Draft Abridged Executive Summary
Comprehensive Review of Frameworks, Methods, and Metrics for Cumulative Impact Assessment of Vulnerable Communities: A Science Perspective

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Note: the complete Executive Summary and the complete Report will be released shortly once the journal article derived from this report has been accepted for publication in the scientific literature.

Abridged Executive Summary

With the goal of achieving environmental justice (EJ), the US Environmental Protection Agency (EPA) and other federal and state agencies are in the process of developing and using various approaches, methods, and data to assess cumulative impacts at communities with environmental justice concerns.[1] These activities are happening at a rapid pace, spurred on by Executive Orders 13985 (2021), 14091 (2021a), 14008 (2021b), and 14096 (2023), which require consideration of environmental justice by federal agencies. It has been recognized that there are health inequities in certain communities, exacerbated by socioeconomic and psychological stressors, background exposures and health conditions, and ethnic and cultural factors, which can be compounded by disproportionate exposure to pollution and environmental degradation. Traditional risk assessments have not fully addressed the potential cumulative impacts of regulatory decisions in these communities, which can result in disproportionate impacts and result in environmental injustice for those communities.

In September 2022, the EPA's Office of Research and Development (ORD) issued their framework for cumulative impact assessment (CIA) and research needs to advance implementation, stating that "*the recommendations of this report are already informing actions within ORD to advance the state of science, and we are prepared to do more as we implement cumulative impacts research in the years to come*" (USEPA, 2022a).

The many policy and social aspects of CIA are important to consider in efforts to mitigate health disparities and improve the health of vulnerable communities; however, it is also important that CIAs be based on the best available science where applicable. Therefore, this report presents the results of a multidisciplinary review and appraisal of frameworks, metrics, methods, and data used or proposed for use in CIA from a scientific perspective. The overall objective of the investigation is to clarify the current underlying science and identify research needs to improve the quality and usefulness of CIAs for communities with EJ concerns.

In the rapidly developing fields of cumulative risk assessment (CRA) and CIA, many different frameworks, methods, and metrics have emerged. To organize this research, the key elements that need to be addressed in a CIA of human health risk in the context of EJ are listed in Table ES-1, along with the section number in this report wherein each element is addressed.

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[1] EO 13985, Advancing Racial Equity and Support for Underserved Communities Through the Federal Government
EO 14008, Tackling the Climate Crisis at Home and Abroad, Section 219: Securing Environmental Justice and Spurring Economic Opportunity
EO 14091, Further Advancing Racial Equity and Support for Underserved Communities through the Federal Government
EO 14096, Revitalizing our Nations Commitment to Environmental Justice for All.

Table ES-1. Elements of cumulative environmental health impact assessment

1. Identify and characterize communities with EJ concerns and underserved communities that are within the exposure area (Section 4)
2. With input from stakeholders, develop a problem formulation framework to visualize within the decision context the potential cumulative impacts based on the place, people, stressors, and their interactions (Section 3)
3. Define exposure scenarios unique to the exposed community, including cultural influences (Section 5)
4. Estimate cumulative chemical stressor exposures, including background source exposures (Section 7)
5. Characterize and incorporate important non-chemical stressors (Section 8)
6. Characterize and incorporate important background physical and biological stressors (Section 6.3)
7. Incorporate background pre-existing health conditions, life-stage exposures, and generational exposures (Section 9)
8. Consider effects of intrinsic genetic/epigenetic/biological dose-response and health-impact modifiers (Section 9)
9. Include consideration of climate and ecosystem services impacts on health (Sections 10 and 11)
10. Describe or quantify relationships among chemical stressors, non-chemical stressors, and health impacts (Section 12)
11. Use qualitative and/or quantitative methods to combine chemical and non-chemical stressor impacts to characterize cumulative impacts (Section 13)
12. Identify how the impacts are influenced by changes in certain variables and assumptions used in developing the CIA, including consideration of uncertainty (Section 13.7)
13. Consider net impacts, positive and negative (Section 13.4)
14. Determine which impacts are disproportionate (Section 13.6)
15. Identify effective interventions for reducing disproportionate impacts and improving health, well-being, and quality of life (Section 13)

