, time, poverty, lower education, language) • **Inform:** Prioritize populations with greatest burdens, allocate resources to reduce barriers to implementation. • **Monitor/Evaluate:** Track progress of LSLR and blood lead levels in vulnerable populations.	• **Safe Drinking Water Act** • **Drinking Water State Revolving Fund** • **Environmental Justice**

continued

TABLE 5-1 *continued*

Case Study	Initiation	Scope & Problem	Approaches to Assess Impacts, Inform Action, and Monitor and Evaluate Outcomes	Examples of Relevant EPA Programs
Chemical class and mixtures management—Ensuring protection of overburdened communities and at-risk groups	• **Context:** Protective risk management of chemical exposures • **Affected:** Populations exposed to chemicals • **Concerns:** Existing chemical risk evaluations inadequately protective and specifically lacking in consideration of multiple chemical exposures	• **Purpose:** Ensure chemical policies protect vulnerable populations • **Processes:** Account for co-occurring exposures and population vulnerabilities; attend to exposed populations with greatest cumulative burdens	• **Assess:** Baseline assessment of cumulative burdens and vulnerabilities relevant to chemical exposures • **Inform:** Support for science policy defaults providing additional protection (e.g., addition of safety factors or modeling dose-response for standard-setting that account for population variability in cumulative exposures to multiple chemical and nonchemical stressors) to populations with high levels of existing cumulative burdens of baseline health or harmful exposures, existing stressors, lack of resources • **Monitor/evaluate:** Track exposure burdens and baseline health.	• **Toxic Substances Control Act New Chemicals Program**

Case 1. Place-Based: Louisiana

Initiation

A predominantly Black, low-income region spanning multiple parishes along the Mississippi River in Louisiana—known as "Cancer Alley"—has a dense concentration of petrochemical facilities. The area has experienced generations of toxic emissions, public health crises, and neglect by regulatory agencies. Applying a CIA framework to this case study elucidates how multiple, overlapping exposures and vulnerabilities contribute to disproportionate burdens—and can inform actionable regulatory strategies that center health, well-being, and accountability.

Scope and problem formulation

Cancer Alley presents a stark example of the limitations of traditional environmental risk assessments, which have historically evaluated emissions source by source and pollutant by pollutant. This piecemeal approach has overlooked the synergistic and additive effects of multiple stressors—including air and water pollution, climate-related flooding, disinvestment in infrastructure, poverty, and racial segregation. Health data show markedly elevated rates of cancer, asthma, and other chronic illnesses, while social indicators reveal weakened access to health care, poor housing conditions, and limited civic power. A cumulative impact assessment reframes these intersecting issues as layered and systemic, necessitating a place-based response that reflects the lived experience of residents and the historical context of land use, zoning, and industrial policy.

Approaches to assess impacts

Assessment begins with compiling existing spatial and temporal data on environmental hazards—such as emission inventories, facility locations, historical permit records, and community-level data—combined with baseline health indicators including cancer rates, respiratory illnesses, and birth outcomes. This is paired with an evaluation of social and structural stressors, including poverty rates, housing quality, education access, historical redlining, and disaster vulnerability.

A community-driven resource and resilience mapping process identifies both gaps (e.g., lack of clinics, green space, and safe drinking water, and degrading flood infrastructure) and strengths (e.g., grassroots organizing, local health advocates). Equally important, community participation is embedded by integrating environmental monitoring data that community members have collected (e.g., targeted hotspot air monitoring) as well as through storytelling, public forums, participatory mapping, and collaborative selection of indicators. This co-production of knowledge ensures that the CIA reflects what communities define as harm, resilience, health promoting, and healing.

Approaches to inform action

CIA findings provide a foundation for regulatory and policy shifts. Immediate actions may include increased inspections and enforcement of industrial facilities with repeated violations near vulnerable populations, denial or suspension of new permits in already overburdened zones, and the use of cumulative burden metrics in future permitting decisions.

In parallel, CIA findings can help to direct public investment to strengthen local infrastructure and social support systems—such as building climate-resilient housing, expanding mobile health services, enhancing transit access, and restoring contaminated lands. Support for community-led solutions is essential, including funding local organizations, training resident monitors, and building formal channels for public influence over land use and enforcement decisions.

Monitor and evaluate outcomes

A robust monitoring and evaluation plan must go beyond compliance reporting. Indicators should include health outcomes, pollution trends, community satisfaction, and metrics of well-being. Tools such as air quality sensors covering vulnerable populations, community health surveys, and neighborhood resilience dashboards and maps can support real-time accountability.

Regular updates and transparent reporting of data and permitting decisions—ideally co-managed by agencies and community representatives—help ensure that the CIA becomes an ongoing mechanism for learning, responsiveness, and course correction, rather than a one-time technical exercise.

Case 2. Population-Based: Urban and Rural Tribal Members in Colorado

This case study demonstrates how the proposed framework for cumulative impact assessment—grounded in health and well-being, systems thinking, and participatory methods—can be applied to population-based assessments that cut across geographic and jurisdictional boundaries. As introduced in Chapters 2 through 4, the framework emphasizes the integration of chemical and nonchemical stressors, the identification of health-promoting resources, and community-guided indicators of well-being. In the case of tribal communities in Colorado, the framework supports a comparative analysis of urban and reservation-based tribal members, revealing how place, identity, and governance structures intersect to shape cumulative impacts on Indigenous populations.

Initiation

Tribal communities in Colorado have long voiced concerns over the fragmented delivery of services, persistent social and health inequities, and the lack of recognition of their unique status in both urban and rural contexts. While some tribal members live on or near reservations, many others reside in cities such as Denver, often far from tribal health services and political institutions. In collaboration with tribal leaders, community-based organizations, and state agencies, a CIA could be used to examine how tribal populations experience overlapping burdens across different environments—and to identify context-specific solutions that respect tribal sovereignty and lived experience.

Scope and problem formulation

Tribal members in both urban and rural areas of Colorado face distinct yet intersecting cumulative stressors. For example, on reservations, infrastructure and transportation challenges can limit access to health care, and environmental degradation can impact water quality. In urban settings, systemic racism, underrepresentation in political processes, housing precarity, and employment discrimination persist. It is critical to note that these compounding impacts are a result of a long history of discriminatory federal policies such as the Indian Removal Act, which forced the removal of Indigenous people from their homelands. Furthermore, relocation programs implemented by the U.S. Bureau of Indian Affairs during the 1950s, which sought to move Indigenous individuals from reservations to major urban centers (Cobb and Fowler, 2007), have led to intergenerational negative impacts.

Standard environmental assessments often fail to capture these layered burdens—particularly those not tied to a specific industrial facility or geographic boundary. A CIA could be used to understand how these social, environmental, and institutional stressors and resources affect tribal populations differently depending on location, and to identify shared policy opportunities (see Chapter 3).

Approaches to assess impacts

The assessment can begin with disaggregated data collection by geography (e.g., urban and rural) and tribal affiliation. Indicators of both stressors and resources include access to health care, housing quality and stability, unemployment rates, environmental exposures, access to clean water, and food insecurity. Tribal health data—where available—could be evaluated alongside state and local data systems to identify disparities and overlapping vulnerabilities.

Crucially, the assessment can incorporate qualitative data gathered through listening sessions, tribal council meetings, and community-led surveys. These participatory efforts identify additional, often unquantified, concerns such as cultural disconnection, lack of representation in decision-making, and barriers to accessing Indigenous-led services in urban areas. Mapping exercises further help visualize where gaps in services and infrastructure overlap with environmental risks and socioeconomic pressures.

Approaches to inform action

The CIA findings can inform tailored policy recommendations for both urban and reservation-based tribal communities. These include expanding culturally competent health care access in cities, supporting tribal housing initiatives, improving water infrastructure on reservations, and strengthening tribal consultation in local and state governance. The assessment also emphasizes the need to bridge jurisdictional divides, encouraging partnerships between tribal governments, urban Native organizations, and state agencies to ensure continuity of services and policy alignment.

Additionally, CIA highlights opportunities to support tribal self-determination and community leadership by funding Indigenous-led data collection, community health programs, and culturally rooted resilience efforts.

Monitor and evaluate outcomes

A monitoring strategy could include periodic tracking of tribal health indicators, service access metrics, and environmental quality across both urban and rural communities. Community-based organizations and tribal governments would co-lead evaluation activities, using tools such as community report cards, storytelling, and participatory mapping. These methods would provide culturally relevant and responsive feedback to policymakers and funders.

To sustain impact, the CIA process can establish feedback mechanisms between communities and agencies, enabling adaptive responses as new needs emerge. This long-term, place-sensitive approach reflects the proposed framework's emphasis on iterative assessment, co-governance, and well-being.

Case 3. Disaster-Specific (East Palestine, OH)[1]

Initiation

On the evening of February 3, 2023, a Norfolk Southern freight train carrying hazardous materials derailed in East Palestine, Ohio (see Figure 5-1). Numerous chemicals were spilled and released into the air, soil, and nearby streams. Additional contaminants were released into the air due to fires, including controlled burns conducted by emergency crews. Community members in East Palestine and surrounding areas exposed to pollutants expressed concerns about the physical, emotional, and social impacts of the derailment.

Scope and problem formulation

A traditional chemical assessment approach was used to determine the potential impacts of the train derailment. For instance, individual chemicals of concern were identified based on the train manifest and subsequent burning. These were then tested and monitored for, and concentrations compared to,

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[1] See National Academies workshop report (NASEM, 2025); see also Union of Concerned Scientists' article on cumulative impacts at East Palestine (Ellickson, 2025).

traditional toxicity values such as EPA reference concentrations or Agency for Toxic Substances and Disease Registry Minimal Risk Levels. However, community members described a variety of physical, emotional, and social impacts of the train derailment and its aftermath that are not captured by traditional chemical risk assessment. Moreover, there was a disconnect between reported acute symptoms by community members and traditional chemical risk assessment conclusions and the challenges of definitively linking symptoms to the event. The community expressed frustration at lack of a single clear source of information, leading to distrust and perception that risks were being downplayed.

A cumulative impacts approach could further identify specific vulnerabilities and needs as well as guide implementation of programs directed at addressing the multiple impacts from the derailment. This approach would not only more comprehensively address both the specific risks from chemical exposures and the nonchemical stressors resulting from the disaster, but more broadly identify preexisting conditions related to health and well-being, key stressors present prior to the incident, and important health-promoting resources or the lack thereof.

FIGURE 5-1. Aerial view of the Norfolk Southern freight train derailment in East Palestine, Ohio on February 5. SOURCE : NTSB, 2023. https://www.ntsb.gov/news/press-releases/Pages/NR20230214.aspx).

Approaches to assess impacts[2]

Approaching the derailment and its aftermath with a cumulative impact lens could have identified some of these challenges in advance while also making them easier to address:

[2] Specific examples based on indicators of Community Baseline Vulnerability in the Climate Vulnerability Index (Tee Lewis et al., 2023) for Census Tract 39029951500 representing most of East Palestine, Ohio.

- A baseline health and well-being assessment could have identified several preexisting issues related to physical health (e.g., lower-than-average life expectancy), mental health (e.g., higher-than-average rates of drug overdose deaths), and children's health (e.g., attention deficit/hyperactivity disorder, teen births). These would be expected to be exacerbated by the derailment and its aftermath in ways independent of the risks from chemical exposures themselves.
- A baseline stressor assessment could have indicated relatively low exposures to most environmental pollution and their sources (brownfields, Superfund sites, hazardous waste sites, high-risk industrial sites, traffic, lead in drinking water). Thus, it is likely the community was not familiar with concepts related to risks from chemical exposures, resulting in greater communication challenges than in areas with high preexisting levels of pollution.
- A baseline resource assessment could have identified community strengths (high degree of social and civic organizing) and challenges (large number of single-parent households, higher unemployment, lower income, lack of access to healthy foods). Thus, the community would be expected to organize strongly. However, their being underresourced also would mean that they are more vulnerable to stressors brought on by the train derailment.

Each of these baseline assessments could have been generated in a bidirectional manner with the community, building trust and reflecting the lived experiences of community members.

Approaches to inform action

The results of these baseline assessments could complement the assessment of chemical-related risks in order to prioritize areas of preexisting vulnerability affected by the direct and indirect effects of the train derailment. Actions could include increased availability and access to resources to address existing health concerns that may be exacerbated, such as addiction and children's health. The strong social and civic engagement could be a means through which these resources could be deployed or coordinated.

Monitor and evaluate outcomes

In addition to continuing to measure chemical exposures related to the derailment and subsequent chemical burn, the monitoring and evaluation plan could include key indicators of the health and well-being of the community (e.g., physical health, mental health, children's health) and the availability and utilization of health-promoting resources.

Case 4. Los Angeles, California Wildfires

The Los Angeles wildfires exemplify widespread, climate-driven disasters that require a shift from traditional environmental assessment models toward a more integrated framework. Under the traditional EPA approach, wildfire impacts are typically assessed through ambient air monitoring and pollutant-specific risk estimates—such as fine particulate matter ($PM_{2.5}$) concentrations compared to established regulatory standards. Although scientifically valid, these assessments offer limited insight into how exposure to wildfire smoke interacts with existing social, economic, and occupational vulnerabilities, and they do not capture the cumulative burden across diverse groups such as low-income residents or frontline workers. Indeed, the burning of buildings and other materials in communities within and beyond the wildland–urban interface releases numerous toxic compounds, including volatile organic compounds, dioxins, asbestos, lead, and other metals, which settle and persist in the environment and transcend indoor spaces, including residences, schools, and workplaces and for which there is a paucity of exposure data available. Moreover, these contaminants can also affect drinking water sources, leading to another exposure pathway for residents returning and rebuilding in burn areas (Jankowski, 2023; Rice et al., 2023; Solomon et al., 2021).

In contrast, the committee's proposed CIA framework provides a more expansive, systems-based model that, when applied to the case of the Los Angeles wildfires, moves beyond pollutant levels to ask: Who is most affected, and why? What resources are available to respond and recover? And how do systems perpetuate or reduce risk over time?

Initiation

In the aftermath of consecutive wildfire seasons, residents across Los Angeles—particularly in lower-income neighborhoods—and frontline workers such as transit operators, firefighters, and utility staff raised alarms about the intensifying and unequal impacts of wildfire smoke, evacuations, and job-related strain. Although air quality advisories were issued, many people reported ongoing health symptoms, missed work, mental stress, and inadequate shelter or information. In applying a CIA grounded in the proposed framework, the community can aim to understand and respond to the convergence of environmental exposure, occupational hazard, and other stressors.

Scope and problem formulation

The wildfire crisis is not only an environmental event but also a compounding layer on top of existing stressors. Standard environmental risk assessments, focused on regional air quality levels, do not account for individual- or neighborhood-level differences in exposure duration, job vulnerability, housing quality, or access to care. Moreover, frontline workers are often excluded from public health planning, despite facing prolonged exposure under extreme conditions. A CIA framed through the proposed approach redefines the problem: wildfires are not isolated threats, but magnifiers of cumulative risks shaped by climate change, place, occupation, and socioeconomic status.

Approaches to assess impacts

Using the proposed framework, the assessment integrates four key dimensions:

- *Environmental stressors*: Mapping of smoke plumes, $PM_{2.5}$ and toxic air contaminant exposure zones, toxic soils, and heat events.
- *Occupational stressors*: Shift data, injury records, and labor protections for essential workers, cleanup crews, and firefighters.
- *Social determinants*: Data on housing instability, income levels, health care access, language barriers, and food security.
- *Resource mapping*: Availability of clean air centers, HVAC-equipped shelters, health care, mental health services, and employer safety policies.

Community-based organizations and worker groups can directly engage in defining relevant indicators, validating data, and identifying gaps not captured in official records, such as informal caregiving burdens, public transit disruptions, and unequal employer support.

Approaches to inform action

Unlike traditional EPA assessments that often result in regulatory thresholds or facility guidance, the proposed CIA framework informs a broader, cross-sectoral action plan:

- *Labor protections*: Enforced rest breaks, hazard pay, and access to personal protective equipment and filtered rest areas for field-based workers.
- *Health response*: Mobile clinics and mental health outreach in smoke-affected zones.
- *Infrastructure upgrades*: HVAC retrofits in schools and public buildings within high-risk areas. Other strategies such as installing utilities underground could be considered.
- *Coordination*: Alignment of transit, housing, and emergency response plans to support both evacuation and continuity of services.
- *Communications*: Multilingual, culturally relevant wildfire health guidance distributed through trusted local channels.

These measures directly address the unequal capacity to respond and recover, especially among renters, service workers, undocumented residents, and individuals with chronic health conditions. Although some of these actions may fall outside of EPA's jurisdictional mandate, together, they encourage interagency coordination (e.g., between EPA, the Occupational Safety and Health Administration, the Federal Emergency Management Agency, and relevant state agencies) and a cross-sectoral approach.

Monitor and evaluate outcomes

Whereas traditional environmental risk approaches may monitor changes in ambient air quality, the CIA framework emphasizes community-centered monitoring of outcomes such as

- Emergency room visits for respiratory illness and heat-related conditions;
- Uptake of workplace protections and health services;
- Resident and worker feedback through participatory scorecards and interviews; and
- Real-time mapping of resource availability and unmet needs.

These indicators could be reviewed in seasonal cycles and used to inform adaptive policy changes, allowing for iterative learning and community accountability.

Case 5. Anticipatory and Retrospective Assessment of Air Quality Regulations

Applications of CIA can facilitate anticipatory and retrospective analysis of proposed regulations and policies. For example, in the realm of air quality, EPA is required to conduct regulatory impact analyses (RIAs) to quantify the social costs and benefits of proposed programs and regulations. These analyses typically involve both detailed modeling of compliance costs and an evaluation of the health and ecological benefits associated with modeled changes in air pollution levels. One of the primary outputs is the quantified health benefits in monetary terms, to allow for direct comparison with compliance costs, but the analyses often include unquantified benefits and discussion of the distributional implications of candidate policies. Although RIAs have a well-developed practice and many elements in common with CIAs (see Chapter 2), application of the steps of CIA to proposed air pollution regulations could provide additional insight to decision-makers and affected communities. Analogous analytical tools could also have merit for state and local decisions.

Initiation

Most federal RIAs arise through a formalized protocol, in which input from affected groups and interest holders primarily occur near the end of the process, when a draft RIA is published with a request for public comment. Within a CIA framework, meaningful engagement including communities, at-risk populations, affected industries, and others would start at the front end of the process. In theory, this could facilitate identification of alternative policy structures to consider, and the incorporation of health outcomes that would be of interest regardless of their contributions to monetized health benefits. In addition, the use of screening tools could provide insight regarding policy structures to consider (i.e., if screening-level analyses show that a candidate policy has much higher or lower benefits than costs or might narrow inequities in exposure burdens) as well as geographic areas that may merit closer attention. Many of these steps may be impractical in the context of federal RIAs given the complex legal landscape, but could be viable in other decision contexts, and elements of the CIA process could help to streamline and better focus federal RIAs.

Scope and problem formulation

Many elements of federal air pollution RIAs have been standardized at EPA and elsewhere, including a national scope, a multidecade future timeline, and quantification of health benefits by characterizing emission changes associated with departures from a baseline or "business as usual" scenario, modeling the resulting changes in air pollution concentrations, and estimating health benefits by linking those changes with epidemiological evidence and baseline population health data. A CIA process at the federal level would use this approach as a foundation but use a meaningful engagement process to refine the universe of questions of interest. This could include geographic resolution (i.e., should the outputs be national aggregate, state resolution, targeting specific geographic areas or emission sources) and the attributes of populations who would be of interest to characterize (i.e., based on socioeconomic status, demographic attributes, or baseline health status). For the analysis plan, a critical conversation includes the timeline for decisions and the acceptable level of uncertainty, as some models could be implemented quickly with more uncertain outputs while others might take years to yield estimates with greater precision. Until recently, this type of analysis has posed significant challenges due to the computational costs and spatial-resolution limitations of many air quality models. However, newer air quality models (e.g., InMAP[3]) have made this type of analysis faster and easier to carry out than many conventional models, which can facilitate rapid CIAs of proposed air quality programs.

Another scoping topic would involve the strategies for inclusion of qualitative information into both the analytical plan and the decision-making process. Most RIAs include extensive qualitative information, but the executive summary and outputs intended to inform decision-making typically center quantitative comparisons of benefits and costs. CIAs should include identification of key components that could not be quantified and explicit strategies for how this information will be utilized in a context where quantitative outputs are available and have historically been emphasized.

Approaches to assess impacts and inform action

As described above, the analytical approach for quantitative air pollution RIAs is well defined, yielding estimates of mortality and multiple morbidity outcomes (in health and economic terms) associated with changes in concentrations of multiple criteria air pollutants. However, the typical RIA does not fully incorporate a cumulative impacts framework, beyond the inclusion of multiple air pollutants. A more expansive CIA could include:

- More detailed information, both quantitative and qualitative, about the high-risk populations for a given exposure and health outcome (including, but not necessarily limited to, hospital admissions, emergency department visits);
- Consideration of connections between the candidate policy measure and health that go beyond changes in air pollution levels (e.g., impacts on employment patterns, accident risks, occupational risks);

[3] See http://spatialmodel.com/inmap/ (accessed June 5, 2025).

- Measures of well-being that go beyond the mortality and morbidity outcomes typically included in RIAs; and
- Formal consideration of the influence of candidate policy measures on the distribution of exposures and health outcomes within and between communities, including through the use of analytical tools that characterize geographic and sociodemographic patterns of exposure inequality.

For decisions at the state and local levels, CIAs would not necessarily need to follow the same analytical approach as federal RIAs, given both differing regulatory requirements and differing policy landscapes. For example, in California, air quality regulation efforts over nearly two decades have sought to achieve reductions in pollution levels, mitigate greenhouse gas emissions, and eliminate exposure disparities among regions across the state. Yet, legacies of discriminatory land use policies, including redlining and siting of freeways, have concentrated traffic-related air pollution in marginalized communities who drive the least and therefore contribute less to traffic-related emissions (Koolik et al., 2024). One study applied an air quality modeling approach to retrospectively assess the extent to which California's aggressive on-road mobile source emission reduction strategies have affected absolute and relative exposures overall and between different population groups across the state (Koolik et al., 2024). Results showed significant overall reductions over two decades in statewide average exposure to $PM_{2.5}$ from on-road vehicles, yet for people of color and disadvantaged community residents, relative exposure disparities increased. Light-duty vehicle emissions were the main driver of the exposure and exposure disparity, although smaller contributions from heavy-duty vehicles especially affect some overburdened groups (Figure 5-2).

