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"A thing is right when it tends to preserve the integrity, stability and beauty of the biotic community. It is wrong when it tends otherwise."[1]

Aquatic life water quality criteria are numeric or narrative descriptions of water quality that protect aquatic life from unhealthy water conditions.[2] The Clean Water Act (CWA) requires the U.S. Environmental Protection Agency (EPA) to

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1. ALDO LEOPOLD, A SAND COUNTY ALMANAC AND SKETCHES HERE AND THERE 224 (1949).

2. *See* USEPA, NATIONAL RECOMMENDED WATER QUALITY CRITERIA—AQUATIC LIFE CRITERIA TABLE https://www.epa.gov/wqc/national-recommended-water-quality-criteria-aquatic-life-criteria-table (last visited Mar. 1, 2020). Aquatic life criteria for toxic chemicals are the highest concentration of specific pollutants or parameters in water that are not expected to pose a significant risk to the majority of species in a given environment or a narrative description of the desired conditions of a water body being 'free from' certain negative conditions.

develop and, as necessary, revise "criteria for water quality that accurately reflect *the latest scientific knowledge*."[3] In carrying out this mandate, the EPA develops water quality criteria for aquatic life ("criteria or criterion") and recommends that each state adopt the EPA criteria into state-specific water quality standards.[4] Directly or indirectly, criteria form a foundational basis of most CWA regulatory programs and enforcement actions.[5] This Article argues that EPA is failing its mandate under the CWA to develop recommended criteria according to the latest science.

First, numeric criteria are currently developed according to the Stephan *et al.* 1985 guidelines ("1985 guidelines") by methods described as "objective, internally consistent, appropriate[,] and feasible."[6] In recent years, however, the scientific community has criticized the 1985 guidelines for

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3. 33 U.S.C. § 1314(a)(1) (emphasis added). The CWA and the EPA do not define "latest scientific knowledge," which this Article refers to as "latest science." This Article does not attempt to define the precise contours of the latest science, but it does attempt to briefly describe the current and relevant science. It is worth emphasizing that the CWA uses the term "latest." Latest suggests that the EPA may have limited discretion to select their most preferred science. Rather, the term latest appears to provide the scientific community with heightened deference to determine the latest science under the CWA because the scientific community discovers, debates, verifies, judges, and communicates the latest science.

4. 33 U.S.C. § 1314(l); 40 C.F.R. § 131.11. Although the EPA develops other types of water quality criteria under the CWA (e.g., criteria for protection of human health), this Article refers exclusively to water quality criteria for the protection of aquatic life. As a result, any reference to "criteria" or a similar term in this Article is a reference to aquatic life water quality criteria. Additionally, all references to "criteria" refer to EPA-developed national recommendations unless stated otherwise.

5. For example, state water quality standards, the National Pollution Discharge Elimination System (NPDES) permitting, CWA § 401 state certifications of federal projects, water quality-based effluent limitations, and even CWA § 404 dredge and fill permits under some circumstances. Criteria are also important features of or implicated in the Rivers and Harbors Act, the National Environmental Policy Act, the Federal Power Act, the Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA), and others.

6. CHARLES. E. STEPHEN ET AL., US ENVIRONMENTAL PROTECTION AGENCY, GUIDELINES FOR DERIVING NUMERICAL NATIONAL WATER QUALITY CRITERIA FOR THE PROTECTION OF AQUATIC ORGANISMS AND THEIR USES 1 (1985) [hereinafter 1985 GUIDELINES]("Because it is not feasible to determine national criteria by conducting such field tests, these Guidelines . . . describe an objective, internally consistent, appropriate, and feasible way of deriving national criteria, which are intended to provide the same level of protection as the infeasible field testing approach.").

emphasizing criteria development through reductionist, single-species toxicity testing that maximizes experimental control and replicability rather than criteria developed by environmentally realistic experiments and field observations that more closely represent nature but are inherently more variable.[7] In other words, the 1985 guidelines are criticized because they precisely describe the concentrations of pollutants that harm aquatic life in laboratory settings, but they may not accurately describe the concentrations of pollutants that harm aquatic life in natural settings. The EPA itself has recognized that the 1985 guidelines may not reflect the latest science.[8] Therefore, the EPA should

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7. *See, e.g.*, David. B. Buchwalter, William H. Clements, & Samuel N. Luoma, *Modernizing Water Quality Criteria in the United States: A Need to Expand the Definition of Acceptable Data*. 36 ENVTL. TOXICOLOGY & CHEMISTRY 285, 285–86 (2017).