These general CIA elements form the foundation for structuring this report. Specifically, these aspects were considered in developing the literature search terms, developing a general understanding of the scientific components and their inter-relationships in a CIA (see Figure ES-1), identifying the types of disciplines and expertise needed for CIAs, and organizing the presentation of findings and recommendations to describe and visualize where they can be applied in the CIA process. Almost every assessment approach described in the searched literature incorporated and often started with some form of a conceptual model or framework that was specific to the place, people, stressors, and decision context involved. Conceptual models show the key scientific components of cumulative impact and their potential interactions and influence on each other. For example, Figure ES-1 is a conceptual model of the technical components and their interactions associated with assessing cumulative impacts. Every component of this conceptual model and every key element shown in Table ES-1 was investigated and is discussed in this report, including summaries of the state of the science, discussions of limitations and uncertainties, and identification of future research needs.

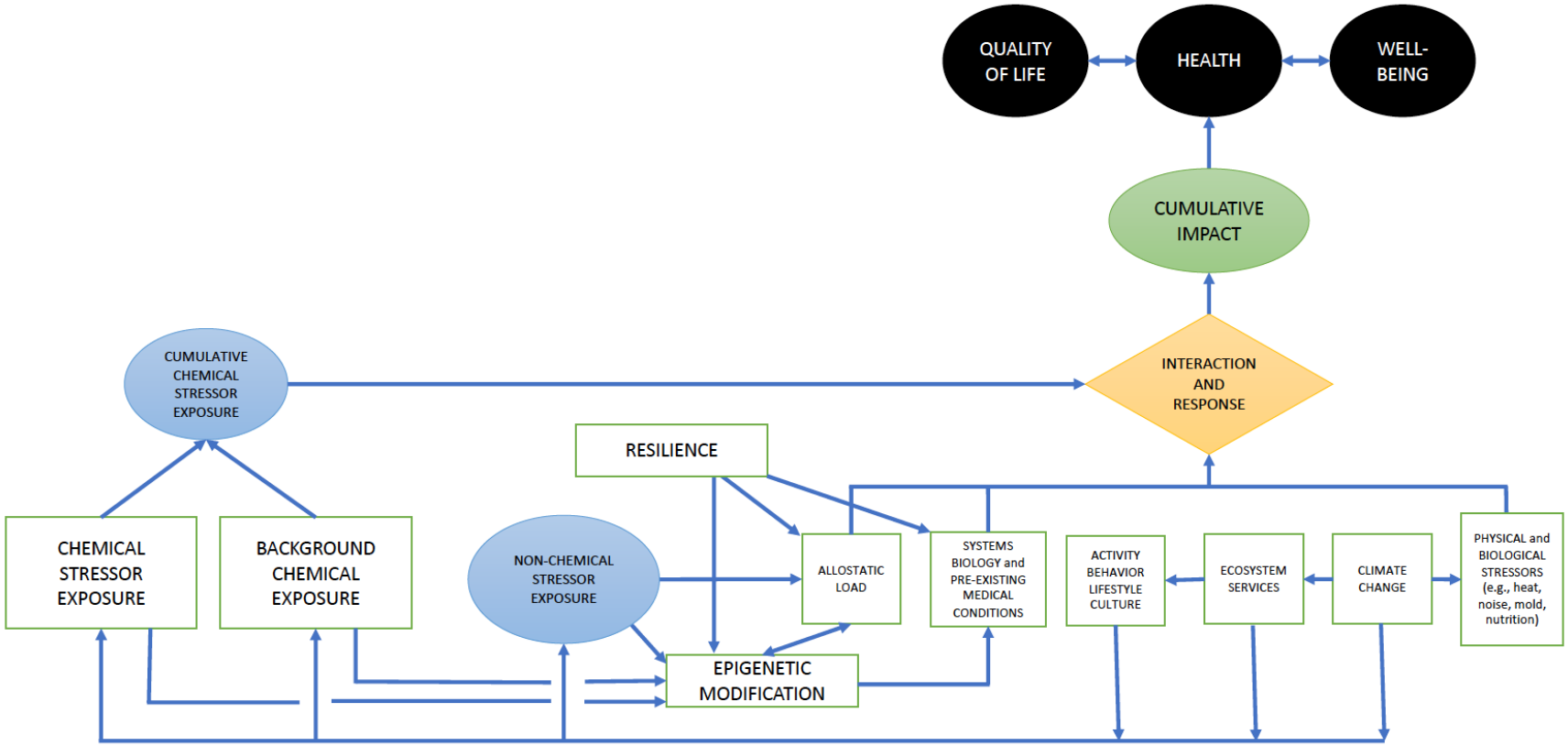

Figure ES-1. Key scientific components of cumulative impact assessment

Figure ES-2 provides an overview of the research approach used for this investigation, beginning with a systematic literature search. The details of each aspect of the research approach are provided in Section 2. Note, in addition to ToxStrategies' experts reviewing papers related to toxicology, epidemiology, exposure science, data and screening tools, and statistics, a formal process was used to elicit input from outside experts in economics, public health, social science, and decision/risk analysis as applied to CIA and EJ.

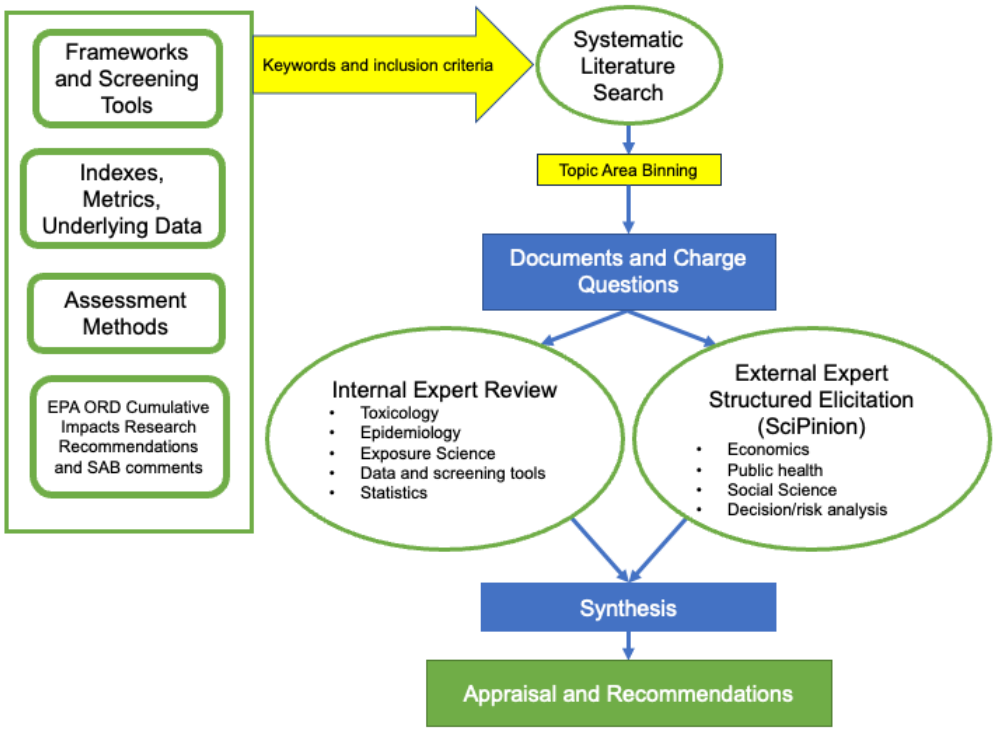

Figure ES-2 Research approach flow chart

The findings and recommendations for this report are presented in three categories: general findings, operational recommendations, and research recommendations (short-term and long-term). .