A CIA approach in this context could include analyses of the magnitude and geographic and sociodemographic distribution of air pollution health benefits, as well as a more expansive consideration of quality of life in communities and qualitative feedback from residents. Such an approach could yield novel outcomes to incorporate into the analysis (including community input on the most meaningful metrics of exposure or health disparities) and policy measures that would be most beneficial to community health (potentially going beyond emission reductions to consider accident risks, accessibility to jobs, and so forth).

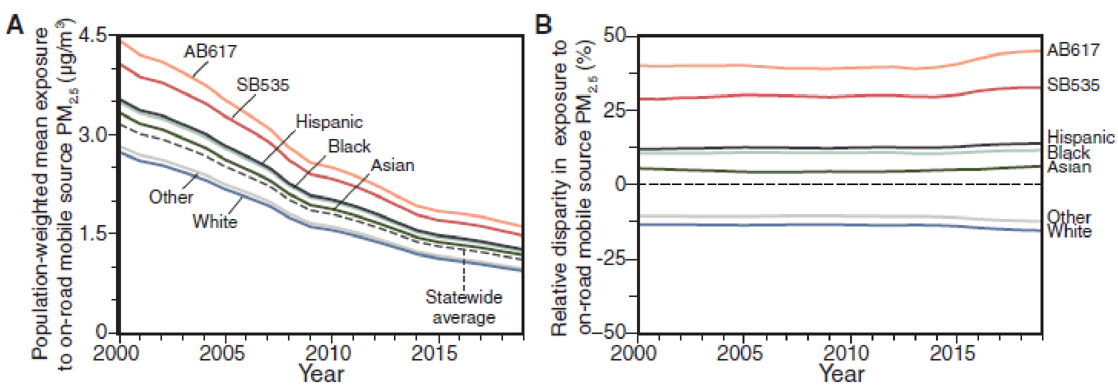

FIGURE 5-2 On-road mobile-source $PM_{2.5}$ exposure and relative disparity in exposure for each demographic group. Statewide population-weighted mean $PM_{2.5}$ exposure concentrations (A) and relative disparity in exposure (B) attributable to on-road mobile sources for the four largest racial/ethnic groups and two policy-relevant communities in California: (1) communities participating in the state's Community Air Protection Program promulgated under Assembly Bill 617; (2) communities designated as disadvantaged under CalEnviroScreen, promulgated based on Senate Bill 535. In each year, relative exposure disparities (B) for each racial/ethnic group are estimated in reference to the statewide average $PM_{2.5}$ concentration attributable to on-road mobile sources (~ 10% of state population) and as SB535 Disadvantaged Communities (~25% of state population) substantially exceed those experienced, on average, for the most exposed.

Monitor and evaluate outcomes

Air pollution RIAs are inherently action-oriented, as they focus on the benefits and costs of proposed policy measures. A broader CIA could emphasize the impacts of alternative policies, as opposed to the benefits and costs of a single candidate policy measure. This would also be consistent with best practice in RIA. Monitoring and evaluation would be an important addition to the process, as it could include tracking of emissions, air quality, or health outcome data in situations where the policy change would be large enough to allow for meaningful tracking; application of prospective modeling tools to quantify benefits of changes in emissions or other source activities in situations where the benefits would be difficult to observe empirically; and consideration of mitigation strategies or plans implemented to address any adverse or inequitable outcomes from policy measures.

Case 6. Assessing the Co-benefits of Climate Policies

Initiation

For nearly two decades, California has been at the forefront of combatting climate change, through the Global Warming Solutions Act of 2006 (Assembly Bill 32, or AB32) and related legislation. The California Air Resources Board along with other state agencies are tasked to implement ambitious strategies to curtail greenhouse gas emissions from mobile and stationary sources through a combination of direct regulations and market incentives. The state has also worked to integrate sustainability goals in its greenhouse gas reduction programs by enhancing their co-benefits, which can include community-level investments in climate mitigation and adaptation initiatives that improve neighborhood amenities as well as the health and well-being of local residents, and near-term reductions in harmful air pollutants from regulated entities that tend to be disproportionately located in neighborhoods with higher proportions of poor residents and people of color (Cushing et al., 2018).

Scope and problem formulation

CIA can be used to assess the air quality, well-being, and other co-benefits of climate policies and elucidate opportunities to adjust investment programs and regulations over time in order to maximize these important outcomes. The committee notes that EPA's approach to quantifying health risks of criteria air pollutants differs from the agency's approach to air toxics, specifically for noncancer health risks, and therefore does not align with best scientific practices for quantifying noncancer health effects.

Approaches to assess impacts and action

Recent analyses by California's Office of Environmental Health Hazard Assessment examined co-benefits of California's climate policies, with a focus on stationary facilities subject to the state's Cap-and-Trade Program, as well as regulation of greenhouse gas emissions from heavy-duty vehicles. Results indicate that co-pollutant reductions were steepest for heavy-duty vehicles compared to stationary facilities with concomitant health benefits, including reductions in air pollution-related mortality. In particular, diesel particulate matter had declined significantly overall in the last two decades, with the largest reductions in disadvantaged communities that were identified by CalEnviroScreen and where diesel pollution burdens have tended to be higher. Regulations incentivizing the use of zero-emission heavy-duty vehicles are projected to result in additional health benefits in the future. Among regulated facilities under the Cap-And-Trade Program, the relationship between greenhouse gas and co-pollutant emissions varies by industrial sector. In addition, regulated entities are disproportionately located in communities of color. Thus, between 2017 and 2022, reductions in $PM_{2.5}$ and air toxics along with associated health benefits were greatest in disadvantaged communities and communities of color, although differences in air pollution burdens associated with both stationary facilities and heavy-duty vehicles persist, particularly for Black Californians. In response to community concerns about the implementation of AB32, other assessments have examined the extent to which programs and policies have performed in reducing greenhouse gas and co-pollutant emissions and the extent to which incentive programs such as the Clean Vehicle Rebate Program, have been accessible to disadvantaged communities. For example, an analysis of the first compliance period of California's Cap-and-Trade Program observed increases in greenhouse gas and co-pollutant emissions ($PM_{2.5}$, nitrogen oxides, sulfur oxides, volatile organic compounds, and other toxic air contaminants) among some categories of regulated entities and that these sources were often disproportionately located in disadvantaged communities (Cushing et al., 2018). Similarly, an assessment of California's Clean Vehicle Rebate Program showed the need to facilitate the distribution of rebates to more low- and moderate-income communities with higher air pollution burdens (Ju et al., 2020). Housing analyses of transit-oriented development also indicated the need to preserve affordable housing (and prevent displacement of low-income residents) in projects intended to mitigate GHG emissions from the transportation sector (Méndez, 2020).

Recent analyses have also assessed the distribution of funds from California Climate Investments (CCIs), which is supported through the Cap-and-Trade Program though SB535; the law requires minimum investment levels of 35 percent to be targeted toward disadvantaged communities identified by CalEnviroScreen. Funded projects include transition to low-carbon freight and passenger transportation; affordable housing near transit stations to reduce the car dependency; accessible transit (including car and bike sharing), urban forestry; installation of energy efficiency and renewable energy projects; and more. Recent reports indicate that since 2014, 73 percent of the total CCI funds are benefiting disadvantaged communities. This amounts to more than $6.7 billion of the total $9.3 billion spent of the $11.8 billion that has been appropriated (excluding cap-and-trade monies awarded and spent on the state's High-Speed Rail Project) (Lim et al., 2024).

Monitor and evaluate outcomes

CIA approaches can enhance co-benefit assessments of climate change policies by centralizing data collection and tracking the distribution and impacts of climate mitigation and adaptation investments and regulatory interventions across the multiple regulatory agencies, including those administering various CCI programs. For tracking the air quality co-benefits, data on mobile-source emissions and exposures should be more granular and inform community-driven and localized monitoring efforts near major roadways and other emission sources of concern, where feasible. These data should also be linked to neighborhood spatial units to facilitate place-based and community-specific assessments of the health implications of myriad regulations and CCI-funded projects. Some data sources integrate emissions data with modeling approaches to characterize health risks related to air toxics across regions (e.g., California's South Coast Air District's Multiple Air Toxics Exposure Study V; South Coast AQMD, 2021). However, some may lack sufficient spatial granularity to comprehensively assess intraregional differences in exposure and health risk burdens. Nonetheless, other air quality modeling packages, for example, InMAP, facilitate this analysis for a subset of compounds, providing national coverage at much higher spatial resolution than many conventional models. Finally, such CIA approaches can engage overburdened communities to better understand local drivers of persistent greenhouse gas and co-pollutant emission hotspots and how best to mitigate them.

Case 7. Lead Service Line Replacement

Initiation

EPA's Lead and Copper Rule required both community water systems serving residences and nontransient noncommunity water systems that typically serve schools, colleges, factories, and hospitals to complete and submit an initial lead service line (LSL) inventory to their state by October 16, 2024.

There are numerous funding sources available from the federal government for lead service line replacement (LSLR), but there are concerns about uneven implementation, particularly for populations and communities that have increased cumulative burdens and who may be more highly impacted by lead exposures in the absence of LSLR.

Scope and problem formulation

A CIA that engages with vulnerable communities could help LSLR programs prioritize most highly impacted populations and communities. The CIA could both identify the populations that would benefit the most from LSLR (e.g., populations with higher child blood lead levels, areas with both older residential and school buildings) as well as ascertain the potential barriers to and negative secondary impacts of LSLR implementation (see Figure 5-3).

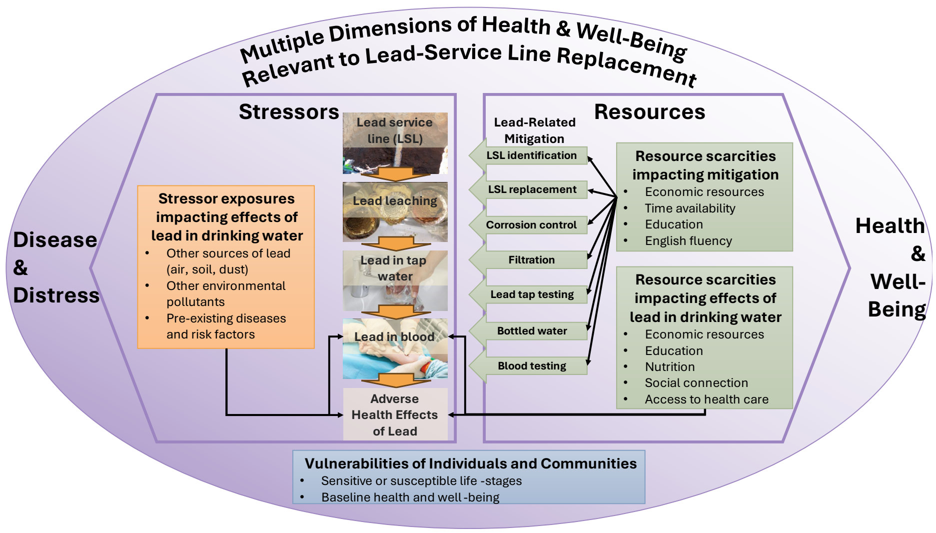

FIGURE 5-3 Cumulative impact assessment approaches to improve outcomes from lead service line replacement programs.

Approaches to assess impacts

The approach could be to first conduct a baseline assessment of cumulative burdens (exposure to stressors and resource scarcities) most relevant to LSL-related lead exposure. These may include factors that increase cumulative exposure (e.g., other sources of lead, nutritional deficiencies, other neurotoxic chemicals), increase vulnerability to effects (e.g., life stage), add to overall burdens on health and well-being (social and economic resources, low health care access, poor baseline health), among others. Additionally, this baseline assessment could identify barriers to implementation, such as economic and time poverty, lower education, and language barriers.

Approaches to inform action

The baseline assessment, when intersected with the LSL inventory, could identify communities to target or prioritize for which LSLR would have a high impact on overall health and well-being due to cumulative burdens from the presence of existing stressors, resource scarcities, or other vulnerabilities. For each of these communities, the barriers to implementation that were identified could be reduced through development of specific programs and policies (e.g., language translation for language barriers).

Monitor and evaluate outcomes

The CIA could prioritize tracking progress of LSLR in the identified vulnerable populations, including testing of lead before and after LSLR to verify exposure reduction. The efficacy of programs to reduce barriers to implementation could also be monitored, and programs adapted to improve outcomes.

Case 8. Chemical Class, Mixtures, and Chemicals Policy

With few exceptions, evaluation of chemicals is done one chemical at a time using traditional risk assessment in evaluating existing chemicals in commerce under the Toxic Substances Control Act (TSCA), in establishing of drinking water standards, and in setting reference exposure levels for use in place-based assessments. Nonchemical stressors are not formally addressed, nor are myriad other exposures that people encounter in their daily lives that can interact with the chemical under consideration, to produce risks of concern that in isolation may not be found risky. Introducing elements of the CIA framework can improve the evaluations to better protect public health, recognizing that there are some constraints, for example, by law, nonhealth endpoints cannot be considered in TSCA assessments of existing chemicals.

Initiation

The potential for addressing multiple related chemicals in a single assessment would be evaluated at the initiation stage. This stage includes evaluating how to approach, through meaningful engagement, the problem of defining the relevant set of chemical exposures and interacting social factors to include in the CIA and considering the legal and programmatic context for the analysis. The general analytical approach could be, for example, to build from a risk assessment that groups chemicals based on co-occurring exposures or shared health effects. As an example, a National Academies report recommends assessment of phthalates as a class of chemicals jointly with other antiandrogens, based on their shared effects on common adverse health outcomes (NRC, 2008; see Chapter 2). The Consumer Product Safety Commission, after consulting the National Academies, is in the process of conducting risk assessments for several subclasses of flame retardants (e.g., polyhalogenated organophosphates [CPSC, 2023]) using a class-based analysis based on chemical structure. The CIA approach would entail jointly analyzing shared health effects and the impacts of nonchemical stressors. A challenge will be to identify communities and other relevant interest holders that can engage meaningfully in defining the universe of relevant chemical and other stressors for analysis. A further challenge is how to remedy information gaps due, for example, to limited ingredient disclosure in products.

Early consideration would be given to determining how to best obtain meaningful input from affected parties (and/or experts representing their interests) on key questions the assessment should address—under TSCA, how to identify overburdened communities to understand their exposures, information sources for nonchemical stressors that elevate risk, and approaches to address the inherent uncertainties in the assessment. TSCA assessments have yet to meet these goals, resulting in underestimated human health risks (Rayasam et al., 2022). These assessments can be improved by applying CIA to include community and expert inputs about real-world factors such as how chemicals are used, how people are exposed, and whether there are subpopulations with high exposures or vulnerability.

Scope and problem formulation

The general processes used at the federal level to evaluate chemicals are dictated by statute and codified in regulations (e.g., 40 CFR Part 702) or regularized in handbooks and provide multiple points for public comment. Proposed methods for conducting the assessment are released for public comment early in the process in the form of scoping or protocol documents.

Meaningful public engagement at the protocol or scoping phase could advance approaches to addressing some cumulative impact issues. Chapter 4 describes methods for addressing uncertainty, including application of additional default uncertainty factors.

Approaches to assess impacts

To evaluate the general protectiveness of the approach, exposures and health conditions, including in select heavily exposed communities or at-risk groups, would be surveyed. Baseline information on health conditions of relevance to the chemicals under evaluation, other related chemical stressors, and resources such as access to nutritious food and health care would be collected. These data would be used in addition to evidence about the biological activity of chemicals alone and in combination when considering the extent that additional protection is warranted.

The assessment would analyze differences in exposures among population groups and differences in relevant health outcomes. For example, a pooled analysis of 16 U.S. pregnancy cohorts found higher phthalate exposures among Black and Latina/Hispanic participants and higher odds of preterm birth in association with phthalate levels in these groups, which are already vulnerable to adverse birth outcomes (Oh et al., 2024) These exposure differences may be seen as outcomes from racialized and gender-based beauty standards (Zota and Shamasunder, 2017).

Another opportunity for assessing cumulative impacts of chemicals on a common health outcome is breast cancer. Breast cancer is the leading cause of cancer incidence and mortality worldwide, and incidence is rising among women under 50 years of age. An analysis that applied a key characteristics approach to EPA data identified more than 900 chemicals with evidence of relevance to breast cancer (Kay, 2024). Lists such as this one can be used in both the assessment phase and in problem identification and initiation phases where chemicals are selected for assessment.

Approaches to inform actions

Qualitative features such as those described above would be integrated into the cumulative impact profile and considered in determinations of chemical policy, such as determinations of significant risk under TSCA and setting of drinking water standards. At this stage of the process a monitoring plan to evaluate outcome of action would be developed.

Monitor and evaluate outcomes

Monitoring reductions in exposures in the population at large, including in the more highly exposed groups (if the chemical is susceptible to biomonitoring), would provide a check on whether the chemical reduction policy was working. Chemical exposure biomonitoring, including as conducted by the National Health and Nutrition Examination Survey, and databases related to chemical use are important long-term tools for evaluating success, as was seen following restrictions in use on bisphenols, PFAS chemicals, flame retardants, and lead.

Summary Highlights Across Case Studies

The above case studies illustrate how a CIA framework can offer a paradigm shift along multiple dimensions in many different contexts at different scales, as summarized in Table 5-2. For instance, in the "Cancer Alley" case study, where predominantly Black communities face disproportionate exposure to industrial emissions alongside chronic disinvestment, health disparities, and climate vulnerability, framing the issues using a CIA lens can move the conversation beyond assessing isolated risks to understanding layered, place-based burdens. Traditional EPA assessments, focused on individual pollutants and permit compliance, have failed to capture the full scope of harm experienced by residents. Similarly, the experiences of urban and rural tribal members in Colorado reveal how cumulative impacts arise from structural inequities across geography, governance, and access to services. Traditional environmental assessments overlook the unique health, housing, economic, and cultural stressors faced by tribal populations—especially those living off-reservation in urban areas.

Likewise, the East Palestine train derailment and subsequent chemical burn exposed the limitations of traditional chemical risk assessments, which failed to account for the community's preexisting vulnerabilities. In contrast with official assurances that chemical levels were below conventional toxicological thresholds of concern, community members experienced significant physical symptoms, psychological distress, and loss of trust in institutions. A CIA lens reframes the event not just as a chemical spill, but as a cumulative disaster compounded by social, economic, and institutional stressors, potentially offering a more holistic, responsive strategy for recovery. Analogously, the Los Angeles wildfires case study illustrates how traditional environmental assessments fail to capture the compounded and intersecting impacts on both frontline workers and marginalized communities. Ambient and indoor air quality monitoring does not necessarily reflect the full range of toxic air contaminant exposures, and comprehensive soil and other surface testing in burn areas, particularly in residential neighborhoods and school sites, has been lacking, often leaving communities to fund that work themselves. In addition, occupational exposures, physical health effects, mental health strain, displacement, and service disruptions experienced across the region are not adequately characterized. The CIA framework provides a more comprehensive approach by integrating environmental, social, and institutional stressors with community and worker voices, accounting for preexisting vulnerabilities and enabling more equitable and comprehensive emergency response strategies.

The CIA is not just applicable to place- or population-based contexts but also can broaden the impact of larger-scale policy and regulatory actions. In the context of air pollution, where RIAs have been applied to quantify health benefits of policy measures for decades, a CIA framework could facilitate earlier engagement of interest holders to inform the decision landscape and the health outcomes of interest. CIA could also provide more expansive consideration of qualitative information (including from impacted communities) and a structure within which it is viable to include linkages between policy and health beyond direct changes in air pollution exposures. The potential for application of screening-level analyses to inform the decision landscape and the targeted use of more comprehensive models where they would be needed to reduce decision-relevant uncertainty would also be enhanced within a CIA framework. CIA approaches can also be applied to evaluations of the co-benefits of climate change policies. As governments and other entities develop climate mitigation strategies to reduce greenhouse gas emissions, associated near-term reductions in harmful co-pollutants from myriad mobile and stationary sources can be analyzed. Similarly, investments in climate mitigation projects, such as electrification, active transit, energy-efficient housing, and urban forestry, among other projects, can convey short-term co-benefits, in addition to addressing climate change. CIA can evaluate prospectively and retrospectively the extent to which communities that disproportionately host major greenhouse gas emission sources may or may not be benefiting from these programs and regulations; such applications of CIA in climate policy can provide opportunities to improve health and well-being.

Chemical-specific statutory actions, such as EPA rules and regulations, can benefit from a CIA-based approach. In the LSLR case study, CIA can help target or prioritize communities for which LSLR would have higher impact on overall health and well-being due to baseline cumulative burdens. Additionally, such a baseline assessment could be used to improve implementation by identifying and addressing specific barriers related to these cumulative burdens such as resource scarcity and baseline vulnerabilities. More generally, CIA can inform chemicals regulation and policy through analyses of differences in both exposure vulnerability and baseline health and well-being across population groups, which can be integrated into determinations of significant risk under TSCA or in setting regulatory standards. Furthermore, the recommended inclusion of the monitoring and evaluation in CIA can prioritize the most highly exposed and overburdened groups, better ensuring protection of vulnerable populations.

