COMMENTS

ADVANCING SCIENCE-BASED CHEMICAL REGULATION: A SYSTEMS APPROACH TO RISK ASSESSMENT

by Zachary Liebowitz

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The current U.S chemical regulation framework was developed in an era when toxicology focused primarily on identifying acute hazards in controlled settings. A growing body of evidence demonstrates that such approaches struggle to capture cumulative exposures, chronic low-dose effects, microbial and ecological dynamics, and cross-species interactions that increasingly define real-world chemical risk. In recognition of these limitations, the U.S. Environmental Protection Agency (EPA) recently issued updated *Guidelines for Cumulative Risk Assessment Planning and Problem Formulation*, which emphasize early identification of combined stressors and vulnerable populations.[1]

Yet, cumulative thinking remains unevenly translated into routine chemical-specific decisionmaking, particularly for antimicrobial compounds regulated under sector-specific statutes. This Comment argues that the future of science-based regulation requires a systems-based framework that integrates "New Approach Methodologies" (NAMs), cumulative risk analysis, and a "One Health" perspective recognizing the interdependence of human, animal, and environmental health.[2]

Quaternary ammonium compounds (QUATs), a widely used class of disinfectants, serve as a case study for examining these structural limits. QUATs are able to disrupt microbial membranes, enabling rapid inactivation of bacteria, enveloped viruses such as influenza and SARS-CoV-2, and certain fungi.[3] Their efficacy, formulation flexibility, chemical stability, and relatively low odor and corrosiveness have made them attractive tools in hospitals, agricultural operations, food processing facilities, and consumer products.

Unlike many traditional pollutants that arise primarily from waste disposal, QUATs saturate the environment due to their usage in public health purposes, particularly infection control and disease prevention. Their regulation therefore requires a careful assessment of both benefits and risks, distinguishing contexts in which their antimicrobial value is justified from those in which cumulative, ecological, or resistance-related harms may outweigh those benefits.

QUATs' extensive use across sectors has resulted in measurable environmental persistence[4] and mounting evidence of broader biological effects, including promotion of antimicrobial resistance,[5] microbiome disruption,[6] and immunotoxicity in vertebrate models.[7] QUATs are not a single compound, but a structurally diverse class of related cationic agents used across healthcare, agriculture, industrial, and household settings.[8] Their functional similarity has often led regulators to evaluate them collectively, some-

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1. U.S. EPA, Guidelines for Cumulative Risk Assessment Planning and Problem Formulation (2025) (EPA/100/B-24/001), https://www.epa.gov/system/files/documents/2025-01/guidelines-for-cumulative-risk-assessment-planning-and-problem-formulation_0.pdf.
2. Centers for Disease Control & Prevention, *About One Health*, https://www.cdc.gov/one-health/about/index.html (June 27, 2025).
3. Megan C. Jennings et al., *Quaternary Ammonium Compounds: An Antimicrobial Mainstay and Platform for Innovation to Address Bacterial Resistance*, 1 ACS Infectious Diseases 288 (2015).
4. Anna Mahony et al., Investigation of Quaternary Ammonium Compounds (QACs) in Wastewater Effluent, Influent, Biosolids, and Environmental Matrices in San Francisco Bay (San Francisco Estuary Institute Contribution No. 1196, 2024).
5. Yue Han et al., *The Impact and Mechanism of Quaternary Ammonium Compounds on the Transmission of Antibiotic Resistance Genes*, 26 Env't Sci. & Pollution Rsch. Int. 28352 (2019); Ângela R. Fernandes et al., *Effect of Prolonged Exposure to Disinfectants in the Antimicrobial Resistance Profile of Relevant Micro-Organisms: A Systemic Review*, 151 J. Hosp. Infection 45 (2024).
6. Mitchell K. Ng et al., *Clinical and Environmental Harms of Quaternary Ammonium Disinfectants and the Promise of Ultraviolet-C (UV-C) Alternatives: A Narrative Review*, 17 Cureus e84022 (2025).
7. Junquan Zeng et al., *Benzalkonium Chloride Induces Hematopoietic Stem Cell Reduction and Immunotoxicity in Zebrafish Larvae*, 284 Ecotoxicology & Env't Safety 116902 (2024).
8. Yang Jiao et al., *Quaternary Ammonium-Based Biomedical Materials: State-of-the-Art, Toxicological Aspects and Antimicrobial Resistance*, 71 Progress Polymer Sci. 53 (2017).

times assuming comparable toxicity and environmental behavior across compounds despite emerging evidence that relatively minor structural differences can produce distinct toxicological profiles.