> Although we can look back with admiration at the foresight that the drafters of the 1985 guidelines possessed . . . Much has been learned about how the world works in practically every facet of ecology, chemistry, and environmental toxicology since 1985 . . . Traditional toxicity testing approaches employed to establish [water quality criteria] have long been criticized, primarily because their translation to nature is questionable;

see also Monica D. Poteat & David B. Buchwalter, *Four Reasons Why Traditional Metal Toxicity Testing with Aquatic Insects Is Irrelevant*, 48 ENVTL. SCI. & TECH. 887, 888 (2014) ("Here we provide evidence for why the test methodologies themselves are inadequate and in need of modernization so that water quality criteria are scientifically up to date."); Manoel Augusto Whitaker Pacheco, Dennis Owen McIntyre, & Tyler Keith Linton, *Integrating Chemical and Biological Criteria*, 24 ENVTL. TOXICOLOGY & CHEMISTRY 2983, 2983 (2005) ("A weakness is that endpoints measured mostly in laboratory tests may not represent adequately their conservation targets."). *Cf.* David DeForest et al., *Retrospective on the United States Environmental Protection Agency's Guidelines for Deriving Ambient Water Quality Criteria*, 13 INTEGRATED ENVTL. ASSESSMENT & MGMT. 1124, 1124 (2017) "[Aquatic life water quality criteria] for several chemicals are more than [thirty] years old—meaning that [thirty]+ years of data are not considered in these [criteria]—and many chemicals still do not have [criteria].").

8. *See, e.g.*, U.S. ENVTL. PROT. AGENCY, INVITED EXPERT MEETING ON REVISING U.S. EPA'S GUIDELINES FOR DERIVING AQUATIC LIFE CRITERIA, https://www.epa.gov/wqc/invited-expert-meeting-revising-us-epas-guidelines-deriving-aquatic-life-criteria (last visited Dec. 22, 2019)

> On September 14-16, 2015, the U.S. EPA, Office of Water, Office of Science and Technology, hosted an invited expert meeting to gather information regarding the state of the science for ecological risk assessment as it pertains to revising the 1985 *Guidelines* . . . EPA is considering information presented during the meeting regarding new and alternative methods for deriving aquatic life criteria in our effort to update the 1985 *Guidelines*.

update the 1985 guidelines for deriving numeric criteria to more accurately reflect the latest science by embracing the complexities of nature rather than fighting complexity through reductionist approaches that better characterize laboratory conditions than ecosystems.

Second, the EPA's over-reliance on developing numeric criteria on a contaminant-by-contaminant basis does not reflect the latest science unless numeric criteria are simultaneously supplemented by more flexible standards such as narrative criteria.[9] Discrete numeric criteria cannot possibly capture the complexities of aquatic life's sensitive in nature: Toxicity varies based on numerous interrelated biotic and abiotic factors. Pollutant mixtures may be more or less toxic than the sum of their parts and may elicit toxic effects on aquatic organisms even though no single pollutant exceeds the criterion value. Moreover, the EPA cannot develop criteria fast enough to keep pace with scientific advances, the diversity of existing pollutants, or the emergence of novel pollutants. The EPA should embrace the supplemental value of narrative criteria by reinforcing every numeric criterion with a companion narrative statement to provide flexibility to otherwise rigid numeric criteria. The EPA should also develop a single national catch-all narrative criterion as a gap-filler for pollutants not directly regulated by more specific criteria.