TABLE 5-2 Takeaways from Case Studies of CIA-Based Approaches in Contrast to Traditional Assessments

Dimension	Typical Traditional Assessment Approaches	Recommended Cumulative Impact Assessment-Based Approaches
Scope of analysis	Chemical-focused assessments; individual pollutant exposures from permitted facilities and time-bound to immediate exposure or event. Separates general public or workers, rarely including occupational health beyond OSHA standards.	Inclusive assessment of environmental, social, economic, and historical stressors, including racism, disinvestment, climate; tribal health, housing, employment, cultural connection; integrates occupational, residential, psychological, and infrastructure vulnerabilities; environmental exposure across urban and rural contexts; temporally inclusive of pre-, during, and post-event.
Health outcomes considered	Adverse physical health endpoints (e.g., cancer) and effects with established pathways to disease.	Inclusive beyond established disease outcomes to encompass health and well-being, including physical, mental, emotional, social, spiritual, and cultural, as well as intergenerational trauma and access to care.
Data types and sources	Quantitative exposure data and modeled risk estimates; data primarily from "official" sector (federal, state).	Uses both quantitative data (e.g., emissions measurements, modeled estimates, health outcomes, administrative data) and qualitative data (e.g., lived experience, community history) as inputs; draws on tribal knowledge, community priorities; considers mechanistic biology and computational toxicology.
Stressors analyzed	Chemical stressors regulated by statute, without link to social or systemic conditions.	Includes nonchemical, structural, historical stressors such as segregation, racism, social inequality; poverty and job insecurity; housing quality, zoning patterns, political disenfranchisement.
Community engagement	Limited to procedural approaches, often only through public comment/regulatory hearings.	Centered and prioritized so that lived experiences inform each step of the CIA process, including problem identification, indicators, and actions; utilizes participatory approaches that lead to co-creation of knowledge and data.
Fairness lens	Acknowledges population variability but lacks mechanisms to prioritize or evaluate fairness.	Explicitly prioritizes historically overburdened communities, acknowledging unequal starting points, and dispersed tribal populations with shared historical and jurisdictional barriers; addresses issues related to distinct identities, tribal or otherwise.
Resource and resilience consideration	Resource availability, protective factors promoting health, well-being; resilience not assessed.	Identifies assets and resources that promote resilience (e.g., civic or community organizing, faith institutions, cultural programs) and gaps or scarcity that need to be addressed (e.g., health care and food deserts, transportation access).
Decision context	Primarily tied to government regulatory framework (e.g., permitting, enforcement) within the government agency.	Informs not only regulatory context, but broader policies related to land use, public health, investment; supports culturally tailored solutions across multiple jurisdictions (including tribes); evaluates multisector (e.g., including private sector) capacity, trust, and ability to support communities.
Policy and action pathways	Focused on pollutant-specific regulatory limits, mitigation, monitoring, compliance without consideration of social or economic policies.	Enables multiagency responses (including tribes), investment in community infrastructure, transformation of regulatory systems to reduce cumulative burdens, policy recommendations beyond environmental regulations, such as housing, jobs, health care, structural and systems-level changes beyond environmental remediation.
Monitoring and evaluation	Limited post-assessment follow-up unless tied to regulatory requirement or compliance.	Includes ongoing tracking of health and well-being (physical, mental, emotional), social, environmental, institutional outcomes; promotes community-led monitoring, storytelling, indicators to track fairness.

NOTE: OSHA = Occupational Safety and Health Administration.

CONCLUSIONS AND RECOMMENDATIONS

Conclusion 5-1: The case studies underscore the applicability of cumulative impact assessment to many different decision contexts. Entities undertaking cumulative impact assessment, including EPA, other national entities, states, and localities need to be flexible to accommodate different community contexts, scales, and programmatic needs while learning from prior experiences in specific communities. Cumulative impact assessments that promote data transparency, access, and linguistic inclusion are likely to have more relevance for and reach to diverse end users and be more reproducible and scalable.

Conclusion 5-2: Based on the case studies, the committee's recommended cumulative impacts paradigm and accompanying five-step process can increase the effectiveness of actions to improve health and well-being. However, additional information is needed on designing cumulative impact assessments for different communities, scales, and programmatic needs (Step 2) and developing monitoring and evaluation strategies that ensure progress toward improved health and well-being (Step 5).

Recommendation 5-1: With respect to the assessment design (Step 2 of the recommended five-step process), EPA's final framework and the practice of cumulative impact assessment should include guiding/diagnostic questions to facilitate adaptability and generalizability to different communities, scales, and programmatic needs, including:

- **When cumulative impact assessment is appropriate rather than health impact assessment, cumulative risk assessment, or other approaches;**
- **Appropriate scope and detail of a proposed cumulative impact assessment, given resource and time constraints as well as community and decision-making contexts, with options ranging from in-depth cumulative impact assessment processes to rapid cumulative impact assessments to address an immediate concern based on readily available data;**
- **Scope of actions available to the regulatory agencies involved and trade-offs among them;**
- **How best to assess and measure the effectiveness of existing and future policies and regulations; and**
- **Anticipatory applications of cumulative impact assessment and potential for reducing impacts across myriad populations and communities.**

Recommendation 5-2: With respect to monitoring and evaluation (Step 5 of the recommended five-step process), EPA's final framework and the practice of cumulative impact assessment should include strategies for:

- **Incorporating both technical indicators and community-defined quantitative and/or qualitative metrics;**
- **Using both retrospective and anticipatory approaches to examine whether/how patterns and population distributions of cumulative impacts are changing over time; and**
- **Supporting ongoing program adjustments to better achieve program goals.**

Conclusion 5-3: A mature application of cumulative impact assessment adopted by many national and state entities is the use of composite-index- or matrix-based approaches for baseline assessments of cumulative burdens to identify communities for specific policy interventions, such as facility siting limitations and targeting of investments for enhancing resources; however, improvements to methodologies, data availability, and comprehensiveness are still needed. These *structured methods provide a replicable and scalable foundation for screening, prioritization, and evaluation.*

Recommendation 5-3: EPA and other national entities, states, and localities should expand use of composite-index- or matrix-based approaches for baseline assessments of cumulative burdens to identify communities for interventions to improve health and well-being. Examples of interventions that can be informed by these types of cumulative impact assessment include:

- **Facility siting decisions and permit approvals or renewals;**
- **Site remediation;**
- **Resource investment allocation; and**
- **Enhanced regulatory protection and enforcement.**

Conclusion 5-4: Capacity building is needed for entities undertaking cumulative impact assessment, including EPA, other national entities, states, and localities, in several areas:

- *Meeting communities, myriad interest holders, and decision-makers where they are to effectively engage them throughout the cumulative impact assessment process. For example, this means understanding what a community actually wants and needs, what resources they already have, what challenges they face, and what their priorities are.*
- *Developing tools that are accessible for myriad end users and that communities and decision-makers can apply locally, on their own.*
- *Developing processes and tools that integrate community knowledge with advanced scientific methods to assess or predict effects of chemical classes and exposures to multiple chemicals over the life course, taking into account the social context.*

Recommendation 5-4: EPA and other national entities, states, and localities should develop, or support development of, tools, best practices, and requisite training to increase capacity at the community, state, and national scales for conducting cumulative impact assessment in diverse contexts. Specific priorities include:

- **Data warehouses and software tools that enable customized development of baseline assessments of health and well-being, stressors, and resources;**
- **Tools that incorporate local, community, and tribal data along with governmental datasets;**
- **Tools that can rapidly include multiple indicators in implementing composite scoring, indexing, or matrix-based approaches;**
- **Retrospective and anticipatory case studies and best practices to demonstrate successful implementation of cumulative impact assessments; and**
- **Tools to integrate social context and community knowledge with scientific methods for assessing the effects of classes of chemicals and chemical mixtures.**

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Appendix A
Committee Biographical Sketches

Weihsueh A. Chiu (*Chair*) is a professor in the Department of Veterinary Physiology and Pharmacology at Texas A&M University. He also has a Research Fellow appointment at the Institute for Science, Technology, and Public Policy at the Bush School of Government and Public Service. Before joining the university in 2015, he worked at the U.S. Environmental Protection Agency (EPA) for more than 14 years, most recently as branch chief in the Office of Research and Development. His research in human health risk assessment includes toxicokinetics, physiologically based pharmacokinetic modeling, dose-response assessment, characterizing uncertainty/variability, environmental justice, climate and disaster risks, systematic review, and meta-analysis, with particular interest in Bayesian and probabilistic methods. Chiu has participated or chaired expert review panels for multiple government agencies, including EPA's Science Advisory Board and Chemical Assessment Advisory Committee, international committees, and work groups. Chiu received an A.B. in physics from Harvard University, an M.A. and Ph.D. in physics from Princeton University, and a Certificate in Science, Technology, and Environmental Policy from the Princeton School of Public and International Affairs. He has served on seven National Academies committees, including chairing the Committee on the Variability and Relevance of Current Laboratory Mammalian Toxicity Tests and Expectations for New Approach Methods for use in Human Health Risk Assessment.

Julia G. Brody is senior scientist and executive director emeritus at Silent Spring Institute and a research associate in epidemiology at the Brown University School of Public Health. She is an expert on environmental chemicals and breast cancer and a leader in community-engaged research and public engagement in science. She joined Silent Spring Institute in 1996, shortly after its founding, and led the organization for 28 years, transforming it into a leading scientific research center on environmental chemicals and women's health. Brody's current research focuses on reporting back to communities and to individuals who participate in environmental health studies to inform them about their own chemical exposures. This interest grew out of Silent Spring Institute's Household Exposure Study, the first comprehensive assessment of endocrine-disrupting compounds in homes. Her research has been supported by the National Institutes of Health (NIH) and National Science Foundation. Her experience includes co-leading an NIH T32 training program at the intersection of social science and environmental health science. She has served on the National Advisory Environmental Health Sciences Council and as an advisor to the California Breast Cancer Research Program. The U.S. Environmental Protection Agency recognized her research with an Environmental Merit Award in 2000. Brody received a Ph.D. in psychology at the University of Texas at Austin.

Zhen Cong is professor and chair of the Department of Health Sciences in the Crean College of Health and Behavioral Sciences at Chapman University. She used to serve as professor and director of the Climate and Health Initiative in the Department of Environmental Health Sciences of the School of Public Health at the University of Alabama at Birmingham. She was previously on the faculty of Texas Tech University and the University of Texas at Arlington; for the latter, she also served as associate dean for Research and Faculty Affairs as well as Ph.D. program director.

Her research focuses on using convergent integrated frameworks and approaches to examine older adults' vulnerability and resilience to disasters and community resilience as well as social, health, and environmental disparities related to disasters. Cong has conducted a series of research projects related to hurricanes and tornadoes to address critical issues such as exposure to risks, risk perception and communication, access and response to warnings, mitigation behaviors, and the recovery process associated with disasters. She is an inaugural cohort member of the National Institutes of Health Climate and Health Scholars and also a Fellow of the Gerontological Society of America. Cong received a Ph.D. in gerontology from the School of Gerontology at the University of Southern California.

Deborah Cory-Slechta is a professor of environmental medicine at the University of Rochester Medical School and previously served as dean for research, chair of Environmental Medicine, and principal investigator of the department's National Institute of Environmental Health Sciences Core Center Grant. Her research, including both animal models and human studies, is focused on the consequences of exposures to environmental chemicals on the brain and their relationship to neurodegenerative and neurodevelopmental disorders. These studies have focused on the impact of air pollution, including ambient air as well as inhaled metals in air pollution. Cory-Slechta has received sustained funding from the National Institute of Health (NIH) over the course of her career for this research. She has served on advisory panels for NIH, the Food and Drug Administration, the U.S. Environmental Protection Agency, and the Agency for Toxic Substances and Disease Registry. In 2017, she received the Distinguished Neurotoxicologist Award from the Neurotoxicology Specialty Section of the Society of Toxicology, and in 2021 was the recipient of the Distinguished Toxicology Scholar Award from the Society of Toxicology. In 2022 she received the Susan B. Anthony Lifetime Achievement Award from the University of Rochester. She has served on several National Academies committees on military and veterans' health, including as chair of the Committee on Gulf War and Health, Volume 10.

Andrew L. Dannenberg is an affiliate professor in the Department of Environmental and Occupational Health Sciences and in the Department of Urban Design and Planning at the University of Washington. Previously he served as team lead of the Healthy Community Design Initiative in the National Center for Environmental Health and as director of the Division of Applied Public Health Training at the Centers for Disease Control and Prevention, as Preventive Medicine Residency director and injury prevention epidemiologist at Johns Hopkins School of Public Health, and as a cardiovascular epidemiologist at the National Institutes of Health. His research and teaching focus on the health aspects of community design, including land use, transportation, equity, climate change, and other issues related to the built environment. He has a particular interest in the use of health impact assessments as a tool to inform community planners about the health consequences of their decisions. Dannenberg received an M.D. from Stanford University, a master of public health from Johns Hopkins Bloomberg School of Public Health, and completed a family practice residency at the Medical University of South Carolina.

Mia V. Gallo, a research scientist, is the associate director for Operations and Research and co-investigator at the Center for the Elimination of Health Disparities and a senior member of the Institute for Health and the Environment at the State University of New York at Albany. She also holds a position as a research assistant professor in the Department of Anthropology. She has a diverse background in the fields of biological and medical anthropology, epidemiology, toxicology, and emergency toxicology, and her research incorporates concepts of physical and biomedical anthropology to study the relationship between environmental factors and human health. With expertise in environmental toxicology and a focus on how pollution affects human populations, Dr. Gallo has been a co-investigator on three U.S. National Institutes of Health–funded projects conducted in collaboration with the Akwesasne Mohawk Nation using the principals of community-based participatory research allowing all stakeholders, including the tribal council, the health service providers, and community members, to offer their expertise and partake in the decision-making process. Her research began with a focus on the effects of persistent organic pollutants, including polychlorinated biphenyls, and heavy metals on children's growth and development, endocrine disruption, and thyroid function, and has expanded to include women's reproductive function and the role of persistent organic pollutants in the development of cardiovascular disease and autoimmune diseases. Early in her career, Dr. Gallo was the recipient of the National Institute of Environmental Health Science's Young Investigator Award, the Reginald Whitehouse Award, and the David Axelrod Award.

Rima Habre is an associate professor of environmental health and spatial sciences at the University of Southern California (USC). Her expertise lies in environmental health, air pollution, and exposure sciences. Her research aims to understand the effects of complex air pollution mixtures in the indoor and outdoor environment on the health of vulnerable populations across the life course. Habre's expertise spans measurement, spatiotemporal and GIS-based modeling, and mobile health approaches to assessing personal exposures and health risks. She leads the Exposure Sciences Research Program in USC's Southern California Environmental Health Sciences Center. Habre received an Sc.D. in environmental health from the Harvard T.H. Chan School of Public Health.

Jerreed Dean Ivanich is an Assistant Professor at the Colorado School of Public Health, Centers for American Indian and Alaska Native Health, and an Adjunct Assistant Professor at the Johns Hopkins Bloomberg School of Public Health, Center for Indigenous Health. He is also the Director of the University of Colorado's American Indian and Alaska Native Health certificate program. As a member of Alaska's Metlakatla Indian Community (Tsimshian), he is dedicated to health research for North American Indigenous (Alaska Native, American Indian, First Nations, and Native Hawaiian) populations. Ivanich's work meets at the intersections of prevention science and social network analysis to improve the health and well-being of American Indian and Alaska Native peoples. He is an Aspen Ascend Fellow (2023 cohort) and a National Academy of Medicine's Emerging Leaders in Health and Medicine Scholar. Ivanich received a B.S. in Criminal Justice from Weber State University, a M.S. in Criminology and Criminal Justice from Georgia State University, and a Ph.D. in Sociology from the University of Nebraska.

Jonathan I. Levy is professor and chair of the Department of Environmental Health at Boston University School of Public Health. His research centers on urban environmental exposure and health risk modeling, with an emphasis on spatiotemporal exposure patterns and related environmental justice issues. He has led multiple studies evaluating the cumulative health risks of chemical and nonchemical exposures, including novel approaches for exposure modeling and multistressor epidemiology. He has emphasized community-engaged research through his career, through individual research projects in partnership with community organizations, and through co-leadership of a Center of Excellence on Environmental Health Disparities Research. He is a recipient of the Walter A. Rosenblith New Investigator Award from the Health Effects Institute and the Chauncy Starr Distinguished Young Risk Analyst Award from the Society for Risk Analysis. Levy received a B.A. in applied mathematics from Harvard College and an Sc.D. in environmental science and risk management from Harvard T.H. Chan School of Public Health. He has been a member of several National Academies committees, including the Committee on the Effects of Changes in New Source Review Programs for Stationary Sources of Air Pollution, the Committee on Improving Risk Analysis Methods Used by the U.S. EPA ("The Silver Book"), the Committee to Develop Framework and Guidance for Health Impact Assessment, and the Committee on Science for EPA's Future.

Cris B. Liban serves as chief sustainability officer at the Los Angeles County Metropolitan Transportation Authority (LA Metro). He has worked at LA Metro since 2003 and has grown his agency's environmental and sustainability practice into the most progressive and forward-looking in the country, implementing over 150 sustainability initiatives to date. Liban was the transportation chapter lead of the recently completed Fifth National Climate Assessment. He has previously held political appointments in the U.S. Environmental Protection Agency's National Advisory Council for Environmental Policy and Technology and the California Climate Safe Infrastructure Working Group. In 2016 he received the Philippines' highest civilian honor for Filipinos living overseas, the Pamana ng Pilipino Award. He was also awarded the *Engineering-News Record's* 2020 Award of Excellence; and in 2021 was elected to the National Academy of Construction, and in 2022, he was honored as a Distinguished Member of the American Society of Civil Engineers. Liban received degrees in geology, civil engineering, and environmental science and engineering. He previously served on the National Academies' Committee on Repurposing Plastics Waste in Infrastructure.

Kristen Malecki is a professor and division director for environmental and occupational health sciences at the University of Illinois Chicago (UIC) School of Public Health. Previously, she was a member of the Risk Sciences and Public Policy Institute at Johns Hopkins University, and her research involved developing new scientific methods for indicator development to advance environmental health. As faculty in the Department of Population Health Sciences at the University of Wisconsin Madison, she was a member of the Molecular Environmental Toxicology Center and the Center for Demography Health and Aging and Center for Demography and Ecology. Her current translational environmental health research uses a molecular biology approach to examine combined chemical (air pollution, water pollution), physical, and social stressors, and their influence on adult chronic disease, aging, and health disparities. She applies emerging multi-omic tools including epigenetics, transcriptomics, and the microbiome to identify interim biomarkers of exposure and response to improve understanding of the biological mechanisms linking environmental stressors across the life course to persistent health disparities. Malecki's work is grounded in communities and uses community-engaged approaches to population and environmental health sciences research. She currently supports Environmental Justice Thriving Communities Technical Assistance Center funded by Blacks in Green in Chicago and is director of the Translational Research Core within the National Institute of Environmental Health Sciences–funded Chicago Center for Health and the Environment. Before becoming an academic, she served as a Council for State and Territorial Epidemiology fellow and the lead epidemiologist for the state Environmental Public Health Tracking Program along with Climate and Health programs within the Bureau of Environmental and Occupational Health at the Wisconsin Department of Health Services. Malecki received a Ph.D. in environmental epidemiology and health Policy and a master of public health from Johns Hopkins University Bloomberg School of Public Health. She previously served on the National Academies Committee on the Use of Emerging Science for Environmental Health Decisions and chaired the workshop planning committee on Public Health Research and Surveillance Priorities from the East Palestine, Ohio train derailment.

Rachel A. Morello-Frosch is an environmental health scientist, epidemiologist, and professor in the School of Public Health and the Department of Environmental Science, Policy and Management at the University of California, Berkeley. Her research examines structural determinants of community environmental health with a focus on social inequality, psychosocial stressors, and how these factors interact with multiple environmental hazard exposures to produce health inequalities. Morello-Frosch's work explores this question in the context of environmental chemicals, climate change, air pollution, and effects on perinatal, maternal, and children's health, often using community-based participatory research methods. In collaboration with communities and scientists, she has developed science policy tools to assess and map the cumulative impacts of chemical and nonchemical stressors to improve regulatory decision-making. She is a member of the White House Environmental Justice Advisory Council and the National Academy of Medicine. Morello-Frosch received a B.A. in development studies from the University of California, Berkeley and an M.P.H. in epidemiology and biostatistics and Ph.D. in environmental health sciences from the University of California, Berkeley School of Public Health. She previously served on the National Academies Committee on Anticipatory Research for EPA's Research and Development Enterprise to Inform Future Environmental Protection.

David J. G. Slusky is a professor of economics at the University of Kansas, where he is also the chair of the Department of Speech-Language-Hearing and a professor of population health (by courtesy). His research focuses on reproductive health care, health disparities, health consequences of environmental exposure, and health insurance, and he has published in top journals in public policy, economics, medicine, and public health, including the *Journal of Policy Analysis and Management,* the *American Economic Journal: Applied Economics,* the *Journal of Health Economics, Pediatrics,* and the *American*

Journal of Preventive Medicine. Slusky also serves as the executive director of the American Society of Health Economists and as a co-editor at the *Journal of Policy Analysis and Management,* is a research associate at the National Bureau of Economic Research and is a research fellow at IZA—Institute of Labor Economics. He is the recipient of the Byron T. Shutz Award for Excellence in Teaching and the De-Min and Chin-Sha Wu Research Award, and delivered the 2020 Seaver Lecture for the Humanities Program, all at the University of Kansas. Professor Slusky received B.S. degrees in physics and international studies from Yale University and an M.A. and Ph.D. in economics from Princeton University.

Yoshira "Yoshi" Ornelas Van Horne is an exposure scientist and environmental justice scholar with expertise in metals exposures, air pollution, and community health. She is an assistant professor in the Department of Environmental Health Sciences at the University of California, Los Angeles. She also serves as the assistant director of Agents of Change Fellowship. Her research focuses on addressing unequal exposures to harmful contaminants that affect structurally marginalized communities. Her active projects are focused on utilizing novel methods for source apportionment of air pollution, assessing the compounding impact of heat using community-driven approaches, and evaluating the impact of federal environmental settlements on population exposures and health outcomes. She is committed to building health equity through community-driven research and is passionate about research translation and communication. To this end, her work not only characterizes inequities in cumulative exposures but also supports community-driven solutions and training efforts. She is currently a JPB Environmental Health Fellow through Harvard T.H. Chan School of Public Health. She is also the recipient of the Health Effects Institute's Rosenblith New Investigator Award (2023). Ornelas Van Horne has a Ph.D. in environmental health sciences from the University of Arizona.