The QUAT example highlights three interrelated challenges that define modern chemical regulation. First, traditional risk assessment frameworks struggle to capture cumulative, low-dose, and system-level effects that unfold across interconnected biological and environmental systems. Second, regulatory decisionmaking remains organized around chemical-specific determinations made at defined statutory moments, limiting agencies' ability to address risks that develop gradually and span multiple sectors. Third, modern chemical governance faces a structural constraint: fragmented statutory authority and increasing judicial scrutiny limit the ability of agencies to incorporate One Health principles and integrate emerging scientific tools, including NAMs and cumulative risk approaches, into routine practice.

Viewed through the lens of QUAT oversight, the problem is not a lack of scientific understanding. Rather, it is a regulatory structure that has failed to evolve alongside advances in toxicology, microbial ecology, and systems science. The parts that follow examine each of these challenges, and consider how a more integrated, preventive model of governance grounded in One Health could better address contemporary chemical risks.

I. Challenge 1: Limits of Traditional Risk Assessment in a Complex World

Static, single-chemical risk assessments have been the backbone of regulatory decisionmaking, but they break down when confronted with the complexity of real-world exposures. In conventional risk assessment, regulators typically evaluate a chemical in isolation, often using high-dose animal studies to derive thresholds like median lethal dose (LD_{50}) or reference doses. These assessments focus on a few "apical" outcomes (e.g., acute toxicity, cancer in a rodent model) and assume other factors remain constant. This simplistic model cannot fully capture cumulative, chronic, and ecosystem-level risks.

Federal regulators have acknowledged this limitation. In 2025, EPA updated its cumulative risk assessment guidance to encourage earlier problem formulation around combined chemical and non-chemical stressors and to incorporate vulnerability considerations into risk planning.[9] However, cumulative assessment often remains conceptual rather than operational. In practice, most chemical decisions still proceed through single-chemical evaluations tied to discrete statutory triggers. For compounds such as QUATs, this disconnect means cumulative ecological and microbial dynamics remain outside the core analytic frame.

Key limitations of the traditional approach include:

- **Cumulative exposure and mixtures:** People and wildlife are exposed to multiple chemicals over time, not one chemical in a vacuum. Traditional risk assessments rarely consider mixture toxicity or aggregate exposure from different sources. For example, QUATs rarely occur alone; they often co-occur with other disinfectants or pollutants, potentially interacting synergistically.

  Classic one-off assessments miss these combined effects. This single-chemical approach offers regulatory clarity and administrative efficiency, allowing agencies to set clear exposure limits and take decisive action against well-characterized hazards. However, these same strengths become limitations when real-world exposures involve overlapping chemicals and interacting stressors that fall outside isolated dose-response assumptions.

- **Chronic low-dose effects:** Regulatory toxicology historically emphasizes acute or high-dose effects in laboratory animals. This focus has historically been effective at identifying overt toxicity and preventing clear, high-dose harms, providing regulators with legally defensible and reproducible safety benchmarks. But subtle harms from long-term, low-level exposure (e.g., endocrine disruption, immunotoxicity) may go undetected. In the case of QUATs, studies have found that even sub-inhibitory (very low) concentrations can perturb microbial communities and induce biological changes, effects that would not be flagged by acute toxicity tests.[10]

- **Ecological and cross-species impacts:** Limiting testing to a small number of standardized model species has enabled consistency, reproducibility, and cost-effective regulatory decisionmaking across large numbers of chemicals. But they often ignore impacts on ecological health (e.g., soil microbes, pollinators, food webs) and assume that findings in one species extrapolate simply to others.