This Article proceeds in two sections. Section I discusses relevant CWA provisions to explain the importance of water quality criteria under federal law. It discusses well-established

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See also Susan M. Cormier et al., *Using Field Data and Weight of Evidence to Develop Water Quality Criteria*, 4 INTEGRATED ENVTL. ASSESSMENT & MGMT. 490, 490–504 (2008)

> Criterion development has relied most heavily on one scientifically rigorous method . . . that uses data from laboratory toxicity tests [according to the Stephan et al. 1985 guidelines]. This clear and consistent methodology has been used successfully to develop criteria when laboratory tests are possible and are sufficient for estimating effects. However, a broader methodology is needed because some effects of pollutants do not lend themselves to conventional toxicity testing.

9. *Cf.* Robert W. Adler, *Resilience, Restoration, and Sustainability: Revisiting the Fundamental Principles of the Clean Water Act*, 32 WASH. U. J. L. & POL'Y 139, 148 (2010) ("[I]t would seem that individual numeric water quality criteria are, at best, necessary but not sufficient to attain aquatic ecosystem health . . . Congress envisioned that water quality standards would address factors other than concentrations of individual pollutants.").

ecology and toxicology principles that are generally not included in criteria development by regulators but reflect the latest science. This section also explains how the EPA currently develops water quality criteria using the 1985 guidelines, and it describes the criteria development modernization effort that the EPA publicly initiated in 2015 and quietly abandoned in 2019. Section II proposes that the EPA resumes efforts to modernize criteria development by revising the 1985 guidelines. This section also proposes that over-reliance on numeric criteria, which are not supported by narrative criteria, is not the latest science. This Article asserts that the EPA may be noncompliant with the CWA's "latest scientific knowledge" mandate and offers specific suggestions for attaining compliance.

The EPA-recommended criteria are merely that—recommendations.[10] States are free to select criteria of their choice as long as the selections are based on "sound scientific rationale" and the EPA approves the selections.[11] However, given the EPA's unmatched scientific and regulatory expertise under the CWA, the criteria recommended by the EPA should, and must, represent the latest science.[12] Such criteria can pressure states with less than protective water quality standards to strengthen their standards.[13] Conversely, when the EPA's recommended criteria do not reflect the latest science, states may rely on those recommendations to the detriment of the nation's aquatic resources. Or worse, states may doubt the EPA's expertise to the detriment of the EPA's mission.[14]

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10. *See* U.S. ENVTL. PROT. AGENCY, BASIC INFORMATION ON WATER QUALITY CRITERIA, https://www.epa.gov/wqc/basic-information-water-quality-criteria (last visited Jan. 4, 2020)

> EPA develops criteria for determining when water has become unsafe for [aquatic life] using the latest scientific knowledge. These criteria are recommendations. State and tribal governments may use these criteria or use them as guidance in developing their own . . . EPA bases aquatic life criteria on how much of a chemical can be present in surface water before it is likely to harm plant and animal life. EPA designs aquatic life criteria to protect both freshwater and saltwater organisms from short-term and long-term exposure.

11. 40 C.F.R. § 131.11(a)(1).

12. 33 U.S.C. § 1314(a)(1).

13. *See* 40 C.F.R. § 131.11(a)(1) ("States must adopt those water quality criteria that protect the designated use.").

14. U.S. ENVTL. PROT. AGENCY, OUR MISSION AND WHAT WE DO, https://www.epa.gov/aboutepa/our-mission-and-what-we-do (last visited Feb. 2, 2020) ("The mission of EPA is to protect human health and the environment.").

Developing criteria is an incredibility difficult and complex process. The 1985 guidelines were groundbreaking thirty-five years ago. Scientists who have contributed to criteria development over the years should be celebrated. Their work is a substantial cause of the CWA's successes. Their work also provides much of the evidentiary basis for this Article's arguments. The EPA's noncompliance with the CWA's latest science mandate is an administrative failure and not a scientific failure. Nevertheless, criteria development must be modernized.