Courtney G. Woods is an associate professor in the Department of Environmental Sciences and Engineering in the Gillings School of Global Public Health at the University of North Carolina (UNC) at Chapel Hill. She directs the Environmental Justice Action Research Clinic at UNC, which collaborates on applied research and technical assistance in communities impacted by environmental hazards across North Carolina and trains the next generation of public health leaders in community-driven research approaches. Woods is also founding member of the Earthseed Land Collective, a Black, Indigenous, and People of Color -led organization that applies cooperative principles to land stewardship and community building and works to redefine the human–natural environment relationship. For over a decade, Woods has employed community-based participatory research methods in exposure and community health assessments. Her upbringing in rural South Carolina and lifelong residency in the southeastern United States has led her to focus on environmental health issues impacting rural communities, including issues of decentralized water and sanitation, industrial animal agriculture, and landfills. In recent years, Woods has been appointed to the U.S. Environmental Protection Agency Board of Science Counselors and to the North Carolina Governor's Environmental Justice Advisory Council. She has also worked on environmental justice issues internationally as a Fulbright and Fogarty fellow. Woods received a B.S. in chemical engineering from the University of Tennessee, Knoxville, an M.S. in chemical engineering from the Georgia Institute of Technology, and a Ph.D. in environmental sciences and engineering with a minor in toxicology from UNC Chapel Hill.

Lauren Zeise (*retired 2024*) was director of the California Environmental Protection Agency's Office of Environmental Health Hazard Assessment (OEHHA). She oversaw the department's activities, including the development of risk assessments, hazard evaluations, toxicity reviews, cumulative impact analyses, frameworks, and methods for assessing toxicity and cumulative effects of vulnerability and environmental exposures on communities, and the department's activities in the California Environmental Contaminant Biomonitoring Program. She played a leading role in OEHHA's development of CalEnviroScreen, a tool used to identify the California communities most burdened by pollution from multiple sources and most vulnerable to its effects. She has contributed to hundreds of chemical health risk assessments, science-based regulations, and guidance documents for conducting risk assessments. Zeise was the 2008 recipient of the Society for Risk Analysis' Outstanding Practitioners Award, and she has served on advisory boards and committees of the U.S. Environmental Protection Agency, the Office of Technology Assessment, the World Health Organization, and the National Institute of Environmental Health Sciences. Zeise received a Ph.D. from Harvard University. She has previously served on numerous National Academies committees, including the Committee on Toxicity Testing and Assessment of Environmental Agents and the Committee on Improving Risk Analysis Approaches Used by EPA.

Appendix B
Community Liaison Biographical Sketches

Axel Adams is a board-certified emergency medicine physician and medical toxicology fellow. Issues of concern for his community include PFAS in the Great Lakes and Mississippi basins of the Upper Midwest, environmental disposition of waste materials of complex manufacturing processes such as semiconductor fabrication, overdose outbreaks related to new psychoactive substances, and invertebrate conservation. He completed his undergraduate education at the University of Wisconsin in molecular biology, and medical school at the University of California, San Francisco and a master's degree at the University of California, Berkeley School of Public Health before complete emergency medicine residency at the University of Washington.

Walter E. Auch III, is currently the Midwest program director at the FracTracker Alliance, a role he has held since 2012. Specializing in terrestrial biogeochemistry with a focus on environmental justice and hydraulic fracturing impacts, Auch conducts research and mapping of environmental impacts, creates aerial image and drone libraries, and publishes peer-reviewed papers. He initiated the "Energy Audio Stories" archive to document personal experiences related to energy development. Recognized with multiple awards, including the 2020 Cornell Douglas Foundation's Jean and Leslie Douglas Pearl Award, and several grants from institutions such as the U.S. Environmental Protection Agency and the George Gund Foundation. Auch is a member of the Soil Science Society of America, the Ecological Society of America, and the American Geophysical Union. He earned his Ph.D. in plant and soil science with a specialization in terrestrial biogeochemistry from the University of Vermont in 2010, completed his M.S. in forest resources and environmental conservation at Virginia Tech, and earned his B.A. in plant and soil science from the University of Vermont. Over the past 5 years, he has served on multiple advisory boards and working groups, including the EPA Environmental Justice Screen Tool Data Gaps and Sources Working Group, the NAACP Ohio Environmental Justice Advisory Board, the Buckeye Environmental Network, and the City of Shaker Heights Tree Advisory Board, and served on the EPA Environmental Justice Science and Analysis Review Panel and the Environmental Justice Screen Science Advisory Board from 2023 to 2024.

Jacqueline Baham, New Orleans East Green Infrastructure Collective (NOEGIC)/Water Wise Gulf South, has a professional background as a mental health specialist (MHS) where she counseled youth ages 5–21 and worked toward the goals of their treatment plan. She has always had a passion for youth and has continued to contribute to the development of youth in New Orleans for almost 20 years. She also has a passion for growing fruits, vegetables, and herbs in an attempt to combat the accessibility to fresh food and produce in New Orleans East where she is a long-term resident. NOEGIC is based in a community that faces food insecurities, affordable housing issues, climate change, environmental justice issues, workforce development crisis, and educational issues. NOEGIC's mission is to equip residents with the knowledge and tools to manage stormwater where it falls, effectively reducing flooding, enhancing community resilience, promoting environmental stewardship, and improving the quality of life for all residents by fostering innovative solutions for stormwater management, and the urban heat island effect.

Jo Banner is the co-founder and co-director of The Descendants Project where she channels her love for Louisiana into protecting her Afro-Creole heritage, descendants of the enslaved who suffer from environmental racism in Louisiana's Cancer Alley, and Louisiana's unique biodiversity. As a Louisiana Cancer Alley resident, Banner champions environmental justice causes and is developing strategies to protect and transform the land into green spaces where communities like hers can thrive. Banner's advocacy has led her to speak before the United Nations (UN). She has now participated in four UN Environment Programme Intergovernmental Negotiating Convenings (INCs) to develop a legally binding treaty to halt plastic and marine pollution as well as speaking before the UN Committee for the Elimination of Racial Discrimination. Banner works with several industries, including entertainment, culture, and heritage, to develop alternative job opportunities for her community. Banner utilizes her degrees in Communications and her management skills to challenge exploitative systems while creating long-lasting pathways of improvement for the health and happiness of her community.

DeeDee M. Bennett Gayle is an associate professor and chair for the Department of Emergency Management and Homeland Security within the College of Emergency Preparedness, Homeland Security, and Cybersecurity at the State University of New York at Albany. She is the lead director of the Extreme Events, Social Equity, and Technology Lab. Her research examines the influence and integration of advanced technologies on the practice of emergency management and for use by vulnerable populations, in particular older adults, people with disabilities, as well as racial and ethnic minorities. Recently, her studies have also focused on workforce development and participation in disaster management fields in the United States. Bennett Gayle secured nearly $2M in research grants and contracts as principal investigator or co-PI, including from the National Science Foundation, the Federal Emergency Management Agency, and the Department of Homeland Security. Employing experimental designs, qualitative one-on-one and focus group interviews, and quantitative survey analysis, her research explores ways to increase disaster preparedness, reduce vulnerability, and shorten recovery. She received her Ph.D. in fire and emergency management from Oklahoma State University. She has a unique academic background, receiving her M.S. in public policy and B.S. in electrical engineering from the Georgia Institute of Technology.

Cassie Cohen is the executive director of Portland Harbor Community Coalition, based in Portland, Oregon. Cohen holds a master of social work from Portland State University, with a concentration in community-based practice, and has over a decade of experience in coalition building with Black, Indigenous, people of color, immigrants, refugees, and asylees, Indigenous/tribal communities, and people experiencing homelessness, focused on addressing relevant environmental justice and health concerns. She has specific significant accomplishments supporting frontline communities to influence agency decision-making processes.

She co-led years-long community engagement processes and successful advocacy efforts to create the Portland Harbor Superfund Site Collaborative Group, an inclusive forum for interested and affected parties to provide input and recommendations to agencies responsible for the cleanup. In addition, she facilitated grassroots involvement in developing a community impact and mitigation plan (CIMP), recognized by EPA Region 10 as a standard-setting model process for development of community-driven CIMPs as part of superfund cleanup processes. Cohen and her coalition lead the development of the currently in-progress cumulative health impacts and resilience plan, driven by frontline community leaders, with support from dozens of public health interagency and academic technical partners. The goal of this group is to envision collective action to achieve an actionable cumulative impact assessment study design and roadmap for resilience investments and interventions.

Jess Conard, M.A. CCC-SLP is a multigenerational resident of East Palestine, Ohio. Conard is a licensed medical speech language pathologist who was launched into grassroots advocacy following the Ohio Train Derailment in February 2023. Conard is a strong advocate for policy implementation and health program resourcing for her community and is leading a national campaign to ban vinyl chloride. Vinyl chloride was the primary hazardous chemical that was purposely drained and burned in her community a few days following the derailment.

Dionne Delli-Gatti is the associate vice president for community engagement with the Environmental Defense Fund and is currently executing an organization-wide effort to implement innovative, scalable, and equitable community engagement strategies with a specific focus on community-driven solutions to reduce the disproportionate and devastating effects of petrochemical operations on frontline communities. With a career spanning over three decades in environmental sustainability, climate policy, and community engagement, Delli-Gatti has experience in the public, private, and advocacy space. She holds an associate arts degree in geology from Sinclair College, a bachelor of arts in environmental geology from Wright State University, and a master of science in environmental science from the University of North Texas. With a career spanning over three decades in environmental sustainability, climate policy, and community engagement, Delli-Gatti has experience in the public, private, and advocacy areas.

Robin Dodson is an exposure scientist at Silent Spring Institute and an adjunct assistant professor at Boston University School of Public Health. Her research focuses on three main areas: development of novel exposure measurements for community-based and epidemiological studies, analysis of environmental exposure data with particular emphasis on semi-volatile organic compounds and interventions aimed at reducing chemical exposures. Dodson investigates environmental exposures of chemicals linked to a range of health outcomes, including asthma, altered neurological and reproductive development, and breast cancer. She recently served as a peer reviewer and dissemination workshop presenter for the National Academies' Why Indoor Chemistry Matters report. Dodson completed her doctorate in environmental health and master in environmental science and risk management at Harvard T.H. Chan School of Public Health.

Jennifer M. Hadayia, is the executive director of Air Alliance Houston, the longest running advocacy nonprofit singularly focused on the public health impacts of air pollution in the Greater Houston Area. She has worked for over 25 years in public health and health equity with state and county health departments and nonprofit organizations in five states and the District of Columbia. Prior to leading Air Alliance Houston, Jennifer was senior staff at Legacy Community Health Services, Inc., the largest Federally Qualified Health Center in the state of Texas, where she ran the public health department. She was also Harris County's first health equity coordinator and developed their first health equity framework, which is still in use today. She was born and raised in Houston, hails from a three-generation Houston Ship Channel family, and is a proud resident of Houston's Near Northside, an environmental justice community inundated by the cumulative impacts of multiple concrete producers and rock crushers, plastics manufacturers, and tailpipe emissions. Hadayia holds an M.P.A. from Columbia University with a concentration in gender and public policy and a B.A.in English from Yale University.

Berneece Herbert is chair of the Department of Urban & Regional Planning at Jackson State University (JSU) in Jackson, Mississippi. She has a doctoral degree in natural resource management and a master in urban and regional planning. Her research areas include urban health indicators, sustainable development, and social equity with specific focus on food security, poverty and hunger, climate change, energy, and public perception. Her technical skills include spatial analysis, vulnerability analysis, and resiliency mapping. Her recent grants have focused on advancing solar energy, green infrastructure, heat mitigation, energy burdens and community empowerment in underserved and underrepresented communities. She has led projects sponsored by agencies such as the Federal Emergency Management Agency, U.S. Digital Service, INROADS, Clean Energy States Alliance, and Jobs to Move America. Her ultimate goal at JSU is to educate and train students to be highly knowledgeable, competent, and innovative thinkers and leaders who will utilize and leverage their knowledge and skills to build healthy, resilient, and sustainable communities. Herbert is a results-oriented and people-centered professional with over 20 years of practice academic, and research experience in higher education and training, community development, strategic planning and management, public-sector investment planning, and policy formulation.

Joseph Kozminski is professor and chair of physics at Lewis University in Romeoville, Illinois, a southwest suburb of Chicago. His current work focuses on examining climate vulnerability factors and expanding air quality monitoring using low-cost sensors in Joliet and the surrounding area in Will Country, Illinois. This area is a supply-chain hub that houses the largest inland container port in North America along with other intermodals, several interstate highways, major rail lines, a ship canal, and an increasing number of warehouses. There are environmental justice communities interspersed throughout this area that are negatively impacted by the traffic, air pollution, loss of green space, and other factors. Kozminski and his students partner with community organizations on this work and on providing community education around air quality and climate vulnerability. Kozminski holds a B.S. in physics and mathematics from the University of Notre Dame and an M.S. and a Ph.D. in physics from Michigan State University.

Alexia Leclercq is a grassroots environmental justice organizer and scholar working with PODER (People Organized in Defense of Earth and her Resources), located in East Austin. She has led dozens of campaigns from pushing for an equitable fossil fuel phase-out at the United Nations (UN) to passing climate legislation, fighting for clean water, addressing aggregate mining pollution, relocating toxic tank farms, and organizing mutual aid. Alexia is also the co-founder of the Colorado River Conservancy and social-environmental justice education nonprofit named Start: Empowerment. Her curriculum has reached over 120,000 students across the United States, and has been featured on Forbes, the Washington Post, and the Guardian. She was awarded the prestigious Brower Youth Award and the 2022 World Wildlife Fund Conservation Award and is the youngest recipient of the Harvard Alumni of Color Conference Award. She served as the 2022 UN Assembly Ambassador and has been a guest lecturer at Harvard, the University of Texas School of Law, University of Connecticut, University of Texas at Austin Dell Medical School, and Princeton University. Leclercq graduated Summa Cum Laude from New York University and Harvard Graduate School of Education.

Stephen H. Linder is a professor in the Department of Management, Policy and Community Health at the School of Public Health of the University of Texas Health Science Center at Houston. He serves as director of the Institute for Health Policy, and co-director of community engagement, Gulf Coast Center for Precision Environmental Research. His current work with county and city health authorities focuses on community-based assessment of health needs and disparities, and on environmental and cumulative risks. His earlier work dealt with public policy design, policy implementation, and environmental policy. His doctorate is in political science with subsequent training in conflict resolution and mediation at the University of Texas School of Law. He is currently a member of the National Academies Board on Environmental Change and Society.

Sophia Longsworth currently works as the toxics policy director at Clean+Healthy, a nonprofit environmental health organization based in Albany, New York. She works on state legislation that advances environmental justice, turns off the tap on toxic chemicals, and ensures protection of the children, wildlife, and the environment. Longsworth is concerned about the air quality in environmental justice communities stemming from decades of legacy pollution from polluting facilities that have intentionally been placed in communities of color and low-income communities. Longsworth is passionate about advocating for populations that have been made vulnerable by the climate crisis, and environmental and social injustices. She hopes to contribute to the improvement of livelihoods through education and policy development. Longsworth is originally from Grenada in the Caribbean and has been living in New York since 2013. She holds a master of public health from St. George's University in Grenada, and master of science in natural resource and environmental management from the University of the West Indies in Barbados.

Andrea Isabel López is a Ph.D. student in the Life Sciences Communication Department at the University of Wisconsin–Madison and a 2021 Civic Science Fellow with Ciencia Puerto Rico. She completed the Margaret E. Mahoney Fellowship with the New York Academy of Medicine and has also worked as a research project coordinator and associate researcher for multiple National Institutes of Health–funded projects based at the Icahn School of Medicine at Mount Sinai and the Albert Einstein College of Medicine. She is a bilingual science communicator and public health researcher with close to 10 years of experience in community-based participatory research, science communication, and project management. López was born in San Juan, Puerto Rico, and is currently based in Madison, Wisconsin. Her work centers on the perspectives of Latine and Puerto Rican audiences and is deeply influenced by the pressing issues facing Puerto Rico, including the legacy of colonialism, the impact of social determinants of health, the increasing frequency of extreme weather events such as hurricanes, and the challenges posed by a precarious energy grid system. She holds an M.P.H. from the City University of New York Graduate School of Public Health and Health Policy.

Beto Lugo Martinez is a grassroots community organizer with fence-line knowledge and expertise rooted in environmental justice and climate justice principles dedicated to improving community health of overburdened communities through a broad range of approaches: environmental health education, community-led participatory research, community-led research, and science. He advocates for community-led solutions at the local, state, and federal levels and continues to educate political officials on how directly and indirectly they perpetuate environmental racism through their policies. Because of his experiences ranging from local to international, Lugo Martinez recognizes how global climate-action table negotiations can be leveraged at the local community level; this can help local community action and change from the bottom up to improve environmental protections and chemical safety and address environmental health hazards. His years of collaboration and knowledge of environmental enforcement, environmental laws, local, state and federal air pollution research, community engagement, and crowdsourcing data make him a trusted community expert in the movement. Lugo Martinez has participated in multimedia enforcement (water, air, soil) and interagency initiatives, as well as workgroups and committees to make policy recommendations that prioritize public health. Through his experiences in developing, implementing, and drafting new and reworking existing policies, he has been able to cultivate skills in analyzing and synthesizing complex policies and practices associated with land use and environmental enforcement, policies that prioritize environmental justice communities. Lugo Martinez is adaptive in high-pressure and politically sensitive situations and has leaned on diplomatic and discrete approaches, as needed, but is also comfortable being an outspoken community activist at local, state, regional, and federal regulatory proceedings, such as public hearings and similar venues. He has experience collaborating with academic institutions and governmental agencies around the nation and has partnered with multiple academic institutions on research-to-action, federally funded National Institute of Environmental Health Sciences research grants. He has co-authored several publications on community led research, and recently co-authored "The Air We Breathe" in the Environmental Health: Foundations for Public Health (Springer, 2024).

Aaron Maruzzo is a researcher at Silent Spring Institute. His research at Silent Spring focuses on toxic chemicals in water, especially in overlooked and marginalized communities. He studies how certain contaminants, such as PFAS chemicals, can impact people's health and the environment. He is interested in the cumulative impacts of chemical and nonchemical stressors on island and coastal communities. Effects from environmental stressors, such as drinking water contamination and climate change, can be magnified in island and coastal communities, but difficult to measure. He is interested in the ways in which we characterize, measure, and report-back these combined effects to support community-based and data-driven action. Maruzzo has previously worked with the Commonwealth Utilities Corporation in Saipan, the Water and Environmental Research Institute in Guam, and the Safer Consumer Products Program at California Department of Toxic Substances Control. He holds a B.A. from Williams College and an M.P.H. in environmental health from the University of California, Berkeley. Maruzzo previously served as a community liaison on a National Academies' panel on PFAS testing and medical monitoring.

Jackie Medcalf is the founder and executive director of Texas Health and Environment Alliance (THEA), a Houston-based nonprofit focused on communities at the intersection of legacy toxic waste sites and climate change. THEA's model is based on the theory that environmental justice can only be achieved when residents have the knowledge to make informed decisions about their health. Using the principles of environmental health literacy, THEA engages community members, provides them with technical analysis of the remediation process and creates opportunities for them to make their voices heard. THEA has used this approach to create a 55,000 member coalition to encourage the EPA to clean up the San Jacinto River Waste Pits Superfund Site, convince the agency to rewrite remediation plans for the Jones Road Ground Water Plume Superfund Site because they were not protective of residents, and launch an investigation resulting in a state determination that part of Houston's historically Black, Indigenous, and People of Color Greater Fifth Ward is a cancer cluster, prompting EPA to require extensive water, soil, and air testing. She holds a bachelor of science in environmental science and geology from the University of Houston–Clear Lake and has studied nonprofit leadership at Rice University.

Antoinette Medina is the Program Manager for the California Rural Indian Health Board, Inc.'s California Tribal Epidemiology Center (CTEC). Medina plays a vital role in CTEC's mission to enhance the health of 109 federally recognized tribes in California by engaging communities in collecting and interpreting health information to establish health priorities, monitoring health status, and developing effective public health services that respect the cultural values and traditions of the communities. As sovereign nations, tribes have the right and responsibility to govern their lands and environment to safeguard them for future generations. As a California tribal citizen herself, Medina is deeply concerned with tribal environmental health issues in California, such as clean air, healthy indoor air quality, food safety, vector-borne and communicable diseases, safe drinking water, fish and wildlife habitats, water contamination, and climate change. She holds a master of public administration and a bachelor of arts in the legal environment of business from the Craig School of Business at California State University, Fresno. Complementing her formal education, Medina has attained public health management, grants management, and conflict resolution certifications. Additionally, she has certifications from the White Bison Wellbriety Training Institute and the Native Wellness Institute.

Esther Min is the director of research at Front and Centered, a diverse and powerful coalition of communities of color–led groups across Washington State, whose missions and work come together at the intersection of equity and environmental and climate justice. She is based in Seattle, Washington and is also affiliated with the University of Washington Department of Environmental and Occupational Health Sciences as clinical faculty. She has worked with frontline communities to create tools and research projects that elevate the importance of documenting and highlighting cumulative impacts on frontline communities. Min received her doctorate at the University of Washington School of Public Health in Environmental and Occupational Hygiene, and her master of public health with emphasis in community health at Touro University California.

Mona Munroe-Younis is founder/executive director of Environmental Transformation Movement of Flint (ETM Flint), a grassroots environmental justice nonprofit in Flint, Michigan. Her work builds on 15+ years of community organizing and partnership development for equitable community investment, including as a City of Flint neighborhood planner, Flint water crisis response liaison between the Flint community and University of Michigan School of Public Health in Ann Arbor, and manager of the University of Michigan Flint Center for Civic Engagement. ETM Flint is sponsoring her participation in this National Academies' committee. Flint residents are deeply concerned about cumulative impacts because of prevalent health impacts and early deaths of residents in predominantly Black, low-income neighborhoods near concentrated industrial activity. While residents have fought industrial encroachment and expansion, all neighboring communities have zoned their heavy industry next to Flint's borders, and the State of Michigan has a long track record of rubber-stamping permits, underscoring the need for national policy to guide state regulations and proactively protect the health of impacted residents. Munroe-Younis has an M.S. in natural resources with concentrations in environmental justice and policy) from University of Michigan in Ann Arbor and a B.S. in environmental science and planning from University of Michigan–Flint.