General Findings

Current scientific understanding of the causal relationships of individual and community health impacts from exposures to chemical and non-chemical stressors is incomplete, uncertain, and variable. The scientific literature clearly documents that non-chemical stressors are at least as important as chemical stressors in affecting health. Conceptually, and from a scientific perspective, the more holistic approach of cumulative impact assessment (CIA) is an improvement over standard single-source, chemical stressor-only risk assessments. Yet, research and development are still needed before many aspects of

cumulative impact assessment (CIA) can be implemented quantitatively with scientific credibility. This is not to say CIAs should not be attempted, but input from all stakeholders early in the process during problem formulation should be used to focus the CIA on impacts important to community health and well-being, on stressors.

- The key stressors should have reasonably good evidence of being related to impacts of interest, and on the decision context the CIA is supporting. In fact, in its current state CIAs would be best utilized as a planning tool for improving community health rather than to determine a go/no go or enforcement decision.
- CIAs will likely consist of a combination of quantitative and qualitative elements and include a significant number of subjective elements and assumptions. Accordingly, CIA interpretations and communications, as well as decisions based on such CIAs, should include discussions and characterizations of scientific uncertainties.
- Care should be taken in CIAs to avoid the use of negative labeling of communities as "EJ" or "economically disadvantaged," which could lead to further discrimination. Importantly, discrimination based on race, ethnicity, or other factors is a significant source of stress, with evidence that it can increase susceptibility to health impacts from chemical and non-chemical stressors. Therefore, any action that may increase discrimination would be counterproductive.

There is no single framework that fits the purpose of all CIAs. CIA designs need to be based on key principles (e.g., Table ES-1) and then tailored to the people, place, stressors, and decision contexts to which they are being applied. Each framework should be developed during the problem formulation phase of the CIA, with collaborative input from stakeholders (e.g., the community, regulators, planners, industry, and others).

Screening tools (e.g., EJScreen) and index-based assessments are not CIAs. They do not directly predict health impacts with scientific certainty. They identify places and people with the potential for disproportionate impacts and EJ issues.

- The components and modules of screening tools are often based on assumptions (e.g., proximity of a location to a potential source as indications of exposure). Socioeconomic information and indexes are typically used as surrogate for some underlying risk factors that may differ when examined at a local level and for which linkages to environmental health are not fully understood. There are also differences across information inputs for different tools, and the same indicators are not necessarily quantified consistently across these tools. In addition, correlations among variables are generally not accounted for, and when outputs are combined, or expressed as indexes, the results do not establish exposure-response relationships. Furthermore, screening tools include metrics selected (inconsistently) from a range of possible values for locations, socioeconomic, and other factors. The sensitivity of results to these uncertainties and assumptions are not clear.

- Although screening tools do not constitute a complete CIA, they can be helpful in identifying locations where undertaking a complete CIA should be considered to assess potential cumulative health impacts more fully. For instance, screening tools can be used to support collaboration and planning of CIAs by helping to identify location and community characteristics, lifestyle and cultural factors, and other stressors of importance to stakeholders (e.g., social vulnerability, housing age and type, access to medical care etc.).
- Our synthesis of the literature evidence base produced one key overall impression of the current CIA discussions—that there is no scientific consensus on how we should define poor and disproportionate health status and no consistent way to characterize and compare communities with respect to relative vulnerability, susceptibility, and level of environmental justice. In designing a CIA, an approach that focuses on identifying clearly disproportionate impacts that influence health, well-being, and quality-of-life disparities should be considered. This could streamline efforts and help identify alternative potential actions that would have the greatest influence on improving health in a timely manner.

Operational Recommendations

There are several challenges in operationalizing, conducting, and utilizing CIAs today. These include organizational and jurisdictional constraints, scientific and methodological obstacles, communication of CIA concepts across all stakeholders, and the complexities of multi-attribute decision analysis for evaluating potential alternative actions.