  QUATs demonstrate the fallacy of this assumption: minor structural differences between QUAT compounds can lead to dramatically different toxicity profiles across species. A QUAT with a slightly longer alkyl chain, for instance, might be far more toxic to aquatic life than a shorter-chain analog. Grouping such chemicals together (as regulators often do) can hide high-risk outliers behind more benign relatives.

- **Adaptive and emergent risks:** Perhaps most important, the traditional model fails to anticipate emergent risks that develop over time through biological adaptation. Traditional risk assessment frameworks perform well when risks are static, immediate, and

9. U.S. EPA, *supra* note 1.

10. Han et al., *supra* note 5; Ng et al., *supra* note 6.

linear, such as direct toxicity endpoints that do not change over time or across populations, but less well for more dynamic scenarios.

A striking example is antimicrobial resistance. QUAT exposure can select for resistant microbes and amplify the spread of antibiotic resistance genes in the environment. This is not a classical toxic endpoint like tumor formation or lethality; it is a population-level/evolutionary outcome. Conventional risk assessments, which do not monitor endpoints like horizontal gene transfer or microbiome shifts, would completely miss this risk. In effect, the static one-off approach is blind to dynamic processes like the evolution of superbugs or the collapse of beneficial microbial populations.

In the case of QUATs, these limitations have led to regulatory blind spots. QUAT-based disinfectants were approved and widely used under frameworks like the Federal Insecticide, Fungicide, and Rodenticide Act (FIFRA)[11] without robust evaluation of their long-term ecological or microbiological effects. Risk assessments focused on immediate outcomes (e.g., does the disinfectant kill bacteria? does it cause acute harm to humans if ingested or touched?), and assumed that if those criteria were met the product was "safe enough." We now know this narrow lens omitted critical risks. For instance, chronic QUAT residues in water and soil can disrupt aquatic ecosystems, and repeated use can drive pathogens to become drug-resistant.

The QUATs case emphasizes the need to overhaul risk assessment. A new approach must evaluate chemicals in the context of cumulative exposures (considering multiple chemicals and routes), account for chronic and sub-lethal effects on biology, and integrate ecosystem-level outcomes alongside human health. Emerging scientific tools can aid this shift.

For example, NAMs like high-throughput in vitro assays, computational models, "omics" techniques, and organ-on-chip systems, offer the ability to screen chemicals rapidly for a wide array of endpoints and species. Unlike traditional animal tests that focus on one endpoint at a time (e.g., does the chemical cause cancer in rats?), NAMs can probe mechanistic effects on cell pathways, immune function, endocrine signaling, and microbial communities in parallel. They can also model how a chemical behaves across different organisms (supporting cross-species extrapolation) and at environmentally relevant doses.

By utilizing NAMs, regulators could detect early warnings, for instance whether a QUAT compound triggers DNA damage in human cell lines, alters gut microbiota composition in vitro, or causes fish gill cell stress in an organoid model, all before those effects manifest in the real world. Modern science provides the tools to move from static, one-off risk assessments to dynamic, multifaceted evaluations. The challenge lies in reforming regulatory practice to use these tools and to embrace a broader conception of risk that mirrors the landscape of today.

II. Challenge 2: Adopting a "One Health" Lens—Intertwined Human and Environmental Impacts

The health of humans, animals, and ecosystems are deeply interconnected, yet our regulatory system largely treats them in silos. A One Health approach recognizes that disturbances in the environment can reverberate into human health (and vice versa), especially for biologically active chemicals.[12] QUATs exemplify why a One Health perspective is essential. These compounds do not confine their effects to the intended targets, such as bacteria on a hospital floor; they disperse into the wider environment and can set off chains of effects across species and habitats, which eventually circle back to people.