Valerie I. Nelson is a steering committee member of the Cape Ann Climate Resilience Collaborative, which includes local climate action nonprofit organizations, municipalities, and programs at the Harvard University Graduate School of Design, Massachusetts Institute of Technology, and University of Massachusetts Boston. Since 2020, her studies have focused on extreme storm scenarios, ecological restoration strategies, and cultural and ethnographic studies, including of Gloucester's environmental justice neighborhood. Upcoming research will explore a variety of community engagement approaches, governance structures, climate finance, and gray and green infrastructure. Nelson is an active member of the Cape Ann Climate Coalition, a grassroots advocacy group with a mission to advance climate action. Challenges on Cape Ann, a region north of Boston, include coastal flooding and extreme storms, heat island effects, droughts, lack of trees and green spaces, lead in pipes, and gas leaks. In prior years, Nelson led the Water Alliance, an international network of experts and advocates in 21st Century water management. She has been an active participant in government–community relations in Gloucester and served two terms on the Gloucester City Council. Nelson was an instructor at the Harvard Kennedy School of Government and a visiting assistant professor at the MIT Department of Urban Studies and Planning and holds degrees in economics from Harvard University, London School of Economics, and Yale University. Nelson served on a 1988 National Research Council Committee, Saving Cape Hatteras Lighthouse from the Sea.

Shalmalee Pandit currently works as a program officer at Stanford's Doerr School of Sustainability, Accelerator, where she determines funding priorities in various sustainability areas, designs programs in the aforementioned areas, and defines the scope of these investment theses. As she lives in a water desert, California, Pandit is most interested in how water and water access affect human and planetary health. Prior to this, Pandit worked at a top global consulting firm, completed a Ph.D. focusing on biological solutions for climate and environmental problems, and commercialized her academic research. Pandit received a B.S. in bioengineering and biomedical engineering from University of California, Berkeley and a Ph.D. in biological and biosystems engineering from the Massachusetts Institute of Technology.

Jacob Park is associate professor, Vermont State University (Castleton) and visiting professor, University of Johannesburg, South Africa. He is an interdisciplinary business school/management studies scholar with expertise in corporate environmental management, sustainable finance, energy transition, and climate change and health (with a special focus/interest in heat health in workplace settings). He is particularly interested in climate change–related social equity and community health concerns including food security, flooding, heat health, and financial resilience. Park served as a community liaison group member for the National Academies PFAS study.

Nikita Patil is the co-founder of Aquasaic, where she focuses on increasing clean water access using biological principles. She is working to serve underresourced communities around the country to improve their access to clean water. Her research has focused on finding the long-term impacts of environmental factors such as nutrition on human health and aging. Patil received her B.S. in biomedical engineering from Boston University and her Ph.D. in biomedical engineering from the University of Texas at Austin. She pursued her postdoctoral research in the neuroscience department of the Jean Mayer USDA Human Nutrition Research Center on Aging at Tufts University.

Kan Shao is an associate professor of environmental and occupational health at Indiana University (IU) School of Public Health–Bloomington, where he primarily works on human health risk assessment research and education. Prior to joining IU, he served as a postdoctoral fellow at the National Center for Environmental Assessment at t EPA. Shao's research primarily focuses on advancing computational and modeling methods to support chemical risk assessment in the face of uncertainty. His major contributions to the field of quantitative chemical risk assessment include the development of the benchmark dose methodology, Bayesian approaches to quantify various sources of uncertainties in dose-response assessment, and a modeling framework to quantitatively integrate mechanistic information. He has received more than $3 million in external grants from the National Institutes of Health to support his research projects in computational toxicology. Shao is now an associate editor of the journal Drug and Chemical Toxicology and served as a reviewer for a few high-profile risk assessment reports, including the National Research Council's Review of U.S. EPA's ORD Staff Handbook for Developing IRIS Assessments: 2020 Version. He holds dual Ph.D.s in civil and environmental engineering and engineering and public policy and an M.S. in machine learning, all from Carnegie Mellon University.

Shereyl Snider is a community organizer with the East Trenton Collaborative and a lead advocate with Lead-Free NJ. Organizations that are helping to sponsor and support the East Trenton Collaborative endeavors are Rutgers Environmental and Occupational Health Sciences Institute, Funds for NJ, and Lead-Free NJ. Snider's focus is on reducing lead exposure in the city of Trenton and providing early testing for children. She began working as a community organizer in 2019, organizing with the East Trenton neighborhood on environmental and traffic safety issues, and in 2021 began working with Lead-Free NJ on advocating for lead testing for children and reducing lead exposure. The issues of concern facing her environmental justice community are the same issues that are affecting many low-income, Black, and Latinx communities. Some of the biggest burdens her community is facing are exposures to lead toxins in water, paint, soil, and dust, causing learning and behavioral issues and producing asthma, high crime, autistic children, and anemia, to name just a few. Snider received a B.A. in liberal studies with a concentration in social justice and history from William Paterson University.

Orly Stampfer is an indoor air quality epidemiologist in the Climate and Health Section at the Washington State Department of Health. Stampfer's current role includes responding to community air quality concerns and developing indoor and outdoor air quality guidance, especially related to wildfire smoke and the use of low-cost air sensors. Their graduate research on air quality and low-cost air sensors was rooted in community and tribal engagement. Stampfer has also been a consultant for Tribal Healthy Homes Network and Front and Centered. Stampfer received an M.P.H. and a Ph.D. in environmental health from the University of Washington Department of Environmental and Occupational Health Sciences.

Raymond Sweet is a climate coordinator based in New Orleans, Louisiana, with a dedicated focus on the Hollygrove-Dixon neighborhood. His primary efforts are concentrated on community engagement to address issues such as the urban heat island effect, extreme weather events, and increased rainfall. Raymond plays a crucial role in educating the community through seminars on nature-based solutions and overseeing green infrastructure installation projects. Beyond his professional duties, Sweet is deeply involved in volunteer work. He has a background as a CASA advocate and continued into a staff role as a volunteer recruiter by recruiting new advocates to support children in foster care. His commitment to social issues extends to organizing efforts for safe housing with the Renter's Rights' Assembly, addressing the needs of the unhoused population. Additionally, Sweet mentors young boys through the Son of a Saint program, contributing to child welfare and development. A native of Tampa, Florida, Raymond brings personal experience with similar environmental and social challenges to his work in New Orleans. He is an active member of the Water Wise Gulf South collective, a network of community-based organizations that collaborates to secure funding and implement solutions for their neighborhoods and the broader city. Raymond also serves on a five-member panel that discusses and develops policies around nature-based stormwater management practices. Currently, Sweet is a member of the Climate Communities Network, where he continues to contribute his expertise and passion for sustainable community development.

Shirlee Tan is the Senior Toxicologist for the Seattle and King County Public Health Department where she serves as a technical advisor for the department on issues related to chemical exposures, impacts, and policies. She works directly with communities and individuals to address ways to reduce chemical exposures and effects. Tan serves on numerous advisory groups for Washington State, focused on chemical policy on and regulation of chemical use, toxics cleanup, and environmental justice. She chairs the EPA's Children's Health Protection Advisory Committee. Tan previously worked for the Organization for Economic Cooperation and Development and EPA on the development of regulatory assays for endocrine-disrupting chemicals, with a particular focus on thyroid and in vitro assays. She also worked for the Smithsonian Institution's National Zoological Park on pesticide misuse in Southeast Asia. Tan holds a Ph.D. in cellular and molecular biology from the University of San Diego and conducted her postdoctoral research studying dopaminergic receptors and neurodegenerative pathways. Tan participated in previous National Academies' workshops on new approach methods and developmental neurotoxicity and children's environmental health.

P. Grace Tee Lewis is a senior health scientist at the Environmental Defense Fund and a visiting scientist in the Program for Population and Environmental Health Disparities in the Center for Precision Environmental Health at Baylor College of Medicine. Tee Lewis leads the Environmental Defense Fund's Data to Action work in Houston, Texas. She provides scientific expertise and guidance to community-based organizations and leaders to build climate/environmental justice capacity and to implement community science efforts. This includes health impacts of criteria and hazardous air pollutants, particularly to environmental justice communities. She also focuses on community exposures from petrochemical facilities and transportation sectors and on strategies to improve regional air quality and public health. In collaboration with Texas A&M University, she also led a multidisciplinary team of community advocates and scientists in development of a national-scale environmental justice screening and mapping tool to identify disadvantaged communities and understand drivers leading to neighborhood-level cumulative vulnerability. She received her Ph.D. from the University of Texas at Houston Health Science Center, School of Public Health in Epidemiology with minors in environmental science and biostatistics.

Inyang Uwak is the research and policy director for Air Alliance Houston (AAH), an environmental justice nonprofit based in Houston, Texas, dedicated to reducing the public health impacts of air pollution through research, education, and advocacy. She has over a decade of experience in air quality epidemiology, human health risk assessment, and environmental health. Some of her work with AAH involves monitoring air quality trends (particularly in fence-line communities), synthesizing the impacts of the data, and then conveying the data or science in understandable and actionable ways to various community stakeholder audiences. She has contributed to written and verbal public comments and policy papers in response to proposed legislation or policy affecting air quality, permit applications, regulations, and enforcement. Uwak has a doctorate in epidemiology and environmental health (Dr.P.H.) from Texas A&M University School of Public Health, a master's in public health (M.P.H.) from the Johns Hopkins Bloomberg School of Public Health, and a medical degree (M.D.) from the University of Calabar College of Medicine.

Elizabeth Vásquez is an associate professor in the Department of Epidemiology and Biostatistics at the University at Albany School of Public Health and the director of the Center for Elimination of Minority Health Disparities. Vásquez's National Institutes of Health–funded research aims to address health inequities beyond individual-level indicators to those that consider the role of social context and place (e.g., neighborhoods, climate) and their contributions to differential health outcomes. This line of work has significant implications on three primary areas in the field of gerontology: (1) evaluation of the effect of specific social and health behaviors on quality of life and health outcomes among racial and ethnically diverse older adults; (2) racial and ethnic differences among risk factors associated with progression of disability, and (3) early-life social disparities. In addition, Vásquez is a fellow with the Sustained Training in Aging and HIV Research program and an affiliated investigator with the Study of Latinos (SOL). She is an alumna of Programs to Increase Diversity Among Individuals Engaged in Health-Related Research, the National Institute of Aging Butler-Williams Scholars Program, and the Hispanic Leadership Institute.

Lily Wu works at California Environmental Protection Agency's Office of Environmental Health Hazard Assessment as a community air protection toxicologist. She has over a decade of experience doing health risk assessments of chemicals for reproductive toxicity. Her work in the last 4 years has engaged several overburdened communities in California's Bay Area, Central Valley, and Salton Sea regions as the state's primary community air protection toxicologist. Her responsibilities include assessing health benefits of community emission reduction plans, and consideration of cumulative exposures of multiple chemical and nonchemical stressors in addressing communities' disparate health outcomes. Wu has extensive work experience and expertise in human health risk assessment, cumulative impact assessment, exposome, and community engagement. She serves as a technical expert on several academic, community, and federal advisory committees, ranging in topics from health equity, pesticides, and environmental justice science. Wu received a B.S. in animal sciences from the University of Illinois, Urbana-Champaign, and a Ph.D. in molecular, cellular, and integrative physiology with a designated emphasis in reproductive biology from the University of California, Davis.

Naomi Yoder is a GIS Data Manager and researcher with the Bullard Center for Environmental and Climate Justice at Texas Southern University, a historically Black university in Houston. Although Yoder's research focuses on geospatial analysis for environmental and justice issues, they have worked as a researcher and science communicator for Gulf Coast environmental policy, advocacy, and justice for six years. Their career has involved studying and communicating about environmental issues for over 20 years. Yoder lives and works in Houston, Texas, and having lived before in New Orleans, Louisiana, they have a keen familiarity with environmental issues in these two "petrochemical states." The Bullard Center's mission is to promote justice—environmental, climate, economic, energy, transportation, food and water, and health justice—and eliminate structural inequality and systemic racism. This is accomplished through interactions with communities where environmental and climate injustice is most pronounced. Civic engagement and advocacy form the core of the Bullard Center's work and thus inform Yoder's contributions. They hold two masters of science degrees, one in marine science (biological oceanography) from University of Southern Mississippi, and one in geography (biodiversity, conservation, and management) from the University of Oxford.

Appendix C
Public Meeting Agendas

MEETING 2:
STATE-OF-THE-SCIENCE AND THE FUTURE OF CUMULATIVE IMPACT ASSESSMENT

Monday, July 22, 2024 (all times listed in ET)

9–10:30 am	**Closed Session**
10:30 am–4 pm	**Open Session**
10:30 am	**Welcome and Introductions** **Kate Z. Guyton**, National Academies Responsible Staff Officer **Weihsueh A. Chiu,** Committee Chair
11 am	**Sponsor Presentation and Committee Q&A** **Alexa S. Dietrich**, Senior Scientist, EPA Office of Research and Development **H. Christopher Frey**, Assistant Administrator for Research and Development; Agency Science Advisor, EPA **Andrew Geller**, Senior Science Advisor; Executive Lead for Environmental Justice; Lead Research, EPA Office of Research and Development **Maureen Gwinn**, Principal Deputy Assistant Administrator for Research and Development; Chief Scientist, EPA **Susan Julius**, Assistant Center Director, Center for Public Health and Environmental Assessment, EPA **Charles Lee**, Senior Policy Advisor for Environmental Justice, Office of Environmental Justice and External Civil Rights, EPA **Sarah Mazur**, Principal Associate National Program Director for the Sustainable and Healthy Communities Research Program, EPA Office of Research and Development **Sean J. Paul**, Special Advisor to the Assistant Administrator for Research and Development, EPA **Louie Rivers**, Senior Social Science Advisor, EPA **Nicolle S. Tulve**, Research Physical Scientist, EPA Office of Research and Development
12:45 pm	**Break**
2–3:30 pm	**Engagement with Community and Tribal Liaison Group**
3:30 pm	**Opportunity for Public Comment** *(Each commenter must register in advance and will have up to 5 minutes to comment. Preference will be given to one speaker per organization.)*
4 pm	**End of Open Session**

4–5:30 pm **Closed Session**

Tuesday, July 23, 2024 (all times listed in ET)

9:00 am–1:00 pm **Closed Session**

STATE-OF-THE-SCIENCE AND THE FUTURE OF CUMULATIVE IMPACT ASSESSMENT: WORKSHOP 1
October 15, 2024

12:00–12:45 pm **Keynote Presentation**
Janet Currie, Princeton University (NAS, NAM)
Panel discussion with committee members:
Cris Liban, Rachel Morello-Frosch, David Slusky

12:45–1:30 pm **SESSION 1: What are the key concepts relevant to cumulative impacts?**
Presentations (prerecorded, available on event page):

- What is cumulative impact assessment?
  Na'Taki Osborne Jelks, Spelman College
- Regulatory policy basis of cumulative impact assessment
  William Boyd, University of California, Los Angeles
  Tracey Woodruff, University of California, San Francisco
- An exposome approach to understanding disparities in risk trajectories to chronic disease outcomes across the life course
  Darryl B. Hood, Ohio State University

Panel Discussion:

- **Shirlee Tan**, Seattle and King County Public Health Department (community liaison);
- **Session 1 Presenters;** and
- **Julia Brody and Jon Levy** (committee moderators)

1:30–1:45 pm **Break**

1:45–2:30 pm **SESSION 2: What is known about the combined impacts of the built, natural, and social environments and their interactions on health and community well-being?**
Presentations (prerecorded, available on event page):

- Combined impacts of pollutants, climate, the social environment, and other factors on community health
  Joan Casey, University of Washington
- Vulnerability, resilience, and capacities to respond to environmental impacts
  Christopher Emrich, University of Central Florida
  Opportunities for promoting health and community well-being
  Denise Dillard, Washington State University
- Salutogenesis
  Sacoby Wilson, University of Maryland

Panel Discussion:
- **Elizabeth Vasquez**, State University of New York (community liaison);
- **Session 2 Presenters;** and
- **Zhen Cong and Jerreed Ivanich** (committee moderators)

2:30–2:45 pm **Break**

2:45–3:30 pm **SESSION 3: What methods and approaches are available for collecting and integrating quantitative and qualitative data across different domains, levels, and scales in cumulative impact assessment?**

Presentations (prerecorded, available on event page):
- The role of geospatial models in representing and addressing cumulative impacts
  Marcos Luna, Salem State University
- Available models to combine cumulative impacts across domains
  Bill Rish, ToxStrategies
- Multicriteria decision analysis
  Ben Trump, U.S. Army Corps of Engineers
- Integration of environmental, health, and government administrative data
  Reed Walker, University of California, Berkeley

Panel Discussion:
- **Berneece Herbert**, Jackson State University (community liaison);
- **Session 3 Presenters**; and
- **Andrew Dannenberg and Rima Habre** (committee moderators)

3:30–4:00 pm **Public Comment Period**
Advance registration required and comment time is limited to 3 minutes

4:00 pm ET **Workshop Adjourns**

STATE-OF-THE-SCIENCE AND THE FUTURE OF CUMULATIVE IMPACT ASSESSMENT: MEETING 6
October 22, 2024

2:00–3:30 pm **Open Session**

2:00–3:00 pm **Panel Discussion**
Sandra Baird, Chief, Toxicology Division, Office of Research and Standards, Massachusetts Department of Environmental Protection
Sabine Lange, Chief, Toxicology, Risk Assessment, and Research Division, Texas Commission on Environmental Quality
Nicky Sheats, Director, Center for the Urban Environment, John S. Watson Institute for Urban Policy and Research, Kean University
Meredith Williams, Director, California Department of Toxic Substances Control (through September 2024)

Ann Wolverton, Senior Research Economist, National Center for Environmental Economics, U.S. Environmental Protection Agency
Zhen Cong and **Kristen Malecki** (committee moderators)

3:00–3:30 pm	**Public Comment Period** Advance registration required and comment time is limited to 3 minutes
3:30 pm	**End of Open Session**
3:30–5:00 pm	**Closed Session**

STATE-OF-THE-SCIENCE AND THE FUTURE OF CUMULATIVE IMPACT ASSESSMENT: WORKSHOP IN LOUISIANA
November 20, 2024

Meeting Overview

This 1-day workshop will center on in-person conversations between local community members and the National Academies ad hoc committee on State-of-the-Science and the Future of Cumulative Impact Assessment. Organized with input from the committee's Community and Tribal Liaison Group, the workshop aims to elevate perspectives and local knowledge from community members in the River Parishes and Greater New Orleans area.

The meeting will be livestreamed via the event webpage.

Public comments will be received in writing via the SLIDO widget on the event webpage.

Wednesday, November 20, 2024 (all times in CT)

10:00 am–4:00 pm	**Open Session**
10:00–10:45 am	**Introductions and Orientation**
10:45 am–12 pm	**World café exercise 1: Stressors that impact health and well being**
12:00–12:45 pm	**Working Lunch**
12:45–1:30 pm	**World café exercise 1: Report-outs**
1:30–2:45 pm	**World café exercise 2: Future vision of cumulative impact assessment**
2:45–3:00 pm	**Break**
3:00–3:45 pm	**World café exercise 2: Report-outs**
4:00 pm	**End of Open Session** **ADJOURN**

STATE-OF-THE-SCIENCE AND THE FUTURE OF CUMULATIVE IMPACT ASSESSMENT: LIAISON TOWN HALL
December 12, 2024

Meeting Overview

This fully virtual Town Hall will center on conversations between the ad hoc committee on State-of-the-Science and the Future of Cumulative Impact Assessment and members of the committee's Community and Tribal Liaison Group on key crosscutting themes pertinent to cumulative impact assessment. This Town Hall aims to amplify community voices by inviting members to share their lived experiences on topics relevant to the committee's charge.

The Town Hall will be livestreamed on the event webpage, where public comments will be received in writing via the SLIDO widget.

Thursday, December 12, 2024 (all times in ET)

12–4:00 pm	**Open Session**
12–12:15 pm	**Introductions and Orientation**
12:15–1:15 pm	**World café exercise 1: Stressors that impact health and well-being**
1:15–1:30 pm	**Break**
1:30–2:00 pm	**World café exercise 1: Report-outs**
2:00–3:00 pm	**World café exercise 2: Future vision of cumulative impact assessment**
3:00–3:15 pm	**Break**
3:15–3:55 pm	**World café exercise 2: Report-outs**
4:00 pm	**End of Open Session** **ADJOURN**

STATE-OF-THE-SCIENCE AND THE FUTURE OF CUMULATIVE IMPACT ASSESSMENT: MEETING 10
February 11, 2025 (Closed Session)
February 12, 2025 (Open Session)

Meeting Overview

This tenth committee meeting will include closed and open sessions.

The closed session on February 11, 1–6 pm MT, will be utilized to discuss the committee's approach to the statement of task and to prepare for the open public meeting.

The open session, February 12, 2025, 10 am–4 pm MT, will center on conversations between the ad hoc committee on State-of-the-Science and the Future of Cumulative Impact Assessment with local tribal members and representatives on key crosscutting themes pertinent to cumulative impact assessment. Organized with input from the committee's community and tribal liaison group, the open session aims to amplify tribal voices by inviting members to share their lived experiences on topics relevant to the committee's charge. Two small-group exercises will be organized to (1) learn about the stressors that impact community members and (2) explore a future vision of improved community health and well-being. This public meeting will be livestreamed on the event webpage, where public comments will be received in writing via the SLIDO widget.