Agencies, and programs within agencies, have different authorities, enabling statutes, and regulations which often concentrate the types of health assessments they can perform to a select set of stressors or agents. As various programs venture forward to design and conduct CIAs, there's been a proliferation of agency-specific tools and guidelines that are often disparate and variable, particularly with respect to terminology, approaches for characterizing disproportionality, criteria for selecting comparison places and groups, and analytical methods, metrics, and screening tools.

- In designing a CIA, while the principles and elements of a CIA may be generalized, different frameworks will be appropriate for different decision contexts, people, and places. To improve the scientific basis of CIAs and promote greater consistency, formal intra-agency and inter-agency collaborations should be considered. This should include inter-agency task forces, for example, in which federal regulatory agencies engage with other federal agencies (e.g., health, transportation, housing, and infrastructure) to coordinate plans to improve community health based on holistic assessments of chemical and non-chemical stressors. Meanwhile, EPA ORD should continue

to collaborate within EPA programs and across other federal agencies in developing frameworks, guidance, and case studies for CIA.

Three of the most challenging scientific and methodological challenges to designing and conducting high-quality CIAs are:

- Selecting models, data, and methods that fit the CIA design objectives and incorporate principles of accuracy, interpretability (e.g., considering local conditions), spatiotemporal resolution (e.g., using appropriate sociodemographic data, ideally at the neighborhood level) and usability (e.g., transparent, reliable, efficient, executable, interpretable)
- Integrating knowledge of cause-and-effect relationships for each specific stressor / risk factor in each of the four domains (biological, social, behavioral, and physical (chemical and environmental)), and using systematic review and formal causal hypothesis testing, rather than relying on inferences from potentially insufficient statistical association evidence or ad hoc observations
- Translating the cause-effect understandings, including magnitude, frequency, and duration of stressors from biological, behavioral, physical (chemical and environmental), and social risk factors, into one or more comparable metrics of health, well-being, and quality-of-life to enable more direct comparisons of impacts and effectiveness of interventions on improving community health

As government entities undertake development and evaluation of potential alternative actions (i.e., interventions) to address outcomes from CIAs, differing levels of government oversight and stakeholder processes can create significant challenges for stakeholder engagement. Public policy decisions are rarely, if ever, solely science based. Instead, while informed by science, policy options and decisions can be shaped by the values, interests, and positions of different social actors, as well as the availability of resources and time constraints. This requires evaluating multiple criteria, some of which may be conflicting, when evaluating options. Nevertheless, the evaluation of alternative actions based on a CIA should be aimed at improving the overall health and well-being of the community in a timely and cost-effective manner. This analysis needs to be based on a robust and fully transparent evaluation of the evidence for the independent and joint impacts of all stressors taken singly and in combination and consider the likelihood of successful implementation of potential alternatives.

- From a cumulative impact perspective, it is important to consider what public health intervention(s) targeting non-chemical stressors will be effective at improving the health status of the residents of vulnerable communities, combined with environmental regulations that are focused on chemical stressors. From a public health perspective and given the objective of CIA to consider the "total environment" it will be important to develop a better understanding of contributions from chemical and non-chemicals stressors, singly and in combination. For example, physical and biological stressors associated with the built environment (e.g., traffic, heat, noise, odor, radon, mold, pests, failed septic systems) may significantly contribute to cumulative health impacts directly or as contributors to increased susceptibility via non-

chemical stress mechanisms or as causes of pre-existing health impacts. Many of these stressors arising from the built environment could be reduced by feasible interventions, although not all are within the purview of federal or state environmental agencies. The same could be true for addressing certain chemical stressors from background sources, wherein the regulatory abilities of a given federal or state agency may be limited or restricted to a particular source subject to a decision.