Consider a few scenarios:

- **Healthcare use ⇨ environmental spread:** In hospitals and clinics, QUAT-based disinfectants are used extensively to kill pathogens on surfaces. This practice can inadvertently select for *multidrug-resistant microbes*. Studies show that bacteria repeatedly exposed to QUATs can develop cross-resistance to medically important antibiotics.[13]

  These microbes (or their resistance genes) do not stay confined to the hospital. They are shed into wastewater and survive sewage treatment, ending up in downstream waterways. Wild animals, like urban birds or rodents, and communities living downstream can then be exposed to these resistant strains. In effect, an infection control measure in hospitals could be seeding the environment with antibiotic resistance, which ultimately poses a risk to public health when those genes find their way into human pathogens.

- **Agricultural use ⇨ zoonotic risk:** QUATs are also used in livestock farming (e.g., to disinfect barns and poultry houses). This can disrupt the microbiome of farm animals—for instance, altering gut flora in chickens or pigs. A disrupted microbiome may make animals more susceptible to infections or promote shedding of pathogenic bacteria.

  Concurrently, the use of QUATs on farms can contribute to the rise of resistant bacteria in livestock. Farm workers and wildlife (like birds) moving through these facilities can then carry these potential pathogens beyond the farm. The concern is that

11. 7 U.S.C. §§136 et seq.

12. Anne-Lise Chaber, *The Era of Human-Induced Diseases*, 15 EcoHealth 8 (2018).

13. Kristin Hegstad et al., *Does the Wide Use of Quaternary Ammonium Compounds Enhance the Selection and Spread of Antimicrobial Resistance and Thus Threaten Our Health?*, 16 Microbial Drug Resistance 91 (2010); Fernandes et al., *supra* note 5.

zoonotic pathogens (disease-causing microbes that jump from animals to humans) could be nurtured in such conditions. If QUAT-driven microbiome changes or resistance help a pathogen flourish in livestock, that pathogen might more readily spill over to humans, as seen in countless examples of zoonotic disease emergence.

- **Household use ⇨ ecosystem accumulation:** QUATs are common in consumer products (e.g., antibacterial wipes, cleaners, personal care items).[14] Individual households might seem like a trivial source of pollution, but collectively they contribute significantly to environmental loading. QUAT residues from homes wash down the drain and have been detected in surface waters and even sediments, since wastewater treatment plants do not completely remove these compounds.

  Over time, QUATs accumulate in the environment, creating continuous low-level exposure for aquatic life and soil organisms. This chronic exposure can reduce biodiversity by selectively killing sensitive species of algae, fungi, or bacteria, and alter ecosystem functions like nutrient cycling. Humans depend on these ecosystem services for clean water and so forth, so an ecological impact eventually becomes an economic and health impact for society.

These examples illustrate a core One Health insight: the fate and effects of chemicals are not constrained by human-defined use categories. The current regulatory practice of evaluating a chemical only within a single sector or for a single species misses these cross-sector linkages. In the United States, no agency presently takes responsibility for integrating the human health and environmental dimensions of a chemical's impact. As a result, critical "transmission points" go unmonitored.

For instance, EPA might assess a disinfectant's risks to aquatic organisms under FIFRA, and the U.S. Food and Drug Administration (FDA) might assess its safety for topical use on people, but who is looking at the intersection (e.g., whether using large amounts of that disinfectant in households could foster environmental changes that then affect human infection rates)? Currently, the answer is "no one." This gap means regulators can be blindsided by problems that emerge outside their narrow field of view.

Adopting a One Health framework in chemical risk assessment would provide a more holistic surveillance and early warning system. By monitoring indicators across human, animal, and ecosystem health, agencies could detect harm that would otherwise fly under the radar. In the case of QUATs, a One Health approach might include requirements to track environmental concentrations of these disinfectants, surveillance for resistance genes in wastewater and wildlife, and epidemiological tracking of any links between QUAT-heavy environments and infection outbreaks. Indeed, recent scientific calls for action have urged the integration of ecotoxicology and microbiome data to develop global indicators of antimicrobial resistance spread in the environment, an essential One Health metric.