Tuesday, February 11, 2025 (all times in MT)

1–6 pm	**Closed Session**

Wednesday, February 12, 2025 (all times in MT)

10 am–4 pm	**Open Session**
10–10:45 am	**Introductions and welcome**
10:45 am–noon	**World café exercise 1: Stressors that impact health and well-being**
Noon–12:45 pm	**Working lunch break**
12:45–1:30 pm	**World café exercise 1: Report-outs**
1:30–2:45 pm	**World café exercise 2: Future vision of cumulative impact assessment**
2:45–3:00 pm	**Working Coffee Break**
3:00–3:45 pm	**World café exercise 2: Report-outs**
4:00 pm	**ADJOURN**

Appendix D
Consideration of Cumulative Impacts and Risk in National Academies Reports

Report Title, Sponsor, and Year of Release	Overview of Committee Charge	Committee Advice Relevant to Cumulative Impact or Risk Assessment	Definition or Use of Cumulative Impacts or Cumulative Risk	Link to Report
Constructing Valid Geospatial Tools for Environmental Justice Sponsor: Bezos Earth Fund Year: 2024	"Consider how environmental health and geospatial data and approaches were built into various environmental screening tools to identify disadvantaged communities." (pp. 16-17) "Consider how data at a variety of scales and resolution may be integrated and analyzed and to make recommendations for an overall data strategy for CEQ in the development of future versions of CEJST or other tools." (p. 17)	"Designate communities as disadvantaged based on cumulative impact scoring approaches that are informed by the state of science; the knowledge, needs, and experiences of agencies, tool developers, and users; and validation efforts conducted in partnership with affected communities. Choose an approach to represent cumulative impacts, such as threshold approaches (e.g., summing thresholds or categories exceeded) or aggregation-based approaches for composite indicator construction." (p. 8) The committee provides detailed advice on many aspects of geospatial tools used to characterize cumulative impact for the purpose of identifying and describing overly burdened communities.	"Cumulative impacts (also called cumulative burdens) are the combined total burden from stressors, their interactions, and the environment that affects the health, well-being, and quality of life of an individual, community, or population." (p. 2)	https://nap.nationalacademies.org/catalog/27317/constructing-valid-geospatial-tools-for-environmental-justice
Compounding Disasters in Gulf Coast Communities 2020–2021: Impacts, Findings, and Lessons Learned Sponsor: National Academies Gulf Research Program Year: 2024	Examine the unique characteristics and effects of the 2020–2021 compounding disasters in the Gulf of Mexico region, and examine how to manage and minimize the effects of these disasters on those who live and work in the region	Impacts expressed as "Compounding disaster risk", with "disaster risk" "a product of hazard, exposure, and vulnerability variables and understood as the potential for loss of life, injury, physical damage or destruction resulting from the occurrence of one or more disruptive events in a given period." (p. 25) Instead of assessment, advice was directed toward reducing compounding disaster risk by addressing vulnerabilities and exposure and building adaptive capacities.	"Cumulative impact" was used once (p. 55): "Many residents, disproportionately communities of color and with low socioeconomic status live close to these and other high-risk chemical facilities, including transport facilities and/or carcinogen-laden hazardous waste (Superfund) sites. Many of these communities have been overburdened by the environmental harms and risks from exposure, cumulative impacts, disproportionate health impacts, and greater vulnerability to pollution for ..."	https://nap.nationalacademies.org/catalog/27170/compounding-disasters-in-gulf-coast-communities-2020-2021-impacts-findings
Transforming EPA Science to Meet Today's and Tomorrow's Challenges Sponsor: EPA Office of Research and Development (ORD) Year: 2023	"Identify emerging scientific and technological advances from across a broad range of disciplines that ORD should consider in its research planning ..." (p. 1) Recommend how ORD might incorporate those advances into its research and development enterprise.	"Fundamental to the consideration of cumulative impacts is the need to incorporate structural factors into environmental health research and risk assessments, using multi-disciplinary and holistic scientific methods. . . . Some of the advanced tools and methods that could be used ... include: Exposure sensors for multiple stressors ...; Geospatial tools/analysis to link multiple place-based stressors and sources of exposure, including quantification of social stressors; Development and assessment of alternative metrics of exposure that cannot be measured directly or holistically characterized (e.g., proximity);	"Cumulative risk refers to the combined risks from aggregate exposures to multiple stressors." (p. 2) Use of cumulative impact: "The cumulative impacts of human activities, including chemical, physical, and biological stressors, are resulting in ubiquitous threats to human health and in massive declines in biodiversity and planetary sustainability" (p. 30)	https://nap.nationalacademies.org/catalog/26602/transforming-epa-science-to-meet-todays-and-tomorrows-challenges

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		Artificial intelligence and machine learning tools combined with extensive exposure testing across different stressors and concentrations to examine real-world risks from multiple stressors; Nontargeted analysis of chemicals linked to biomarkers of exposure and health outcomes; Exposure modeling; and Genetic and epigenetic analysis to understand exposure and effect biomarkers of toxicity." (p. 36)		
Children's Environmental Health: Proceedings of a Workshop Sponsor: EPA Year: 2023	"… organize and convene a public workshop to discuss the state of science and knowledge about children's environmental health." (p. 3)	Not a committee consensus study, but a workshop proceeding.	"Cumulative risk assessment," although not defined, was used throughout. Several speakers stressed importance of nonchemical stressors.	https://nap.nationalacademies.org/catalog/26848/childrens-environmental-health-proceedings-of-a-workshop
Health Risk Considerations for the Use of Unencapsulated Steel Slag Sponsor: EPA Year: 2023	"… conduct a review of existing information and analyses related to electric arc furnace (EAF) slag and assess human health risks associated with the unencapsulated use of EAF slag." (p. 9) The committee focused on residential exposure.	"Inequitable cumulative exposures to multiple stressors (chemical and nonchemical) in those communities can exacerbate health risks associated with exposure to slag components. Important considerations include the following: • How racism influences cumulative exposures as part of cumulative risk, particularly with a lens toward health equity; • Role of historical factors and practices that impact community exposures; and • Structural racism, social determinants of health, and occupational exposures. (p. 71)	Cumulative risk or impact is not defined. It is discussed in the context of redlining: "Psychosocial stressors as a result of these land-use decisions combined with varied environmental stressors heighten the cumulative risk for adverse health impacts." (p. 68)	https://nap.nationalacademies.org/catalog/26881/health-risk-considerations-for-the-use-of-unencapsulated-steel-slag
The Potential Impacts of Gold Mining in Virginia Sponsor: Virginia Department of Energy Year: 2023	"Evaluate the impacts of gold mining in Virginia, with an emphasis on potential impacts of gold mining on public health, safety, and welfare." (p. 20)	"Robust analyses of the potential impacts of mining consider cumulative health risks. Human populations are exposed to multiple hazard types, including biological, physical, chemical, psychological, and social .... These hazards can occur through different exposure settings ... and multiple media ... These multiple, sometimes synergistic, stressors can lead to asymmetric impacts within and between communities, and historically underresourced and underrepresented populations are often most affected.	"Cumulative risk" is implicitly defined on page 5 using the language in the previous column. Cumulative impact is mentioned once in the context of NEPA requirements, on p. 118. A discussion of cumulative risk assessment, including technical challenges, appears on pp. 109-111.	https://nap.nationalacademies.org/catalog/26643/the-potential-impacts-of-gold-mining-in-virginia

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		To minimize impacts to human health and the environment, the Virginia General Assembly and state agencies should ensure that robust site- and project-specific analyses of impacts are completed prior to the permitting of a gold mining project." (p. 5)		
Building Confidence in New Evidence Streams for Human Health Risk Assessment: Lessons Learned from Laboratory Mammalian Toxicity Tests Sponsor: EPA Year: 2023	"… review of the variability and relevance of existing laboratory mammalian toxicity tests for human health risk assessment to inform the development of approaches for validation and establishing scientific confidence in using New Approach Methods (NAMs), and recommendations on expectations associated with NAMs when they cannot be compared with human studies." (p. 15)	The committee noted "consistent with a recommendation in the 2008 *Phthalates and Cumulative Risk Assessment* report ..., *Science and Decisions: Advancing Risk Assessment* (NRC, 2009) recommended that cumulative risk assessments should move away from the narrow focus on a 'common mechanism of action' and broaden to encompass stressors that have the same or similar health outcomes." (p. 25) The 2023 committee declined to provide advice and stated that the earlier committee "recommendation was generally in the context of human epidemiologic or experimental animal studies, and the implications for moving toward an in vitro approach as suggested by NRC (2007) was not addressed." (p. 25)	Discussed but did not define "cumulative risk" (e.g., p. 25): "Furthermore, in its discussion of cumulative risk, *Science and Decisions: Advancing Risk Assessment* recommended that the EPA also account for nonchemical stressors, vulnerability from other chemical exposures, background risk factors, and their interactions with chemical stressors. The 2009 report and more recent articles identify multiple intrinsic (or biological) factors (e.g., genetics, preexisting or underlying health conditions) and life stage (e.g., developmental) and extrinsic factors (e.g., nutritional status, built environment, psychosocial stressors due to factors such as poverty, job stress, and discrimination) that can increase susceptibility to chemical exposures."	https://nap.nationalacademies.org/catalog/26906/building-confidence-in-new-evidence-streams-for-human-health-risk-assessment
An Approach for Assessing U.S. Gulf Coast Ecosystem Restoration: A Gulf Research Program Environmental Monitoring Report Sponsor: National Academies Gulf Research Program Year: 2022	"To assess the cumulative effects of multiple restoration projects [following the *Deepwater Horizon* disaster] along the U.S. Gulf of Mexico coast in the context of long-term environmental trends; to consider effects of acute events and long-term environmental changes; to discuss synergistic and antagonistic effects of multidecadal restoration activities; and to recommend adaptive management strategies to address these factors." (p. 1)	Ecosystem domain. "Enhanced, consistent, and sustained long-term monitoring, analysis, synthesis, and reporting of environmental trends and indicators are urgently needed to enable the detection and tracking of cumulative effects of multiple restoration projects. Monitoring efforts should focus on developing the lines of evidence to support the assessment of cumulative effects at estuarine, regional, and larger scales." (p. 7)	"Assessment of cumulative impacts—additive, synergistic, and possibly antagonistic effects—of multiple restoration projects of similar or diverse nature over spatial and temporal scales beyond that of an individual project are uncommon in the GoM [Gulf of Mexico]." (p. 113) The term "cumulative risk" does not appear in the report.	https://nap.nationalacademies.org/catalog/26335/an-approach-for-assessing-us-gulf-coast-ecosystem-restoration-a
Toward a Future of Environmental Health Sciences: Proceedings of a Workshop–in Brief Sponsor: NIEHS Year: 2022	Workshop organized by the National Academies Standing Committee on the Use of Emerging Science for Environmental Health Decisions, which examines issues regarding the	Not a committee consensus study, but a workshop proceeding. (General thoughts were expressed by speakers about use of omics data to assess cumulative risk. One speaker raised the possibility of combining qualitative data with exposome measurements.)	References one speaker "defining cumulative impacts as the combined effects of multiple pollutants, usually from multiple sources, as they interact with social and other factors in the community." (p. 3)	https://nap.nationalacademies.org/catalog/26639/toward-a-future-of-environmental-health-sciences-proceedings-of-a

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	use of new science, tools, and research methodologies for environmental health decisions and informs government agencies on emerging issues and science in environmental health.		Cumulative impacts were discussed in the environmental justice context.	
A Class Approach to Hazard Assessment of Organohalogen Flame Retardants Sponsor: Department of Health and Human Services Year: 2019	Develop a scientifically based scoping plan to assess additive, nonpolymeric organohalogen flame retardants as a class for potential chronic health hazards under the Federal Hazardous Substances Act, including cancer, birth defects, and gene mutations.	The committee noted "An approach that addresses one chemical at a time does not consider cumulative risks that might be posed by exposure to multiple chemicals that act via a similar mechanism or that perturb the same biologic system. The report *Phthalates and Cumulative Risk Assessment: The Tasks Ahead* (NRC 2008) included the caution that 'phthalates may not all act by the same mechanisms, and they do not have parallel dose–response curves. However, those facts do not negate the appropriateness of using general dose- addition methods in a cumulative risk assessment' (p. 9). The concern expressed by the committee that wrote that report applies to other classes of chemicals if chemicals in those classes have similar activity in biologic systems." (p. 6)	Discussed cumulative risk assessment in the context of chemical categories "And EPA assessed the cumulative risk associated with the class of cholinesterase-inhibiting pesticides ... and then developed a framework and guidance document for cumulative risk evaluations of pesticide classes...." (p. 9) "Considering the cumulative risk associated with multiple subclasses could also provide a basis for determinations related to the entire class." (p.18) Report also discusses the combined effects of multiple chemical stressors (p. 6). Report does not discuss nonchemical stressors or cumulative impacts.	https://nap.nationalacademies.org/catalog/25412/a-class-approach-to-hazard-assessment-of-organohalogen-flame-retardants
Leveraging Artificial Intelligence and Machine Learning to Advance Environmental Health Research and Decisions: Proceedings of a Workshop—in Brief Sponsor: NIEHS Year: 2019	Workshop organized by the National Academies Standing Committee on the Use of Emerging Science for Environmental Health Decisions, which examines issues regarding the use of new science, tools, and research methodologies for environmental health decisions and informs government agencies on emerging issues and science in environmental health.	Not a committee consensus study, but a workshop proceeding. (One speaker as an example of use of AI in environmental health discussed an attempt to "use machine learning to develop a cumulative environmental risk score that goes beyond standard linear models." (p. 2)	Only one use of the word "cumulative" in the proceedings. See previous column.	https://nap.nationalacademies.org/catalog/25520/leveraging-artificial-intelligence-and-machine-learning-to-advance-environmental-health-research-and-decisions
Vibrant and Healthy Kids: Aligning Science, Practice, and Policy to Advance Health Equity Sponsor: Robert Wood Johnson Foundation Year: 2019	Provide an overview of stressors that affect prenatal through early childhood development and health; identify promising models and opportunities for translation of the science to action; identify outcome measures to enable subgroup analyses; develop a roadmap to apply the science to tailored	"Recognize the impact of both adverse and enriching experiences across the life course and cumulative effects on health and well-being." (p. 367) "Health equity is conceptualized as a probabilistic challenge, with a person's overall odds of good health as a cumulative function of probabilities." (p. 566)	Key message: "Over time, biological and social-psychological development interact to shape the way health develops over the life course. Neither is deterministic—health outcomes are never set in stone. Rather, they are probabilistic—together, they cumulatively 'set the odds' for good health." (p. 27)	https://nap.nationalacademies.org/catalog/25466/vibrant-and-healthy-kids-aligning-science-practice-and-policy-to

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	interventions (based on biological, social, environmental, economic, and cultural needs; and provide recommendations in these areas, including how systems can better align to advance health equity.	"studies using cumulative risk scores typically do not consider the sequential timing or intensity of risk factors and are limited by the assumption that each type of risk is equally weighted and additive." (p. 203)	"'cumulative life adversity' includes experiences of parents through their life course.' (p. 68) "The chapter summarizes the evidence for the way multiple domains (family cohesion and healthy social connections; health care; healthy living conditions including economic security, and nutrition and food security; neighborhood conditions, housing, and environmental safety; early care and education) converge to create an accumulation of risk. This composite risk is heavily influenced by racism and discrimination and affects outcomes across a child's entire life course." (p. 143)	
Approaches to Understanding the Cumulative Effects of Stressors on Marine Mammals Sponsors: U.S. Navy, Department of the Interior, NOAA, U.S. Marine Mammal Commission Year: 2017	Review the present scientific understanding of cumulative effects of anthropogenic stressors on marine mammals with a focus on anthropogenic sound. The committee will assess current methodologies used for evaluating cumulative effects and identify new approaches that could improve these assessments.	"Cumulative risk from exposure to multiple stressors cannot be predicted based on existing scientific theory and data for individual marine mammals or their populations. The Committee developed a Population Consequences of Multiple Stressors ... model to provide a conceptual framework for... assessing the risks associated with aggregate exposures to one kind of stressor, such as sound, and the cumulative exposure associated with sound and other stressors. . . . the concept of interaction webs was introduced." (pp. 1-2) The assumption of additivity is often wrong (p.5) The committee provided a decision tree for "identifying situations where studies of the possible interactions between stressors should be given a high priority when considering the effect of a focal stressor on a population." (p. 52)	The report defined "cumulative risk as the combined risk from exposures to multiple stressors integrated over a defined relevant period: a day, season, year, or lifetime." (p. 1) "NEPA [National Environmental Policy Act] regulations require agencies to include in each EIS [environmental impact statement] an evaluation of direct, indirect, and cumulative impacts associated with the action and proposed alternatives. Cumulative impact is defined for these purposes as 'the impact on the environment which results from the incremental impact of the action when added to the other past, present, and reasonably foreseeable future actions regardless of what agency (federal or non-federal) or person undertakes such other actions." (p. 12) Stressors are "defined by how they influence an individual animal" (p. 2), ecological drivers affect "multiple components of an ecosystem ... by changing exposure to a suite of extrinsic stressors." (p. 2)	https://nap.nationalacademies.org/catalog/23479/approache s-to-understanding-the-cumulative-effects-of-stressors-on-marine-mammals

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Using 21st Century Science to Improve Risk-Related Evaluations Sponsors: EPA, FDA, NIEHS, National Center for Advancing Translational Sciences Year: 2017	Provide recommendations on integrating new scientific approaches into risk-based evaluations.	The sufficient-component-cause model of Rothman (1976) and Rothman and Greenland (2005) can be used to consider the multiple factors that can combine to cause disease in an individual or population. (Ch. 7) The report then provides advice on identifying components, mechanisms and pathways that contribute to overall disease. (pp. 118-120). "The substantial advances in analytical chemistry noted in this report are producing more complete data on the extent of cumulative exposure to chemicals." (p. 38) The report proceeds to discuss the advances.	The term "cumulative risk assessment" is used but is not defined. The report focuses on chemical-specific effects in Chapter 5, noting cumulative risk assessment is common for carcinogens and not as common for noncarcinogens, and notes the application to noncarcinogens for organophosphate pesticides for cholinesterase inhibition.	https://nap.nationalacademies.org/catalog/24635/using-21st-century-science-to-improve-risk-related-evaluations
Review of California's Risk- Assessment Process for Pesticides Sponsor: California Department of Pesticide Regulation (CDPR) Year: 2015	Conduct an independent peer review of CDPR's "risk assessment practices to ensure that they are scientifically credible." (p. 3)	Recommended that CDPR should monitor activities of EPA and the California Office of Environmental Health Hazard Assessment in developing guidance on unified approaches to risk assessment including performing cumulative risk assessment. References advice given the National Academies' reports *Science and Decisions: Advancing Risk Assessment* (NRC, 2009) report and *Phthalates and Cumulative Risk Assessment* (NRC, 2008).	Cumulative risk assessment "which is the characterization of the combined risks to health posed by multiple agents or stressors." (p. 21) The report notes that consideration is given to nonchemical stressors.	https://nap.nationalacademies.org/catalog/21664/review-of-californias-risk-assessment-process-for-pesticides
Opportunities for the Gulf Research Program: Community Resilience and Health: Summary of a Workshop Sponsor: National Academies Gulf Research Program Year: 2015	Workshop convened to "examine opportunities to improve the health, well-being, and resilience of communities in the Gulf of Mexico region." (p. 1)	Not a committee consensus study, but a workshop proceeding. *(The keynote speaker noted that the field does not yet have the right tools and methods to do cumulative risk assessment well. Another speaker urged quantifying the values of ecosystem services to humans. "Human health and well-being is the cumulative or ecosystem service." (p. 47) Human health and well-being result from a number of services provided by healthy ecosystems that can be impacted by a variety of stressors.)*	"Cumulative risk assessments attempt to integrate across all of the chemical risk factors to which an individual is exposed and through all of the pathways of exposure." (p. 10) The keynote speaker noted that evidence is accumulating suggesting that nonchemical stressors such as psychosocial stress can induce epigenetic changes and noted the hypothesis that an individual's set of epigenetic changes can serve as a biosensor of exposure to multiple chemical and nonchemical stressors and that research in this area may contribute to future capacity to conduct cumulative risk assessment.	https://nap.nationalacademies.org/catalog/21691/opportunities-for-the-gulf-research-program-community-resilience-and-health

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Manager's Guide to the Integrated Ecological Framework Sponsor: Strategic Highway Research Program Year: 2014	Guide created "for managers and decision makers to understand what is entailed in conducting a transportation/infrastructure planning process ... to ensure the best transportation/infrastructure and conservation outcomes possible." (p. 3)	This is a contractor-written report and is not a National Academies' committee consensus study. "[A] quantitative assessment of cumulative effects facilitates better comparison among scenarios and quantifies mitigation needs." (p. 18)	"Cumulative effects assessment: A process used to determine cumulative impact. According to 40 CFR § 1508.7, cumulative impact is the effect 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 nonfederal) or person undertakes such other actions. Cumulative impacts can result from individually minor but collectively significant actions taking place over a period of time." (p. 37)	https://nap.nationalacademies.org/catalog/22423/managers-guide-to-the-integrated-ecological-framework
Sustainability Concepts in Decision-Making: Tools and Approaches for the US Environmental Protection Agency Sponsor: EPA Year: 2014	Examine tools for incorporating sustainability concepts into EPA assessments	"New techniques are needed for broader characterizations of cumulative risks to better account for the full range of environmental stressors, particularly for environmental justice analyses (see Chapter 6). A broadening of the risk assessment and risk management paradigm raises the need for screening-level risk-assessment tools (such as databases, computer software, and other modeling resources) (NRC 2009)" (p. 35) "EPA should develop a range of risk assessment methods to better address cumulative risk and intergenerational and environmental justice considerations ...." (p. 124)	"... EPA has attempted to widen the context in which risk assessment is performed to include the early consideration of a broad range of decision options, and the cumulative threats of multiple social, environmental, and economic stressors to public health and the environment." (p. 35) "Finding: Risk analysis as commonly applied to environmental issues often does not adequately account for the full range of human health and ecosystem risks, including cumulative risks, intergenerational considerations, and the distribution of risks among population groups." (p.124)	https://nap.nationalacademies.org/catalog/18949/sustainability-concepts-in-decision-making-tools-and-approaches-for-the
Identifying and Reducing Environmental Health Risks of Chemicals in Our Society: Workshop Summary Sponsor: NIEHS Year: 2014	Plan and conduct a workshop on identifying and reducing health risks of chemicals.	Not a committee consensus study, but a workshop proceeding. (Speaker Richard Denison questioned assuming a threshold in single-chemical risk assessment, "especially in light of cumulative effects and the fact that we are being exposed to multiple chemicals and other types of stressors?" (p. 12) Speaker John Balbus reported on *Science and Decisions* (NASEM, 2009) recommendations: EPA should "draw on other approaches, such as those from ecological risk assessment and social epidemiology, to incorporate interactions between chemical and nonchemical stressors in assessments." (p. 56)	Several speakers referred to cumulative risk assessment in the context of multiple chemical and non-chemical stressors. Some speakers were asked to give overviews of various NASEM and other reports. John Balbus in his summary of the 2009 Science and Decisions report: "You have to look at exposures in context—not only in the context of co-exposures with other chemicals, but also in a context of multiple nonchemical stressors, whether that is psychological stress, nutritional stress, or socioeconomic stress." (page 56)	https://nap.nationalacademies.org/catalog/18710/identifying-and-reducing-environmental-health-risks-of-chemicals-in-our-society