- Some of the independent expert panel have suggested consideration should be given to incorporating analyses of costs and net benefits to community environment and health when evaluating different alternative actions. Costs, benefits, and their balance are again strongly influenced by the people, place, and decision context to which a CIA is being applied.
- Caution is advised when considering alternative actions that call for a change in personal behaviors within a population group − these actions are likely to be very challenging because, for example, (a) persons feeling marginalized may consider themselves as involuntary victims of others' behavior (not their own) and (b) they may view the behaviors they are being asked to change as a sacrosanct part of their culture. Again, direct involvement of the potentially affected community in planning, implementing, and interpreting the CIA is important.

Research Recommendations

In general, considerably more research is needed to understand how the relationship between non-chemical stressors, chemical stressors, and health effects can best be addressed in CIAs. This includes understanding and possibly quantifying the combined effects of exposure to chemical and non-chemical stressors. Systematic reviews are recommended across a broad range of chemical and non-chemical stressors to determine the type, availability, and reliability of biomarkers for exposure, susceptibility, and effects and to evaluate important likely causal relationships.

In the past, CIA assessments of cumulative impacts have focused on health impacts related to cumulative chemical exposures and have missed potential opportunities to incorporate analysis of how interventions related to other stressors might impact the environmental health status of vulnerable communities (Juarez et al., 2014; Payne-Sturges et al., 2018; Stingone et al., 2017). Indeed, methodological challenges are being recognized in the scientific community in attempts to incorporate non-chemical stressors into CIA studies.

This is not to say that CIA cannot be used to support planning and decision-making until more research is completed. While longer-term research is directed at resolving uncertain relationships between chemical and non-chemical stressors, and ways to quantify cumulative impacts more fully, in a specific place, there are likely a set of primary chemical and non-chemical stressors for certain domains (biological, social, and behavioral) that:

(1) have been identified and prioritized by affected communities as stressors related to impacts of concern,

(2) have weight of evidence that they may contribute significantly to higher susceptibility to chemical exposures and exacerbate environmental health impacts, and

(3) have available data to develop common metrics that can be used to integrate with data from chemical stressors.

In the near-term, researchers should consider designing studies and methods to examine the relative effect of interventions that would target specific important non-chemical stressors, in combination with chemical stressors, on improving overall community health. This will help avoid expensive time-consuming programs or costly interventions that may not have the positive, measurable improvements to health anticipated by communities, create unforeseen outcomes, or cause delays in realizing health benefits.

Focusing CIAs in the near-term may be facilitated by the development and testing of response-based conceptual model visual tools (see Section 3.6). These tools hold great promise in helping focus discussions among stakeholders, policy makers, and subject-matter experts on those specific factors and interactions that drive health impacts. In addition, these tools can be used to help focus research investments on areas where critical information and better data are needed to assess causal linkages.

It is clear that to improve designs of research related to health impacts from cumulative exposures by vulnerable population groups there is a need to synthesize data and methodological approaches from traditionally distinct disciplines (e.g., sociology, psychology, economics, decision analysis, epidemiology, demography/geography, medicine, public health, toxicology, and genetics) and multiple viewpoints (e.g., community, government, public health, industry). One important need is to develop consistent and concise terminology related to all aspects of CIA. The literature review found many inconsistencies in terminology that complicated synthesis of concepts, methods, and metrics. We have developed a preliminary summary of terminology herein.

A rigorous approach is needed for identifying activity, lifestyle, and cultural factors that may influence susceptibility to environmental impacts at a place and community where a CIA is being prepared. In addition, further research is needed to identify the ways in which segregation and other aspects of discrimination may affect cumulative environmental health impacts—for example, through stress mechanisms. Consistent and more rigorous consideration of race in research designs, including best practices for when and how to consider race and ethnicity is also needed. Migration history and status are also potentially important factors affecting health. To identify the basis for health disparities, research should study the factors underlying racial disparities, rather than race itself. Importantly, conclusions regarding the contribution of genetics should be based on direct tests of genetic traits, and not race.

To understanding the role in a CIA of possible elevated pre-existing health conditions in a community, research needs to address (1) how pre-existing health conditions affect susceptibility to environmental exposures, and (2) how to account for potential

disproportionate health impacts where the community or population group has elevated pre-existing health conditions relative to the general population, and the extent to which these may be exacerbated by socioeconomic factors, such as access to health care.