Crucially, One Health is not just about surveillance, but also about intervention. If we recognize that, for example, overuse of QUATs in hospitals is contributing to downstream antibiotic resistance, policies can be adjusted (e.g., implementing stricter wastewater disinfection or switching to safer alternatives in certain applications). Without a One Health perspective, such connections remain obscured until it is too late. A stark warning is the "silent" spread of antimicrobial resistance: the World Health Organization and the Centers for Disease Control and Prevention have noted that environmental antimicrobial resistance is a growing threat to human health, yet environmental agencies historically have not treated it as their mandate.

In summary, the One Health lens forces us to ask new questions in risk assessment: not just "is this chemical safe for humans at *x* exposure?" but "how does this chemical impact living organisms, and what are the feedback loops to human health?" For QUATs, this means examining how their widespread use may undermine the very public health goals they were meant to serve, by eroding microbial ecosystems and amplifying disease risks.

Embracing One Health in regulatory science would push agencies to coordinate data and actions. Regulators could, for example, incorporate NAM-derived endpoints for immune and microbiome effects across species, align chemical approval decisions with national antimicrobial resistance action plans, and build cross-agency data-sharing networks to track outcomes in real time. The end result would be a chemical regulatory system that anticipates and prevents systemwide harms, rather than reacting after the fact.

III. Challenge 3: Structural Constraints in Fragmented Chemical Governance

Modern chemical hazards increasingly operate at the intersection of human health, animal health, and environmental integrity. QUATs exemplify this reality: they select for antimicrobial resistance, disrupt microbiomes, persist in wastewater and sediments, and exert toxic effects across aquatic and terrestrial species.[15] These are not narrow toxicological endpoints but system-level ecological disruptions. Yet, U.S. chemical law remains built around single-chemi-

14. Robyn T. Carson et al., *Use of Antibacterial Consumer Products Containing Quaternary Ammonium Compounds and Drug Resistance in the Community*, 62 J. Antimicrobial Chemotherapy 1160 (2008).

15. William A. Arnold et al., *Quaternary Ammonium Compounds: A Chemical Class of Emerging Concern*, 57 Env't Sci. & Tech. 7645 (2023); Han et al., *supra* note 5; Ng et al., *supra* note 6; Mahony et al., *supra* note 4; Sarah C. Marteinson et al., *Increased Use of Sanitizers and Disinfectants During the COVID-19 Pandemic: Identification of Antimicrobial Chemicals and Considerations for Aquatic Environmental Contamination*, 31 Env't Revs. 76 (2022).

cal, single-use evaluations that were never designed to govern such One Health risks.

The U.S. regulatory framework divides authority over chemicals among multiple statutes and agencies, including the Toxic Substances Control Act (TSCA),[16] FIFRA, FDA, and the Occupational Safety and Health Administration. This fragmentation prevents any single institution from assessing how a chemical behaves across biological and environmental systems. QUATs illustrate this problem clearly: a disinfectant may be approved under FIFRA for killing microbes on hospital surfaces, reviewed by FDA for topical safety, and entirely escape environmental scrutiny once discharged into wastewater, even though environmental exposure is where antimicrobial resistance and ecological harm emerge.[17]

Even where statutes allow risk evaluation, agencies remain constrained to operate within narrow legal mandates, and those constraints are now compounded by growing legal uncertainty over how far agency authority extends. This uncertainty has intensified following the U.S. Supreme Court's decision in *Loper Bright Enterprises v. Raimondo*, which eliminated *Chevron* deference and requires courts to independently determine the "best reading" of statutes.[18] In the absence of a clear, predictable standard for how courts will assess agency interpretations, regulators face heightened litigation risk when addressing harms not explicitly named in statutory text.

One Health endpoints such as microbiome disruption, resistance gene propagation, or ecosystem-level toxicity do not fit neatly within traditional statutory categories like "cancer risk" or "acute toxicity." Without clearer guidance on how courts will evaluate these emerging endpoints or the processes by which judicial review will occur, efforts to implement comprehensive One Health chemical governance remain legally fragile and institutionally uncertain.