I. WATER QUALITY CRITERIA INTEGRATE SCIENCE INTO THE LAW

The CWA utilizes layers of protective regulatory mechanisms "to restore and maintain the chemical, physical, and biological integrity of the Nation's waters."[15] Water quality criteria are critical to many of these mechanisms because the criteria form a qualitative and quantitative basis for their implementation.[16] Ultimately, however, criteria protectiveness is limited to the extent that criteria sufficiently integrate the realities of nature into their development and implementation.[17] Achieving the CWA's ambitious goals requires, in substantial part, marrying its regulatory mechanisms with developing "criteria for water quality [that] accurately reflect[] the latest scientific knowledge."[18]

This section first describes some relevant provisions of the CWA to place water quality criteria within the statute's regulatory framework. It then briefly describes important aquatic ecotoxicology principles[19] to explain why it is difficult to

15. *See* 33 U.S.C. § 1251(a) (explaining the purpose of the CWA); *see* S. D. Warren Co. v. Me. Bd. of Envtl. Prot., 547 U.S. 370, 385 (2006) ("[T]he Act does not stop at controlling the 'addition of pollutants,' but deals with 'pollution' generally . . . which Congress defined to mean 'the manmade or man-induced alteration of the chemical, physical, biological, and radiological integrity of water.'") (citing 33 U.S.C. § 1362(19)).

16. Criteria are distinct from two prominent CWA regulatory mechanisms: (1) the general prohibition against point source discharges, and (2) technology-based effluent limitations. 33 U.S.C. § 1311.

17. *See* Buchwalter, Clements, & Luoma, *supra* note 7, at 286 (concerning that the traditional approach reflected in the 1985 guidelines "lack[] ecological realism").

18. 33 U.S.C. § 1314(a)(1).

19. Aquatic ecotoxicology is the scientific study of the effects of water pollution on aquatic organism individuals and groups.

integrate current CWA regulations with modern science. Next, this section discusses the current EPA criteria development process. The section concludes by describing the EPA's efforts to modernize its criteria development policy and the interruption of those efforts.

A. WATER QUALITY CRITERIA ARE FOUNDATIONAL TO THE CLEAN WATER ACT

Water quality criteria are numeric or narrative descriptions of water quality used to determine when water is not suitable for particular uses.[20] For example, a numeric criterion for pollutant X could be "Aquatic life should not be affected unacceptably if pollutant X does not exceed Y grams per liter for more than one-hour every three-years." A narrative criterion for pollutant X could be "No pollutant X in amounts that cause physiological harm to aquatic life."

The section examines criteria within two prominent CWA regulatory mechanisms—effluent limitations and water quality standards—to illustrate the importance of developing criteria that accurately reflect the latest science. Effluent limitations (i.e., technology-based effluent limitation and water quality-based effluent limitations) focus on minimizing the adverse effects of point source pollution by requiring that dischargers remove certain amounts of particular pollutants from contaminated effluent before the effluent is discharged to

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20. 33 U.S.C. § 1314; *see also* U.S. ENVTL. PROT. AGENCY, WATER QUALITY STANDARDS HANDBOOK CHAPTER 3: WATER QUALITY CRITERIA 1–2, https://www.epa.gov/sites/production/files/2014-10/documents/handbook-chapter3.pdf.

> Water quality criteria represent the conditions (*e.g.*, concentrations of particular chemicals, levels of certain parameters) sufficient to restore and maintain the chemical, physical, and biological integrity of water bodies and protect applicable designated uses. Generally, criteria provide for the protection and propagation of fish, shellfish, and wildlife as well as recreation in and on the water. If a criterion is exceeded, the water quality may pose a human health or ecological risk, and protective or remedial action may be needed.