There is a need to improve the integration of the tools and models of toxicological risk assessment with those of epidemiological risk assessment in the context of biologically plausible linkages between cumulative exposures and health effects. Specific approaches for selecting quantitative methods for epidemiological research supporting CIA need to be outlined and made available in the published literature.

Accounting for cumulative impacts will require a consistent approach to incorporating chemical stressor exposures from all potentially significant background sources at a location and within a population group of interest. More work is needed to improve methods which combine chemical stressor exposures from multiple media (i.e., air, soils, water, sediment, foods, and consumer products) in assessing cumulative impacts. This may be addressed partly by the EPA's Integrated Model Framework (Section 3.2.5); however, more work is needed on this tool in creating consistent and compatible data and models, resolving spatial and temporal differences, and facilitating coupling of models across different media, models, and data sets. For example, georeferencing community water quality data and data describing the physical condition of drinking-water systems for community water systems would be helpful.

There is a need to strengthen approaches for assessing exposure to chemical mixtures, particularly to address possible additive, antagonistic, or synergistic effects. Both laboratory-based mechanistic research and systematic review and meta-analysis methods may be useful to gather and integrate data related to mixtures. Identification of chemicals with similar modes of action, common adverse-outcome pathways and similar health endpoints may be useful. In addition, more rigorous hypothesis-based research is needed on the potential effects of early life stage exposures (chemical and non-chemical) on gene-environment interactions and epigenetic programming alterations that may persist into adulthood. Additional research into the feasibility of using physiologically based pharmacokinetics models to evaluate genetic polymorphisms, and the impacts of chemical and non-chemical stressors, on absorption, distribution, metabolism, and excretion of chemical stressors would be informative.

Formal testing of hypotheses underlying the role of allostatic load and epigenetic modification should be considered to determine whether these are primary mechanisms or measures of how non-chemical stressors, susceptibility, and health effects interact. More research into how telomere length could serve as a comparative indicator of biological aging (e.g., loss of functional reserve capacity or loss of resilience) from cumulative stressor exposures is also recommended. Research is also needed in developing a better understanding of resilience, its underlying mechanisms, potential biomarkers for resilience, and its role in mediating responses to stressors and subsequent cumulative impact.

Continuing, and strengthening, research regarding genetic and other biomarker databases to better inform health disparity, including the National Institute of Environmental Health Sciences environmental genome project, the Veterans Administration Million Veteran

Program—one of the world's largest databases of genetic, military exposure, lifestyle, and health information, the Department of Defense serum biorepository—with samples taken before, during and after service, and CDC's NHANES studies which assess the health and nutritional status of adults and children in the U.S. and includes analysis of human biomonitoring data to quantify chemical exposures.

Ecosystem services – the various benefits that humans derive from healthy ecosystems – can play a key role in community health. Research is needed to improve the understanding of how different ecosystem service metrics may affect health, including factors such as vegetation type, duration of exposure, location of green space (urban vs. rural), and buffer size of the greenspace. Currently, reporting the effects of different natural environments and health is uneven; there was a large emphasis on green space but limited consideration of other natural environments (e.g., blue space) or other ecosystem services (e.g. fishing and hunting). Ecosystem services should be incorporated into multi-attribute decision analysis research and models.

For environmental decisions and policies based on CIA results, multi-attribute decision analysis research is needed to develop and test different models for evaluating the range of potential alternative actions. This can begin with articulation of a set consistent principles and methods that includes evaluation of effectiveness, efficiency, and equity. Furthermore, there is a need to develop ways to monitor and measure the effectiveness of actions taken to improve community health – this is especially important for near-term interventions that are based on uncertain relationships among chemical stressors, non-chemical stressors, and other influencing factors. When significant resource expenditure is likely, multi-attribute decision analysis can achieve greater risk-reduction value for resources spent compared to prioritization ranking or scoring methods.

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