Although EPA has articulated cumulative risk planning principles in its recent guidance,[19] translating those principles into enforceable regulatory decisions remains challenging when statutory text does not explicitly reference ecosystem-level disruption, microbiome alteration, or resistance dynamics. In a post-*Chevron* environment, agencies may hesitate to rely on cumulative ecological reasoning absent clear congressional authorization.

IV. Why One Health Requires a Different Model of Risk Control

Because One Health hazards emerge from interactions among microbes, hosts, and environments, they cannot be controlled solely through endpoint-based regulation. QUATs demonstrate how seemingly benign antimicrobial use can generate population-level threats through resistance selection and ecological disruption.[20] These risks accumulate slowly, spread across species, and are difficult to reverse once established. Traditional regulatory models, which respond only after clear harm has been demonstrated, are ill-suited to manage such dynamics.

A One Health framework therefore demands preventive governance rather than reactive regulation. It requires continuous screening of chemicals for their capacity to destabilize microbial and ecological systems, not just for their ability to cause overt toxicity in laboratory animals. This shifts the locus of risk control upstream, from enforcement to design.

V. NAMs as the One Health Screening Infrastructure

NAMs provide the scientific infrastructure needed to operationalize One Health governance. In vitro assays, organ-on-chip systems, and omics-based platforms can detect immune suppression, microbiome disruption, endocrine effects, and ecotoxicity at environmentally relevant concentrations.[21] Unlike traditional animal testing, NAMs allow simultaneous evaluation across biological pathways and species.

For QUATs, NAMs can identify formulations that promote resistance gene transfer,[22] impair hematopoietic or immune function,[23] or damage aquatic cells.[24] These tools enable pre-market One Health screening, allowing hazards to be detected before chemicals saturate ecosystems and supply chains.

VI. Private-Sector Responsibility for One Health Risk

Because statutory regulation cannot keep pace with complex biological risk, product manufacturers must play a central role in One Health governance. QUAT producers determine which compounds enter hospitals, farms, and households, and therefore how much selective pressure is placed on microbial and ecological systems. A One Health-aligned industry model requires manufacturers to use NAM-based screening to evaluate not only efficacy, but also downstream ecological and resistance risks.

16. 15 U.S.C. §§2601-2629.
17. Arnold et al., *supra* note 15; Han et al., *supra* note 5; Ng et al., *supra* note 6.
18. 603 U.S. 369 (2024).
19. U.S. EPA, *supra* note 1.
20. Hegstad et al., *supra* note 13; Fernandes et al., *supra* note 5; John P. Makumbi et al., *Synergizing Ecotoxicology and Microbiome Data Is Key for Developing Global Indicators of Environmental Antimicrobial Resistance*, 87 Microbial Ecology 150 (2024).
21. U.S. EPA, New Approach Methods Work Plan (2021) (EPA/600/X-21/209), https://www.epa.gov/system/files/documents/2021-11/nams-work-plan_11_15_21_508-tagged.pdf; Organisation for Economic Co-operation and Development (OECD), Guidance Document on the Validation and International Acceptance of New or Updated Test Methods for Hazard Assessment (2005), https://doi.org/10.1787/e1f1244b-en; U.S. Food and Drug Administration (FDA), Roadmap to Reducing Animal Testing in Preclinical Safety Studies, https://www.fda.gov/files/newsroom/published/roadmap_to_reducing_animal_testing_in_preclinical_safety_studies.pdf.
22. Han et al., *supra* note 5; Fernandes et al., *supra* note 5.
23. Zeng et al., *supra* note 7.
24. Arnold et al., *supra* note 15; Marteinson et al., *supra* note 15.

Risk-benefit analysis must incorporate long-term externalities such as wastewater contamination,[25] resistance emergence,[26] microbiome disruption,[27] and ecological toxicity.[28] Products that provide marginal disinfection benefits but generate substantial One Health harms represent unsustainable technological choices, even if they satisfy narrow regulatory criteria.