Please note that although other types of water quality criteria (*e.g.*, criteria for protecting human health) are developed under the CWA by the EPA, this Article focuses on EPA-recommended water quality criteria for aquatic life that protect the propagation of fish, shellfish, and wildlife under the CWA. *See* 33 U.S.C. § 1251(a)(2).

navigable waters.[21] Water quality standards focus on the quality of the navigable water itself rather than the characteristics of the effluent discharged from the point source.[22] Water quality criteria are foundational to water quality-based effluent limitations and water quality standards.[23]

i. Effluent Limitations, the National Pollution Discharge Elimination System, and Water Quality Criteria

The CWA imposes a total prohibition against the "discharge of any pollutant by any person."[24] However, a National Pollution Discharge Elimination System ("NPDES") permit acts as an exception to that prohibition—and to the CWA's "zero-discharge goal"[25]—by allowing a permittee (e.g., chemical producers, power

21. 33 U.S.C. §§ 1311–12; *see also* U.S. Envtl. Prot. Agency, National Pollution Discharge Elimination System (NPDES) Permit Writers Manual, 5-1 (2010) [hereafter NPDES Manual]

> Technology-based effluent limitations (TBELs) aim to prevent pollution by requiring a minimum level of effluent quality that is attainable using demonstrated technologies for reducing discharges of pollutants or pollution into the waters of the United States. TBELs are developed independently of the potential impact of a discharge on the receiving water, which is addressed through water quality standards and water quality-based effluent limitations.

22. 33 U.S.C. §§ 1313; *see also* U.S. ENVTL. PROT. AGENCY, STANDARDS FOR WATER BODY HEALTH, https://www.epa.gov/standards-water-body-health/what-are-water-quality-standards (last visited Jan. 4, 2020)

> Water quality standards (WQS) are provisions of state, territorial, authorized tribal or federal law approved by EPA that describe the desired condition of a water body and the means by which that condition will be protected or achieved . . . To protect human health and aquatic life in these waters, states, territories and authorized tribes establish WQS. WQS form a legal basis for controlling pollutants entering the waters of the United States.

23. 33 U.S.C. §§ 1311–13.

24. 33 U.S.C. § 1311(a); 33 U.S.C. § 1362(12) ("The term 'discharge of a pollutant' and the term 'discharge of pollutants' each means (A) any addition of any pollutant to navigable waters from any point source . . . ."); 33 U.S.C. § 1362(6) ("The term 'pollutant' means dredged spoil, solid waste, incinerator residue, sewage, garbage, sewage sludge, munitions, chemical wastes, biological materials, radioactive materials, heat, wrecked or discarded equipment, rock, sand, cellar dirt and industrial, municipal, and agricultural waste discharged into water."); 33 U.S.C. § 1362(14) ("The term 'point source' means any discernible, confined and discrete conveyance. . . ."); 33 U.S.C. § 1362(7) ("The term 'navigable waters' means the waters of the United States, including the territorial seas.").

25. 33 U.S.C. § 1251(a)(1) ("[I]t is the national goal that the discharge of pollutants into the navigable waters be eliminated by 1985."). "Despite significant progress toward reducing pollutant discharges over the past four decades,

plants, concentrated animal feedlots, and wastewater treatment plants) to discharge pollutants to navigable waters according to the conditions of their NPDES permit.[26] The EPA delegates to most states, some territories, and some tribes, the power to grant and condition their own NPDES permits that are enforceable under federal law, but the EPA retains veto authority over the permits.[27]

NPDES permits require that permittees install pollution mitigation procedures and technologies (i.e., effluent limitations) that remove pollutants from point source effluent before the effluent is discharged to a navigable water.[28] As an

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however, it is notable that we remain a long way from achieving the goal several decades after the deadline for the initial goal passed." Robert W. Adler, *The Decline and (Possible) Renewal of Aspiration in the Clean Water Act*, 88 WASH. L. REV. 759, 765 (2013). *See, e.g.*, *id*. at 777 ("[I]ndustries continued to discharge nearly a quarter of a billion pounds of toxic pollutants into U.S. surface waters in 2011.").