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		In the short term, the EPA should "develop databases and default approaches to allow for incorporation of key nonchemical stressors in cumulative risk assessments in the absence of population-specific data, considering exposure patterns, contributions to relevant background processes, and interactions with chemical stressors" (p. 56) Speaker Ila Cote noted, "…chemicals that interact with the same pathways are more likely to interact in terms cumulative risk than chemicals that don't interact in the same pathways". "Chemicals and nonchemical stressors could be evaluated via their pathway interactions." (p. 65)		
Risks and Risk Governance in Shale Gas Development: Summary of Two Workshops Primary sponsor: National Science Foundation Year: 2014	Workshops to examine the range of social and decision-making issues in risk characterization and governance related to gas shale development.	Not a committee consensus study, but a workshop summary. ("Methods of risk analysis. Thomas Webler referred to the *Understanding Risk* report, which recommended that understanding be developed with the stakeholders (National Research Council, 1996) and contrasted it to the focus in this workshop on what the scientists know. . . . he suggested that the project consider what it takes to engage with stakeholders in discussion of the risks, as *Understanding Risk* recommended. He also commented favorably on the presentation from [Resources for the Future], which emphasized cumulative and synergistic risks and said that in addition to considering particular kinds of risks, their interactions need to be kept in mind.") (pp. 69-70)	"Krupnick described in some detail the conceptual framework his group uses for thinking about types of risks. He distinguished cumulative risks (which arise when multiple risk pathways affect the same actors) from synergistic risks (which arise when multiple associated pathways act together to make things worse)." (p. 59) "One participant suggested that Krupnick's idea of cumulative risk assessment leaves out the social part, including community impacts and environmental justice issues, and thought that a different term might be used. He also took issue with the word 'accidents,' saying that these are incidents and are preventable through stronger safety culture. Krupnick agreed." (p. 63). Another speaker used the term cumulative impact: "Conn described the [Comprehensive Gas Development Plan] as focusing on issues of the location of wells and the cumulative impact at landscape scale of placing multiple wells, with the aim of addressing these issues before permits for wells are issued." (p. 124)	https://nap.nationalacademies.org/catalog/18953/risks-and-risk-governance-in-shale-gas-development-summary-of

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Assessing Risks to Endangered and Threatened Species from Pesticides Sponsors: NOAA, U.S. Department of Agriculture, EPA, U.S. Fish and Wildlife Service Year: 2013	Examine scientific and technical issues related to determining risks to listed endangered species by pesticides. Among other things, the committee was specifically asked to consider "cumulative effects."	"Population models provide an appropriate framework for incorporating baseline conditions and projected future cumulative effects into the assessment." (p. 133) "The stressors that currently affect listed species are considered part of the environmental baseline conditions. Therefore, the interaction of existing stressors with the pesticides under consideration is within the purview of the Services and appropriately part of a biological opinion" (p. 100) "The responses to multiple stressors that are likely to have an effect (or have an increased effect) in the future are the cumulative effects. . . . [P]opulation models ... provide an objective, quantitative, and practical framework for incorporating baseline conditions and projected future cumulative effects into the ecological risk assessment in a way that is relevant to the requirements of the ESA [environmental site assessment]." (p. 101) "The difference between the projections of that model and of the baseline model is an estimate of the degree to which current use and past use of the pesticide are contributing to the risks faced by a listed species or preventing its recovery. Thus, the risk assessor uses the information (risks with and without the pesticide) to inform the reregistration decision. The procedure described here does not require any more data than the case in which the baseline data are coming from populations that are not exposed to a pesticide." (p. 101)	The term "cumulative effects" is used in the report, not cumulative risk assessment or cumulative impacts. Cumulative effects (p. 12) "are defined by regulation under the ESA as 'those effects of future State or private activities, not involving Federal activities that are reasonably certain to occur within the action area of the Federal action subject to consultation' (50 CFR 402.02). However, cumulative effects typically are more broadly defined as effects that interact or accumulate over time and space. The committee could not determine a scientific basis for excluding past and present conditions (the environmental baseline) from the consideration of cumulative effects and therefore used that broad definition in its evaluation." (p. 12)	https://nap.nationalacademies.org/catalog/18344/assessing-risks-to-endangered-and-threatened-species-from-pesticides
An Ecological Approach to Integrating Conservation and Highway Planning, Volume 2 Sponsor: Strategic Highway Research Program*a* Year 2012	The contractor's report addresses the scientific and technical processes needed for this integrated approach. [integrated transportation and conservation planning while expediting transportation project delivery].	This is a contractor-written report and is not a *National Academies* committee consensus study. (The report lays out a process for cumulative assessment. A step-by-step cumulative effects assessment and alternatives (CEAA) process provides the foundation. "CEAA process guides a scientifically rigorous ecological assessment process that:	The term "cumulative effects assessment" is used throughout the report, although the term cumulative impact is used on page 15: "As with data, science is imperfect and incomplete. Few species have been studied sufficiently to provide empirical values for viability (e.g., retention goals, minimum required occurrence sizes), which form the basis in the CEAA for determining cumulative impacts."	https://nap.nationalacademies.org/catalog/22804/an-ecological-approach-to-integrating-conservation-and-highway-planning-volume-2

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		(1) evaluates direct and cumulative effects on resources from any potential planning alternative or project; (2) assists in the identification or creation of alternatives; and (3) identifies the best mitigation and enhancement opportunities. It addresses several key questions .... What areas and resources will be directly affected by transportation development? How will those resources be affected cumulatively through the affected region?" (p. 3) Linking measurement scales provides as one outcome "A framework for understanding and presenting cumulative effects analyses." (p. 5)		
Linking Community Visioning and Highway Capacity Planning Sponsor: Strategic Highway Research Program Year: 2012	The contractor report presents a Vision Guide—a blueprint for preparing, creating, and implementing a visioning process. That process is part of a decision framework for transportation planning projects.	This is a contractor-written report and is not a National Academies' committee consensus study. (Community Impact Assessment–four step process involving gathering community information from secondary sources, mapping available data for presentation to public, compiling list of involved parties and building working relationships, analyzing available data and presenting it to the public.) (p. 37) (Provides categories of quality of life: economic competitiveness; environmental stewardship, transportation and mobility; public health, safety, and security; social and cultural resources; community development; governance and public services.)	Separate consideration of "direct, indirect and cumulative impacts" per NEPA. "**Direct effects** are caused by the action and occur at the same time and place. Indirect effects are caused by the action and occur later or farther removed but are still reasonably foreseeable. **Indirect effects** may include induced changes in land use, population density, and related effects on air, water, and other natural systems. **Cumulative impact** is 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 undertakes other actions." (pp. 37-38) **"[C]ommunity impact assessment (CIA)** has become accepted terminology to describe the process used to evaluate the effects of transportation decisions on the quality of life." "This process includes an examination of not only direct effects but indirect and cumulative effects (ICE)." (pp. 36-37)	https://nap.nationalacademies.org/catalog/14580/linking-community-visioning-and-highway-capacity-planning
Sustainable Development of Algal Biofuels in the United States Sponsor: Department. of Energy Year: 2012	Examine the sustainable development of algal biofuels.	Committee proposed a stepwise framework to aid in decision-making that includes "cumulative impact analyses."	Cumulative impact analyses "examine the cumulative effects of a resource or an environmental effect of algal biofuel production in addition to the existing activities in the production area." (p. 8)	https://nap.nationalacademies.org/catalog/13437/sustainable-development-of-algal-biofuels-in-the-united-states

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			(Monetized environmental benefits are considered in the "cost-benefit analyses" not in the cumulative impact analyses.) "**Cumulative effects** are defined 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' (43 CFR 1508.7)." (p. 198)	
Science for Environmental Protection: The Road Ahead Sponsor: EPA Year: 2012	"…assess the overall capabilities of the agency to develop, obtain, and use the best available scientific and technologic information and tools to meet persistent, emerging, and future mission challenges and opportunities." (p. 3)	"A challenge before the agency is the characterization of cumulative effects using complex, incomplete, or missing data. Even as EPA seeks to improve its understanding of risks, some prevention based decisions may need to be made in the face of uncertainty." (p. 191) "Cumulative risk assessment contains many subcategories of exposure, health, and ecologic risk analyses, and it is important for EPA to examine its research portfolio in this domain carefully to ensure that it is well aligned with the ultimate decision contexts." (p. 138) Systems thinking... must include cumulative effects of multiple stressors. (page 109)	"Race or socioeconomic status may increase the risk of cumulative environmental effects that result from living disproportionally closer to pollution sources (Bullard 2000)." (p. 34) "An area of increasing recognition is that of cumulative effects from the built and social environment on health and well-being. Multiple exposures and social factors can interact to increase risks and affect community health status." (p. 35)	https://nap.nationalacademies.org/catalog/13510/science-for-environmental-protection-the-road-ahead
Evaluation of the Updated Site-Specific Risk Assessment for the National Bio- and Agro-Defense Facility in Manhattan, Kansas Sponsor: Department of Homeland Security Year: 2012	Evaluate an updated risk assessment of a biosecure laboratory that identifies emerging and unknown disease threats. The specific concern was the accidental release of foot and mouth disease virus	Of limited informativeness to the current committee's charge. The 2012 committee valuated the development and "use a method of estimating the cumulative risk of an FMD [foot and mouth disease] infection resulting from an accidental release from the Kansas site over the operating lifetime of the facility " (p. xii)	Evaluated the assessment of the cumulative probability of release of foot and mouth disease virus from a facility.	https://nap.nationalacademies.org/catalog/13418/evaluation-of-the-updated-site-specific-risk-assessment-for-the-national-bio-and-agro-defense-facility-in-manhattan-kansas
Exposure Science in the 21st Century: A Vision and a Strategy Sponsor: EPA Year: 2012	"Develop a long-range vision for exposure science and a strategy for implementing the vision over the next 20 years" (p. 5)	"the first step in a risk assessment should involve defining the scope of the assessment in the context of the decision that needs to be made. Adaptive exposure assessments could facilitate that approach by tailoring the level of detail to the problem that needs to be addressed. Such an assessment may take	In the environmental justice context of Presidential Executive Order 12898 (February 11, 1994) that: "There is a need to include multiple chemical, physical, or biologic stressors but also to consider other vulnerability and susceptibility factors that influence the effects of these stressors, such	https://nap.nationalacademies.org/catalog/13507/exposure-science-in-the-21st-century-a-vision-and-a

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		various forms, including very narrowly focused studies, assessments that evaluate exposures to multiple stressors to facilitate *cumulative risk assessment,* or assessments that focus on vulnerable or susceptible populations. (pp. 12-13) As one of the "Strategies that the present committee believes may improve the efficiency, quality, and utility of the exposure-assessment component of risk assessment: .... *Assess and quantify cumulative and aggregate exposures.* There is a need to include multiple chemical, physical, or biologic stressors but also to consider other vulnerability and susceptibility factors that influence the effects of these stressors, such as nutritional and psychosocial status, including stress. Exposure assessments may therefore need to collect information about exposure to a variety of chemical and nonchemical stressors that may interact to influence health risk." (pp. 61-62) "Exposure science can help communities to identify and address differential, cumulative, and emergent exposures. Community members can be among the first to identify an exposure of concern." (p. 157) The CBPR [community based participatory research] approach allows the research process to increase a community's ability to study differential and cumulative exposures, address environmental justice and health issues, and increase engagement of minority-group and low-income stakeholders" (p. 160)	as nutritional and psychosocial status, including stress. Exposure assessments may therefore need to collect information about exposure to a variety of chemical and nonchemical stressors that may interact to influence health risk." (p. 62)	
Improving Health in the United States: The Role of Health Impact Assessment Sponsors: Robert Wood Johnson Foundation, NIEHS, California Endowment, CDC Year: 2011	"Develop a framework, terminology, and guidance for conducting HIA of proposed policies, programs, and projects at the federal, state, tribal, and local levels, including the private sector." (page 4)	"As noted above, there is a growing consensus that individual health and public health are shaped by genetic, behavioral, social, economic, and environmental factors. Therefore, the committee concludes that HIA practice should not be restricted by a narrow definition of health or restricted to any particular policy sector ..., level of government …, type of proposal, or specific health outcome or issue (for example, asthma	"The committee notes that cumulative impact assessment as defined in NRC (2009) is somewhat broader than cumulative risk assessment in that it captures a wider array of end points and includes more qualitative components than cumulative risk assessment. However, it is generally oriented more toward characterizing impacts and less toward informing specific interventions or decisions." (p. 31 footnote 2)	https://nap.nationalacademies.org/catalog/13229/improving-health-in-the-united-states-the-role-of-health

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		or obesity). HIA may be useful in a broad array of decision contexts, including many decision types to which it has not yet been applied." (p. 9) "The most common approach in HIA is to describe and characterize each effect separately (see Chapter 3) and allow users to make judgments about the cumulative nature of the effects. The committee endorses that approach even if a summary measure of effects is used. Generally, decision-makers must balance multiple desirable and adverse effects related to a decision and will need to "weight" or assign values to them on the basis of institutional rules, constituent preferences, or some other approach. Keeping effects separate and assigning values allow decision-makers to consider tradeoffs among health and nonhealth effects clearly." (p. 101) "The committee emphasizes that the appropriate assessment of direct, indirect, and **cumulative health effects** in EIA under NEPA is a matter of law ..., and recent efforts have successfully integrated the HIA framework into EIA." (p. 12)	"The CEQ (1997, p. 9) issued detailed guidance on the implementation of Executive Order 12898 and in it advised agencies to 'consider relevant public health data and industry data concerning the potential for multiple or cumulative exposures to human health or environmental hazards in the affected population and historical patterns of exposure to environmental hazards, to the extent such information is reasonably available. For example, data may suggest there are disproportionately high and adverse human health or environmental effects on a minority population, low-income population or Indian tribe from the agency action. Agencies should consider these multiple, or cumulative effects, even if certain effects are not within the control or subject to the discretion of the agency proposing the action.'" (p. 156) "Moreover, traditional risk assessment tends to focus on adverse health effects rather than on beneficial and adverse effects.... Although risk assessments include qualitative elements ... they are generally secondary to the quantitative elements, and outcomes that cannot be quantified are rarely decision-relevant. Even in the context of cumulative risk assessment, NRC (2009) emphasized the importance of retaining the key attributes of quantitative risk assessment." (pp. 31-32)	
Sustainability and the U.S. EPA Sponsor: EPA Year: 2011	Provide an operational framework for integrating sustainability as one of the key drivers within the regulatory responsibilities of EPA. Address how the existing framework rooted in the risk assessment/risk management paradigm can be integrated under the sustainability framework. Identify the scientific and analytical tools needed to support the framework. Identify the expertise needed to support the framework.	"This goal has resulted in a call for simple tools to adequately address community concerns in evaluating community status with respect to environmental justice. Environmental justice and cumulative impact analyses can be used in priority-setting processes to direct resources to address the most heavily affected communities, to evaluate equity and fairness issues in siting and permitting decisions, and to facilitate community considerations of resource use (Morello-Frosh et al. 2011). In sustainability decision making, environmental justice tools may be similarly used." (p. 64)	In the section on sustainability tools, 1) "the NRC (2009) emphasized the need for tools for fuller characterizations of cumulative risks, including qualitative ones, that adequately account for the full range of chemical and other stressors, particularly for environmental justice contexts. Such risk descriptions could be useful inputs for sustainability decision making." (p. 61) 2) "The tools include quantitative and semiquantitative methods for screening communities of concern, for conducting specific community evaluations of	https://nap.nationalacademies.org/catalog/13152/sustainability-and-the-us-epa

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		"EPA should develop a range of risk assessment methods to better address cumulative risk and intergenerational and environmental justice considerations...." (pp. 73-74) "Research aimed at elucidating the cause-and-effect relationship between an environmental problem and an adverse consequence, especially cumulative impacts, should be focused on disadvantaged communities and should seek their engagement and cooperation." (p. 123)	3) cumulative environmental impacts or risks, and for looking at cumulative exposures and impacts in planning for land use (OEHHA 2010)." (p. 64) "The goal of a cumulative risk assessment in a community setting is to fully account for the combined effects of multiple exposures—chemical, biologic, psychosocial, and physical—on a community, a goal that cannot be achieved using standard risk assessment methodology (IOM 2009)." (p. 64)	
Assistance to the U.S. Army Medical Research and Materiel Command with Preparation of a Risk Assessment for the Medical Countermeasures Test and Evaluation (MCMT& E) Facility at Fort Detrick, Maryland: A Letter Report Sponsor: US Army Year: 2011	"Review and provide technical input to the EIS being prepared for the MCMT&E facility [Medical Countermeasures Test and Evaluation (MCMT&E) facility" (p. 12) at Fort Detrick in Frederick, Maryland]. The facility handles infectious agents.	"The decision process for choosing the appropriate models that account for the transmission pathways should be formalized in the context of the specific scenarios that will be assessed. Particular attention should be placed on the interdependencies of the transmission pathways. The interdependencies of these pathways should be extended to consider overall or cumulative risks." (p. 7)	"'Cumulative risks' refer to 'the combined risks from aggregate exposures to multiple agents or stressors' (EPA 2003)." (p. 7 n.2) The focus was on the likelihood of transmission of an infectious agent across multiple transmission pathways.	https://nap.nationalacademies.org/catalog/13161/assistance-to-the-us-army-medical-research-and-materiel-command-with-preparation-of-a-risk-assessment-for-the-medical-countermeasures-test-and-evaluation-mcmte-facility-at-fort-detrick-maryland
Long-Term Health Consequences of Exposure to Burn Pits in Iraq and Afghanistan Sponsor: Department of Veterans Affairs Year: 2011.	"Determine the long-term health effects from exposure to burn pits in Iraq and Afghanistan, using the Balad Burn Pit in Iraq as an example and examine existing literature that has detailed the types of substances burned in the pits and their by-products." (p. 1)	The committee did not make recommendations about cumulative risk assessment. It found the data insufficient for conducting a formal analysis. Ultimately it found an epidemiological study challenging but feasible to conduct.	Cumulative risk was not defined. The term was used in the context of multiple chemical exposures to burn pit releases. Vulnerability and psychosocial stressors did not appear to be considered. "However, health risks may be greater due to multiple pollutants, cumulative risk. Cumulative risk assessment can be used to characterize the effects of multiple exposures based on the dose and known effects of each pollutant." (p. 57)	https://nap.nationalacademies.org/catalog/13209/long-term-health-consequences-of-exposure-to-burn-pits-in-iraq-and-afghanistan
Hidden Costs of Energy: Unpriced Consequences of Energy Production and Use Sponsor: Department of Treasury Year: 2011	"Define and evaluate key external costs and benefits—related to health, environment, security, and infrastructure that are associated with the production, distribution, and use of energy but not reflected in market prices or fully addressed by current government policy." (p. 3)	Does not provide advice for cumulative risk or cumulative impact assessment. Relies on approach in the 2003 NASEM report *Cumulative Environmental Effects of Oil and Gas Activities on Alaska's North Slope*. See below.	In discussing the framework for evaluating external effects, the committee noted that "Evaluating damages requires an estimation of the impacts—the tangible manifestations of the burdens of energy use." (p. 47) "A potential source of complexity in impact assessment is cumulative effects, which can be important but are often inadequately assessed.	https://nap.nationalacademies.org/catalog/12794/hidden-costs-of-energy-unpriced-consequences-of-energy-production-and

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			Our discussion here largely follows NRC (2003a)" (p. 48) NRC 2003a is *Cumulative Environmental Effects of Oil and Gas Activities on Alaska's North Slope* (below)	
Evaluation of a Site-Specific Risk Assessment for the Department of Homeland Security's Planned National Bio- and Agro-Defense Facility in Manhattan, Kansas Sponsor: Department of Homeland Security Year: 2010	Examine the SSRA [Site-Specific Risk Assessment] for the Department of Homeland Security's Planned National Bio- and Agro-Defense Facility (NBAF) in Manhattan, Kansas. Address work plans and specific questions posed by DHS.	"The SSRA [site specific risk assessment] did not account for the **cumulative risk** of a release and infection that could spread across the expected life span of the NBAF [facility]."…"the SSRA did not provide a cumulative risk assessment[2] [footnote 2, see next column] for multiple agents and stressors by all routes and pathways to determine the overall risk of operating the NBAF in Manhattan, Kansas." (p. 30)	"The 2009 National Research Council report *Science and Decisions: Advancing Risk Assessment* defines cumulative risk as 'the combination of risks posed by aggregate exposure to multiple agents or stressors in which the aggregate exposure is by all routes and pathways and from all sources of each given agent or stressor.'" (p. 30 n.2)	https://nap.nationalacademies.org/catalog/13 031/evaluation-of-a-site-specific-risk-assessment-for-the-department-of-homeland-securitys-planned-national-bio-and-agro-defense-facility-in-manhattan-kansas
Science and Decisions: Advancing Risk Assessment Sponsors: EPA, CDC Year: 2009	Develop scientific and technical recommendations for improving the risk analysis approaches used by EPA. Conduct a scientific and technical review of EPA's current risk analysis concepts and practices.	"…EPA [should] explicitly define and maintain a conceptual distinction among cumulative risk assessment, cumulative impact assessment, and community-based risk assessment, which overlap but are conflated in many discussions." (p. 224) "…cumulative impact assessments would generally include the outputs of cumulative risk assessment and other considerations; but, depending on the nature of the decision, the quantitative cumulative risk component may have more or less significance in a cumulative impact assessment." (p. 224) "…to have terminology that distinguishes the full discussion of possible health effects from the myriad other effects that may be considered in a cumulative impact assessment and that may be important for a decision at hand." (p. 224) "Noncancer effects do not necessarily have a threshold.... Background exposures and underlying disease processes contribute to population background risk and can lead to linearity at the population doses of concern" (p. 265)	"Cumulative impact assessment would consider a wider array of end points, including effects on historical resources, quality of life, community structure, and cultural practices (CEQ 1997), some of which may not lend themselves to quantification...." (p. 224) "We further propose that EPA apply the term cumulative risk assessment only to an analysis that considers in some capacity all the components mentioned in EPA's definition of cumulative risk assessment. An analysis that does not consider nonchemical stressors, that considers only a subset of routes and pathways of exposure, or that does not consider vulnerability should not be termed a cumulative risk assessment." (pp. 224-225) The committee proposed "that cumulative risk assessment be defined as evaluating an array of stressors (chemical and nonchemical) to characterize—quantitatively to the extent possible—human health or ecologic effects, taking account of such factors as vulnerability and background exposures." (p. 224)	https://nap.nationalacademies.org/catalog/12 209/science-and-decisions-advancing-risk-assessment