VII. Toward One Health Chemical Governance

The convergence of NAMs, cumulative risk science, and One Health theory offers a pathway beyond regulatory paralysis. Rather than waiting for statutory reform, chemical safety can be governed through preventive screening, transparent data-sharing, and manufacturer accountability, aligned with public health and environmental protection goals. QUATs illustrate that great risks can arise not just from acute toxicity, but also from slow, systemic biological disruption. Governing such risks requires tools and institutions designed for complexity, not just compliance.

VIII. Conclusion

QUATs reveal a fundamental truth about 21st-century chemical risk: the most dangerous hazards are no longer single-species toxicities, but system-level biological disruptions. QUATs reshape microbial communities, promote antimicrobial resistance, persist in wastewater and sediments, and exert ecotoxic effects across aquatic and terrestrial organisms.[29] These impacts do not occur in isolation. They propagate through interconnected biological and environmental systems, linking environmental contamination to human disease risk. This makes QUATs not merely a regulatory challenge, but a One Health failure.

Traditional chemical regulation was never designed to manage such risks. Laws like TSCA and FIFRA focus on discrete uses, endpoints, and exposure scenarios, while One Health hazards emerge from cumulative exposure, microbial adaptation, and ecological feedback loops. In a post-*Chevron* legal environment, agencies face even greater constraints in interpreting their mandates to address harms that are diffuse, delayed, and cross-sectoral.[30] As a result, waiting for statutory modernization alone is no longer a viable strategy for protecting human and environmental health from biologically active chemicals.

The future of chemical safety therefore lies in preventive, biology-centered governance. NAMs provide the tools to make this shift possible. In vitro systems, organ-on-chip platforms, and omics-based assays can detect immune disruption, microbiome alteration, resistance selection, and ecotoxicity at environmentally relevant concentrations, allowing One Health risks to be identified before they become irreversible.[31] Applied to QUATs, these methods can flag formulations that promote resistance genes,[32] impair immune and hematopoietic systems,[33] or damage aquatic organisms.[34]

Yet, science alone is not enough. Because regulatory systems are slow and fragmented, product manufacturers must become central actors in One Health risk management. The private sector controls which disinfectants, antimicrobials, and formulations enter hospitals, farms, and households, and therefore determines how much selective pressure is placed on microbial and ecological systems. A One Health-aligned approach requires NAM-based screening and risk-benefit analysis that accounts for downstream costs such as wastewater contamination,[35] antimicrobial resistance,[36] microbiome disruption,[37] and ecosystem toxicity.[38]

The case of QUATs demonstrates that chemical safety in the modern world cannot be achieved through narrow compliance alone. It requires a shift from reactive regulation to proactive One Health governance, grounded in predictive science and shared responsibility across public and private sectors.

By integrating NAM-based screening, cumulative risk assessment as envisioned in recent federal guidance,[39] and One Health principles into how chemicals are designed, evaluated, and deployed, society can move from managing chemical harm to preventing it. The stakes extend far beyond disinfectants. They encompass the resilience of microbial ecosystems, the integrity of the environment, and the long-term sustainability of human health itself.

25. Mahony et al., *supra* note 4.
26. Hegstad et al., *supra* note 13; Fernandes et al., *supra* note 5.
27. Ng et al., *supra* note 6.
28. Arnold et al., *supra* note 15; Marteinson et al., *supra* note 15.
29. Arnold et al., *supra* note 15; Han et al., *supra* note 5; Ng et al., *supra* note 6; Mahony et al., *supra* note 4; Marteinson et al., *supra* note 13.
30. *See* Loper Bright Enters. v. Raimondo, 603 U.S. 369 (2024).
31. U.S. EPA, *supra* note 21; OECD, *supra* note 21; FDA, *supra* note 21.
32. Han et al., *supra* note 5; Fernandes et al., *supra* note 5.
33. Zeng et al., *supra* note 7.
34. Arnold et al., *supra* note 15; Marteinson et al., *supra* note 15.
35. Mahony et al., *supra* note 4.
36. Hegstad et al., *supra* note 13; Fernandes et al., *supra* note 5.
37. Ng et al., *supra* note 6.
38. Arnold et al., *supra* note 15.
39. U.S. EPA, *supra* note 1.