26. 33 U.S.C § 1311(a) ("Except as in compliance with this section and sections 302, 306, 307, 318, 402, and 404 of this Act [33 USCS §§ 1312, 1316, 1317, 1328, 1342, 1344], the discharge of any pollutant by any person shall be unlawful."); 33 U.S.C. § 1251(a); *see also*, U.S. ENVTL. PROT. AGENCY, NPDES PERMIT BASICS, https://www.epa.gov/npdes/npdes-permit-basics (last visited Jan. 4, 2020)

> The Clean Water Act prohibits anybody from discharging 'pollutants' through a 'point source' into a 'water of the United States' unless they have an NPDES permit. The permit will contain limits on what you can discharge, monitoring and reporting requirements, and other provisions to ensure that the discharge does not hurt water quality or people's health. In essence, the permit translates general requirements of the Clean Water Act into specific provisions tailored to the operations of each person discharging pollutants;

33 U.S.C. § 1342(k) (describing NPDES permit shield).

27. 33 U.S.C. § 1342. This Article refers to states, territories, and tribes as "states."

28. 33 U.S.C. § 1311

> In order to carry out the objective of this chapter there shall be achieved . . . effluent limitations for categories and classes of point sources . . . which (i) shall require application of the best available technology economically achievable for such category or class, which will result in reasonable further progress toward the national goal of eliminating the discharge of all pollutants;

40 C.F.R. § 122.44; *see also* U.S. ENVTL. PROT. AGENCY, NPDES PERMIT LIMITS, https://www.epa.gov/npdes/npdes-permit-limits (last visited Nov. 29 2018)

> Effluent limitations serve as the primary mechanism in NPDES permits for controlling discharges of pollutants to receiving waters. When developing effluent limitations for an NPDES permit, a permit writer must consider limits based on both the technology available to control the pollutants (*i.e.*, technology-based effluent limits) and limits that

additional safeguard, NPDES permits may also contain whole effluent toxicity (WET) test procedures that require dischargers to conducted toxicity tests on the effluent itself to ensure that the effluent discharge is not more toxic than expected.[29] Importantly, if technology-based effluent limitations are insufficient to protect state water quality standards, the state's NPDES permitting authority must implement more stringent water quality-based effluent limitations.[30] As discussed below, criteria are a fundamental component of state water standards. Therefore, criteria directly affect which technologies and procedures a permittee uses to eliminate or reduce certain pollutants from effluent discharges because the effluent discharges must avoid exceeding applicable water quality criteria.[31] Otherwise, a permittee would violate their NPDES permit.[32] To put it another way, water quality criteria developed through the latest science ensure that NPDES permits actually serve their protective purpose by requiring that effluent limitations adequately protect aquatic life from the known dangers of pollutants.

> are protective of the water quality standards of the receiving water (*i.e.*, water quality-based effluent limits).

29. U.S. ENVTL. PROT. AGENCY, WHOLE EFFLUENT TOXICITY, https://www.epa.gov/npdes/whole-effluent-toxicity-wet (last visited Feb. 14, 2020)

> Whole Effluent Toxicity (WET) describes the aggregate toxic effect of an aqueous sample (e.g., whole effluent wastewater discharge) as measured by an organism's response upon exposure to the sample (e.g., lethality, impaired growth, or reproduction). EPA's WET tests replicate the total effect of environmental exposure of aquatic life to toxic pollutants in an effluent without requiring the identification of the specific pollutants . . . WET limits are included in permits to ensure that the state or tribal water quality criteria for aquatic life protection are met.

30. 33 U.S.C. § 1311(a); 40 C.F.R. § 122.44; 40 C.F.R. § 125.3; *see also* NPDES MANUAL, *supra* note 21, at 6-1

> [Water quality-based effluent limitations] are designed to protect water quality by ensuring that water quality standards are met in the receiving water. On the basis of the requirements of [40 C.F.R.] 125.3(a), additional or more stringent effluent limitations and conditions, such as [water quality-based effluent limitations], are imposed when [technology-based effluent limitations] are not sufficient to protect water quality.