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New Approaches to Ecological Surveys Sponsor: American Association of State Highway and Transportation Officials Year: 2009	"…survey transportation and natural resource professionals familiar with transportation systems to identify ecological survey needs related to transportation activities and to identify technologies, techniques, and innovative methods to fulfill those needs." (p. 11)	*This is a contractor-written report and is not a National Academies' committee consensus study.* ("The Colorado DOT recently (2008) released a cumulative impacts analysis document, 'Area Wide Coordinated Cumulative Effects Analysis.' The project evaluated whether and how a spatial accounting approach can be used to identify the cumulative impacts on the environment that result from the incremental impacts of multiple transportation and other projects, and related urbanization at a regional scale.... This type of analysis is close to what the survey respondents voiced was a necessary approach" (p. 21)	Cumulative impacts were not defined but is a term used in a number of places. "*Ecosystems Long-Term and Cumulative Impacts* There are regulatory reasons for assessing long-term impacts, including the Endangered Species Act. To help meet these requirements and go beyond the scope of the law, there are new approaches to examining the effects and potential effects of transportation on ecosystems and processes." (p. 21)	https://nap.nationalacademies.org/catalog/14334/new-approaches-to-ecological-surveys
Phthalates and Cumulative Risk Assessment: The Tasks Ahead Sponsor: EPA Year: 2008	Conduct an independent scientific evaluation of phthalates in the context of cumulative risk assessment. Consider the strengths and weaknesses of cumulative-assessment approaches, to provide recommendations to EPA on conducting a cumulative risk assessment of phthalate chemicals, and to identify additional research needs	"…not a comprehensive toxicologic profile or risk assessment of any particular phthalate or of the chemical class as a whole." (p. 4) The question is whether cumulative risk assessment of phthalates should be conducted and if so, how. The committee found that it should be performed because exposure to multiple phthalates occurs and multiple phthalates contribute common adverse outcomes. Some phthalates cause androgen insufficiency and other chemicals do as well. The committee recommends that a cumulative risk assessment be conducted for phthalates and that the assessment include other antiandrogens. The committee found that the mixture effects (antiandrogenic) were predicted well with the dose addition method, even though multiple mechanisms were involved. "The evidence supports the use of dose addition as an approximation in estimating cumulative risk posed by phthalates and other antiandrogens." "The current practice of restricting cumulative risk assessment to structurally or mechanistically related chemicals ignores the important fact that different chemical exposures may result in the same common adverse outcomes." (p. 10)	"The committee ... agreed with recent publications that define cumulative risk broadly to mean the risk posed by multiple chemicals and other stressors that cause varied health effects and to which people are exposed by multiple pathways and exposure routes and for varied durations." (p. 4)	https://nap.nationalacademies.org/catalog/12528/phthalates-and-cumulative-risk-assessment-the-tasks-ahead

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Environmental Impacts of Wind-Energy Projects Sponsor: Council on Environmental Quality Year: 2007	Carry out a scientific study of the environmental impacts of wind energy projects. Consider adverse and beneficial effects, including impacts on landscapes, viewsheds, wildlife, habitats, water resources, air pollution, greenhouse gases, materials-acquisition costs, and other impacts. Develop an analytical framework for evaluating those effects to inform siting decisions.	The committee developed "an analytic framework for reviewing wind-energy proposals and for evaluating existing installations" that would "provide a basis ... for undertaking an assessment of the cumulative effects of other human activities. It also could be used to project the likely cumulative effects of additional wind-energy facilities ...."	"When numerous small decisions about related environmental issues are made independently, the combined consequences of those decisions often are not considered (Odum 1982). As a result, the patterns of the environmental perturbations or their effects over large areas and long periods are not adequately analyzed. This is the basic issue of cumulative effects assessment." (p. 25)	https://nap.nationalacademies.org/catalog/11935/environmental-impacts-of-wind-energy-projects
Models in Environmental Regulatory Decision Making Sponsors: EPA, Department of Transportation Year: 2007	"Assess evolving scientific and technical issues related to the selection and use of computational and statistical models in decision-making." (p. 2)	No specific advice related to the conduct of an assessment was provided.	"Cumulative Risk—The combined risks from aggregate exposures to multiple agents or stressors." (p. 230). Cumulative impact is discussed in the context of model performance. (pp. 2 and 103) "cumulative (from multiple pesticides) and aggregate (exposure from multiple pathways) health risk" are discussed. (p. 43; see also pp. 59-60)	https://nap.nationalacademies.org/catalog/11972/models-in-environmental-regulatory-decision-making
Monitoring, Analyzing, and Reporting on the Environmental Streamlining Pilot Projects Sponsor: American Association of State Highway and Transportation Officials Year: 2005	Contractor-performed research. Objective was to use the experiences of the pilot projects to identify effective ways to improve efficiency and reduce the time frame of the project development process while ensuring environmental protection and to judge their applicability beyond the pilot project settings	This is a contractor-written report and is not a National Academies' committee consensus study.	Cumulative impact assessments were performed under NEPA and the California Environmental Quality Act regulatory rubrics.	https://nap.nationalacademies.org/catalog/22056/monitoring-analyzing-and-reporting-on-the-environmental-streamlining-pilot-projects
Rebuilding the Unity of Health and the Environment: The Greater Houston Metropolitan Area: Workshop Summary. Sponsor: NIEHS Year: 2005	"bring together a variety of viewpoints including those of Houston area policy makers, planners, developers, and health care providers to discuss environmental health issues with each other and with various local communities" (p. 7)	Not a committee consensus study, but a workshop proceeding. (Speaker Ken Sexton addressed cumulative risk. "...anyone who has ever attempted a cumulative risk assessment knows that when you try to evaluate aggregate effects on a population from a diversity of environmental stressors, the discussion rapidly moves away from the science because the science simply isn't there. The process necessarily becomes qualitative and attitudes, biases, and perceptions play a prominent role in the final outcome. We therefore have to strengthen the scientific underpinnings that are the foundation for realistic assessment of cumulative risks." (p. 18)	Neither cumulative risk nor impact were defined. See previous column for the context of the use of cumulative risk by the only speaker that addressed it.	https://nap.nationalacademies.org/catalog/11221/rebuilding-the-unity-of-health-and-the-environment-the-greater

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Review of the Army's Technical Guides on Assessing and Managing Chemical Hazards to Deployed Personnel. Sponsor: U.S. Army Year: 2004	Review three Army documents to identify deficiencies and make recommendations for improvements: Technical Guide 248 (TG-248), a general approach to assessing chemical, radiological, physical, and endemic disease hazards; TG-230, specific guidance on the chemical subset of hazards and military exposure guidelines; and Reference Document 230 that describes how exposure guidelines were derived.	"establish a qualitative classification scheme that identifies chemicals known to interact or cause similar effects and that might be encountered simultaneously during a deployment." (p. 11) "The number of chemicals for which CCEGs [chemical casualty estimating guidelines] are needed appears limited, making it feasible to identify those compounds that are likely to be present in mixtures and combinations of concern. Additivity assumptions could be applied using a probabilistic method consistent with the probabilistic nature of the CCEGs." (p. 89) "The subcommittee agrees with the Army's assumption that the toxicity of a mixture of chemicals that have similar modes of action will be equal to the sum of the weighted dose toxicities of the individual chemicals in the mixture." "In practice, the HI method could be applied to chemicals that have similar target-organ effects." (p. 123)	"Cumulative risk is the likelihood of occurrence of an adverse health effect resulting from exposure to multiple chemicals that have common modes of toxicity from all routes and pathways." (p. 11)	https://nap.nationalacademies.org/catalog/10974/review-of-the-armys-technical-guides-on-assessing-and-managing-chemical-hazards-to-deployed-personnel
Cumulative Environmental Effects of Oil and Gas Activities on Alaska's North Slope Sponsor: EPA Year: 2003	Review information about oil and gas activities (including cleanup efforts) on the North Slope and, based on its review, assess the known and probable cumulative impacts of such activities on the physical, biotic, and human environments of the region and its adjacent marine environment	"the committee developed a general process to identify how effects accumulate with respect to different receptors (i.e., the organisms, communities, and environments that are affected). The key elements are: (a) specify the class of actions whose effects are to be analyzed; (b) designate the time and space scales over which the relevant actions take place; (c) identify and characterize the receptors whose responses to the actions are to be assessed; and (d) determine the magnitude of the effects on the different receptors and whether they are accumulating or interacting with other effects." (p. 2)	"A cumulative effect was defined [by CEQ] as '. . . the incremental impact of the action when added to other past, present, and reasonably foreseeable future actions. Cumulative impacts can result from individually minor but collectively significant actions taking place over a period of time.'" (p. 2)	https://nap.nationalacademies.org/catalog/10639/cumulative-environmental-effects-of-oil-and-gas-activities-on-alaskas-north-slope
Biosolids Applied to Land: Advancing Standards and Practices Sponsor: EPA Year: 2002	Conduct an independent evaluation of the technical methods and approaches used to establish the chemical and pathogen standards for biosolids	The committee did not provide specific advice for cumulative risk or impact assessment.	Does not define cumulative risk or impact but does define cumulative exposure (combined exposures to multiple pollutants by multiple pathways and routes of exposure. (p. 335) Discusses cumulative risk as an emerging concern for risk assessment.	https://nap.nationalacademies.org/catalog/10426/biosolids-applied-to-land-advancing-standards-and-practices

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Environmental Cleanup at Navy Facilities: Risk-Based Methods Sponsor: U.S. Navy Year: 1999	Indicate the strengths and weaknesses of risk-based methodologies for cleaning up contaminated Navy sites, including the Risk-Based Corrective Action standard devised by the American Society for Testing and Materials (ASTM). Advise on how such a methodology should be implemented at Navy facilities.	The committee found insufficient consideration was given to the cumulative effects of multiple contaminants and multiple exposure pathways in the ASTM standard.	"...cumulative risk assessment, which evaluates the effects on potential target receptors of multiple chemicals and multiple exposure pathways originating from a single waste site."	https://nap.nationalacademies.org/catalog/6330/environmental-cleanup-at-navy-facilities-risk-based-methods
Understanding Risk: Informing Decisions in a Democratic Society Sponsors: EPA, DoD, HHS, USDA, DOE, Nuclear Regulatory Commission, EPRI, and American Industrial Health Council Year: 1996	"Risk characterization" is a complex and often controversial activity that is both a product of analysis and dependent on the processes of defining and conducting analysis. The study committee will assess opportunities to improve the characterization of risk so as to better inform decision making and resolution of controversies over risk.	The report provides extensive advice about using a participatory analytic-deliberative process it proposes to reach an understanding of a risk situation for decision- making. "...an often overlooked danger to risk decision making is a fundamental misconception about how risk characterization should relate to the overall process of comprehending and dealing with risk." (p. 1) "Risk characterization is the outcome of an analytic-deliberative process. Its success depends critically on systematic analysis that is appropriate to the problem, responds to the needs of the interested and affected parties, and treats uncertainties of importance to the decision problem in a comprehensible way. Success also depends on deliberations that formulate the decision problem, guide analysis to improve decision participants' understanding, seek the meaning of analytic findings and uncertainties, and improve the ability of interested and affected parties to participate effectively in the risk decision process. The process must have an appropriately diverse participation or representation of the spectrum of interested and affected parties, of decision makers, and of specialists in risk analysis, at each step." (p. 3) "Some fairness concerns, described in terms of ''environmental justice' for minority and low-income populations, were given prominence by Presidential Executive Order 12898, issued in February 1994.	"Cumulative risk" is used once without definition to refer to a specific case elucidating an issue in problem formulation in a discussion of fairness. (p. 40) (Other uses of the term "cumulative" were for cumulative probability distributions.) However, the treatment of the components of risk for analysis is broad and coherent with the notion of "cumulative impact," for example, "Getting the right science: The analysis has addressed the significant risk-related concerns of public officials and the spectrum of interested and affected parties, such as risks to health, economic well-being, and ecological and social values, with analytic priorities having been set so as to emphasize the issues most relevant to the decision." (p. 7) "Some fairness concerns, described in terms of 'environmental justice' for minority and low-income populations, were given prominence by Presidential Executive Order 12898, issued in February 1994. The Executive Order recognized that federal agencies' risk analyses had not previously made equity issues a routine part of the problem definition and directed them to do so. Effective implementation of the order would make the analysis of some aspects of fairness and equity an essential input into risk characterization." (p. 41)	https://nap.nationalacademies.org/catalog/5138/understanding-risk-informing-decisions-in-a-democratic-society

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		The Executive Order recognized that federal agencies' risk analyses had not previously made equity issues a routine part of the problem definition and directed them to do so. Effective implementation of the order would make the analysis of some aspects of fairness and equity an essential input into risk characterization." (pp. 40-41)		
Science, Policy, and the Coast: Improving Decisionmaking Sponsor: NOAA, EPA, and the Minerals Management Service Year: 1995	Make recommendations for improving the use of science in coastal policy and management. In information gathering, the committee held three regional symposia, in which "Particular attention is paid to the common thread of addressing cumulative Impacts." (p. 12)	"No ready solutions or easy approaches for addressing the complex problem of cumulative impacts emerged from the symposia, but some common issues were identified. First, a shared understanding must be achieved among scientists and policymakers about what constitutes cumulative impacts. Second, improved methods for evaluating cumulative environmental impacts must be developed and applied. Third, the capacity of existing governance arrangements to manage such impacts effectively must be enhanced." (p. 24)	The committee noted "the following definition garnered acceptance" at the symposia it held: "Cumulative impacts are those that result from the interactions of many incremental activities, each of which may have an insignificant effect when viewed alone, but which become cumulatively significant when seen in aggregate. Cumulative effects may interact in an additive or synergistic way, may occur on-site or offsite, may have short-term or long-term effects, and may appear soon after disturbance or be delayed (Dickert and Tuttle, 1985)." (p. 24)	https://nap.nationalacademies.org/catalog/4968/science-policy-and-the-coast-improving-decisionmaking
Improving Interactions Between Coastal Science and Policy: Proceedings of the Gulf of Maine Symposium Sponsor: NOAA, EPA, and the Minerals Management Service Year: 1995	The symposium considered how the connection between science and policy in issues related to the U.S. coastal ocean could be improved. Three issues were focused on: (1) responding to the cumulative impact of land and water activities in the region's estuaries and near-coastal environments; (2) protecting regionally significant terrestrial and marine habitats; and (3) using indicators of environmental quality as a tool to maintain the health of the Gulf of Maine.	Not a committee consensus study, but a workshop proceeding. ("A process for developing and using scientific data and information, that addresses the complexity of ecosystems, should also be incorporated. Politics, culture, economics, and social factors must be considered in responding to cumulative impacts. Cumulative impact problems require policy solutions developed at levels ranging from interstate and interprovince to county and local. Mechanisms for coordinating actions among all levels should be developed." p. 2)	The issue paper by Carolyn Hunsaker provided multiple references for definitions and assessment frameworks for cumulative impact.	https://nap.nationalacademies.org/catalog/9151/improving-interactions-between-coastal-science-and-policy-proceedings-of-the

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Improving Interactions Between Coastal Science and Policy: Proceedings of the California Symposium Sponsor: NOAA, EPA, and the Minerals Management Service of the Department of the Interior Year: 1995	The primary purpose of the symposium was to consider how the connection between science and policy in issues related to the U.S. coastal ocean could be improved. The workshop focused on three issues that are important in California: coastal habitat mitigation strategies, coastal sediment and water quality, and cumulative impacts of development.	Not a committee consensus study, but a workshop proceeding. ("Symposium participants who focused on cumulative impacts of development concluded that managing cumulative impacts may provide an opportunity for integration of science and policy." (p. 3) One technically oriented "means to improve science-policy interactions" was to "improve conceptual development and the refinement of analytical tools for regional approaches." "however, we suggest that the problem of complexity in cumulative impacts assessment and management is not so much the lack of standard terminologies and definitions but rather, a lack of clear conceptual thinking and/or articulation among practitioners about cumulative impacts, particularly among policymakers. To clarify, we suggest that there is a relatively straight-forward way to approach this topic if we are careful to distinguish three ideas in our discussions: cumulative impact or effect, cumulative impacts assessment, and cumulative impacts management." (p. 187)	From workshop issue paper by Peter M. Douglas, Elizabeth Fuchs, and Charles Lester: "The concept of cumulative impact assessment is confounded by inconsistencies in definitions. The lack of standard terminology and the overlapping of definitions continue to impede progress in relating science to regulatory needs." (p. 186) "the World Wildlife Fund recently listed ten distinct cumulative impacts definitions. These range from the Council on Environmental Quality's regulation defining cumulative impacts as 'the impact on the environment which results from the incremental impact of [an] action when added to other past, present, and reasonably foreseeable future actions …,' to a definition identifying the functional pathways that may lead to cumulative impacts (see Table 2), to William Odum's concern for 'the tyranny of small decisions.' Thus, some of the definitions focus on the nature of various impacts while others take a more procedural approach, contrasting incremental decisionmaking with comprehensive analysis and/or planning." (pp. 186-187) "We believe this commonality is clearly captured in the following definition of cumulative impacts: 'cumulative impacts are those that result from the interactions many incremental activities, each of which may have an insignificant effect when viewed alone, but which become cumulatively significant when seen in the aggregate. Cumulative effects may interact in an additive or a synergistic way, may occur onsite or offsite, may have short-term or long-term effects, and may appear soon after disturbance or be delayed.'" (pp. 189-190)	https://nap.nationalacademies.org/catalog/9856/improving-interactions-between-coastal-science-and-policy-proceedings-of-the

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Recommendations for the Disposal of Chemical Agents and Munitions Sponsor: U.S. Army Date: 1994	The report compares alternatives to the baseline system (incineration technology) and makes recommendations for the best approach to stockpile disposal.	No advice was provided regarding assessment methods.	The term "cumulative impact" is not used in the report. Although not defined, "cumulative risk" refers to the risk that accrues over time resulting from delay in disposal of munitions.	https://nap.nationalacademies.org/catalog/2348/recommendations-for-the-disposal-of-chemical-agents-and-munitions
Managing Troubled Waters: The Role of Marine Environmental Monitoring Sponsor: NOAA, EPA, and the Minerals Management Service of the Department of the Interior, U.S. Army Corp of Engineers, California State Water Resources Control Board Year: 1990	Review the current status of monitoring systems and technology, assess marine environmental monitoring as a component of sound environmental management, and identify needed improvements in monitoring strategies and practices.	The committee provides laudatory remarks on a cumulative assessment approach that uses a matrix to qualitatively score ecosystem components against sources of perturbation (pp. 60-61) "This cumulative assessment approach presents a synoptic picture of natural and human sources of disturbance and impacts and their effects on natural resources.... A particularly useful aspect of this approach is the identification of multiple and cumulative impacts. Further, it includes information about the limits of scientific certainty associated with potential impacts."	The term "cumulative impact" is not defined but used to represent the impact of multiple human activities on the environment and ecosystems. The term cumulative effects is also used in a similar context, for example, "Multiple human activities occurring within the same area or time span can interact to create complex cumulative effects." (p. 54).	https://nap.nationalacademies.org/catalog/1439/managing-troubled-waters-the-role-of-marine-environmental-monitoring
Surface Coal Mining Effects on Ground Water Recharge Sponsor: Office of Surface Mining Reclamation and Enforcement (OSM) of the U.S. Department of the Interior Year: 1990	Undertake an assessment of technologies currently used to evaluate groundwater recharge.	No advice was provided relevant to our committee's charge.	A variety of regulatory requirements involve the assessment of the probable *cumulative impacts* of all anticipated mining in the area upon the hydrology of the area and particularly upon water availability.	https://nap.nationalacademies.org/catalog/1527/surface-coal-mining-effects-on-ground-water-recharge
Land Use Planning and Oil and Gas Leasing on Onshore Federal Lands Sponsor: Bureau of Land Management and U.S. Forest Service Year: 1989	This report identifies problems in land use planning that are caused by current leasing practices and the availability and reliability of information at the planning stage.	No specific advice related to the conduct of an assessment is given.	The term cumulative impacts is used at multiple places in the report without elaboration or definition. It may be referring to the impact of multiple federal actions. "Cutting the other way, however, are decisions construing the National Environmental Policy Act as requiring agencies to consider, before taking any action, the cumulative impacts of several individual, contemporaneous agency actions in a single environmental analysis, such as where several pending proposals for energy development "will have cumulative or synergistic environmental impact upon a region" (Kleppe v. Sierra Club, 427 U.S. 390, 410 [1976]). (p. 135)	https://nap.nationalacademies.org/catalog/1480/land-use-planning-and-oil-and-gas-leasing-on-onshore-federal-lands

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Ecological Knowledge and Environmental Problem-Solving: Concepts and Case Studies Primary Sponsor: National Research Council Fund Year: 1986	Explores how the scientific tools of ecology can be used more effectively in dealing with a variety of environmental problems.	Advice is not provided for cumulative impacts and risks. Chapter 9 is devoted to "cumulative effects" and a number of recommendations mostly for research are provided (pp. 102-103). "Cumulative environmental effects should be placed in readily seen time and space scales.... This should help to identify different susceptibilities of different time and space scales, for environments and ecosystems."	The term "cumulative effects" is used frequently: "There is increasing recognition that some of our most severe environmental problems involve the cumulative effects of many small local actions—individually insignificant, but collectively creating major regional and even global changes." (p. 3) The term "cumulative impact" was used in the context of the impact of multiple projects (pp. 14, 64, 76, 94) the " ... 'tyranny of small decisions' ... when numerous small decisions on related environmental issues are made more or less independently, the combined consequences of the decisions are not addressed; therefore, no provision is made for analyzing the patterns of the perturbations or their effects over large areas or long periods...." (p. 94)	https://nap.nationalacademies.org/catalog/645/ecological-knowledge-and-environmental-problem-solving-concepts-and-case-studies

NOTES: CDC = Centers for Disease Control and Prevention; EJST = Climate and Economic Justice Screening Tool; CEQ = Council on Environmental Quality; FDA = Food and Drug Administration; NIEHS = National Institute of Environmental Health Sciences; NOAA = National Oceanic and Atmospheric Administration.

[a] Conducted under a memorandum of understanding among the American Association of State Highway and Transportation Officials (AASHTO), the Federal Highway Administration (FHWA), and the National Academy of Science.