31. *See supra* note 30 and accompanying text.

32. *See supra* note 26 and accompanying texts.

ii. Water Quality Standards and Water Quality Criteria

Water quality standards are regulatory baselines for establishing restoration and protection objectives and form one of the legal bases for water pollution controls under the CWA.[33] Water quality standards are typically established by states, and once approved by the EPA, water quality standards become enforceable under federal law through the CWA.[34]

The CWA requires that states adopt water quality standards consisting of three parts: (1) a water body's designated use (e.g., public water supplies, industrial use, or propagation of fish, shellfish, and wildlife),[35] (2) a water quality criteria (i.e., the maximum concentration of pollution that protects a water

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33. *See* 40 C.F.R. § 131.2.

> [Water quality standards] define[] the water quality goals of a water body, or portion thereof, by designating the use or uses to be made of the water and by setting criteria that protect the designated uses . . . . States adopt water quality standards to protect public health or welfare, enhance the quality of water and serve the purposes of the Clean Water Act (the Act) . . . [including], wherever attainable, provide water quality for the protection and propagation of fish, shellfish and wildlife . . . . Such standards serve the dual purposes of establishing the water quality goals for a specific water body and serve as the regulatory basis for the establishment of water-quality-based treatment controls and strategies beyond the technology-based levels of treatment required by sections 301(b) and 306 of the Act.

See also U.S. ENVTL. PROT. AGENCY, WATER QUALITY STANDARDS HANDBOOK CHAPTER 1: GENERAL PROVISIONS (2014), https://www.epa.gov/sites/production/files/2014-10/documents/handbook-chapter1.pdf ("[Water quality standards] establish the environmental baselines used for measuring the success of CWA programs, so adequate protection of aquatic life and wildlife, recreational uses, and sources of drinking water, for example, depends on developing and adopting well-crafted [water quality standards].").

34. 40 C.F.R. § 131.4; *see also* STANDARDS FOR WATER BODY HEALTH, *supra* note 22 and accompanying text.

35. 40 C.F.R. § 131.10 ("Each state must specify appropriate water uses to be achieved and protected."); *see also* 33 U.S.C. § 1313; U.S. ENVTL. PROT. AGENCY, THE USES OF A WATER BODY, https://www.epa.gov/wqs-tech/key-concepts-module-2-use (last visited Jan. 17, 2019). The CWA provides a list of designated uses that must be considered when developing water quality standards. *See* 33 U.S.C § 1313(c)(2)(A) (including public water supplies, propagation of fish and wildlife, recreational purposes, agricultural, industrial, and other purposes).

body's designated use),[36] and (3) an antidegradation policy.[37] If the EPA disapproves of a state's water quality standards, or the state fails to submit water quality standards for certain pollutants such as toxic pollutants, then the EPA will establish legally binding water quality standards for the state.[38] Although states have wide latitude to establish water quality standards according to that state's needs,[39] water quality standard development is an intensive process with regard to both science and regulation.[40] Therefore, the EPA encourages states to base their water quality standards on EPA guidances and criteria recommendations such as the National Recommended Aquatic Life Water Quality Criteria.[41]

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36. *See* 40 C.F.R. § 131.3 (b) ("Criteria are elements of State water quality standards, expressed as constituent concentrations, levels, or narrative statements, representing a quality of water that supports a particular use. When criteria are met, water quality will generally protect the designated use.").

37. Antidegradation policies ensure that high quality waters that are currently complaint with water quality standards maintain and protect "existing instream water uses and the level of water quality necessary to protect the existing uses." 40 C.F.R. § 131.12; *see also* U.S. ENVTL. PROT. AGENCY, WATER QUALITY STANDARDS HANDBOOK CHAPTER 4: ANTIDEGRADATION (2012), https://www.epa.gov/sites/production/files/2014-10/documents/handbook-chapter4.pdf.

38. 33 U.S.C. § 1313 (c); 40 C.F.R. § 131.11; 40 C.F.R. § 131.5; *see also* 33 U.S.C. § 1362(13)

> The term "toxic pollutant" means those pollutants, or combinations of pollutants, including disease-causing agents, which after discharge and upon exposure, ingestion, inhalation or assimilation into any organism, either directly from the environment or indirectly by ingestion through food chains, will, on the basis of information available to the Administrator, cause death, disease, behavioral abnormalities, cancer, genetic mutations, physiological malfunctions (including malfunctions in reproduction) or physical deformations, in such organisms or their offspring.

39. *But see* Mississippi Comm'n on Nat. Res. v. Costle, 625 F.2d 1269, 1275, 1276 (5th Cir. 1980) ("Despite this primary allocation of power, the states are not given unreviewable discretion to set water quality standards. . . EPA's role also is more dominant when water quality criteria are in question.").

40. *See* Christopher B. Power & Jennifer J. Hicks, *Water Quality Standard Setting Under the Clean Water Act: Is It Nimble Enough to Avoid Wasteful Spending on the Wrong Goals?*, 116 W. VA. L. REV. 1075, 1085–86, 1088–91 (2014) (explaining state reliance on the EPA for state water quality standards and criteria development, and the difficult regulatory process for adopting water quality standards).

41. 33 U.S.C. §§ 1313, 1314(a); 40 C.F.R. § 131.11 (b); *see also* Arkansas v. Oklahoma, 503 U.S. 91, 101 (1992) ("The EPA provides States with substantial guidance in the drafting of water quality standards.").

Water quality criteria describe the maximum permissible amount of a pollutant that protects a water body's designated use.[42] For example, aquatic life water quality criteria are developed to protect "any designated uses related to protection and propagation of fish, shellfish, and wildlife."[43] Aquatic life water quality criteria are generally more protective than criteria developed to protect "industrial" designated uses, but may be less protective than criteria developed to protect "drinking water" designated uses.[44]

The EPA encourages states to develop criteria as numeric values.[45] For example, the EPA recommends a numeric criterion of 1.4 micrograms of mercury per liter of water (μg/L) to protect aquatic life from acute exposure to mercury.[46] Therefore, mercury concentrations higher than 1.4 μg/L are expected to have adverse health effects on aquatic life. Criteria may also be expressed as a narrative statement when "numerical criteria cannot be established or to supplement numerical criteria."[47]

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42. *See* 33 U.S.C. §§ 1313; 40 C.F.R. § 131.11 ("[C]riteria must be based on sound scientific rationale and must contain sufficient parameters or constituents to protect the designated use. For waters with multiple use designations, the criteria shall support the most sensitive use.").

43. Water Quality Standards Handbook Chapter 3, *supra* note 20, at 14.

44. *See id.* at 26 ("Generally, criteria developed for human health and aquatic life will be sufficiently stringent to protect agricultural and industrial designated uses because those uses are generally less sensitive than human health and aquatic life designated uses.").

45. *See* 40 C.F.R. § 131.11(b).

46. *See* AQUATIC LIFE CRITERIA TABLE, *supra* note 2. Criteria typically consist of three parts: (1) a magnitude expressed as a numeric value or narrative statement, (2) a duration for how long a criteria may be exceeded before adverse health effects are expected, and (3) a frequency indicating how often a criteria may be exceeded before adverse health effects are expected. For example, a more complete criteria for acute exposure to mercury could be expressed as, 1.4 μg /L for one hour every three years.

47. 40 C.F.R. § 131.11 (b); *see also* 33 U.S.C. § 1314(a)(8) ("The Administrator . . . shall develop and publish information on methods for establishing and measuring water quality criteria for toxic pollutants on other bases than pollutant-by-pollutant criteria, including biological monitoring and assessment methods."); 33 U.S.C. § 1313 (c)(2)(B)

> Such criteria shall be specific numerical criteria for such toxic pollutants. Where such numerical criteria are not available, whenever a State reviews water quality standards pursuant to paragraph (1), or revises or adopts new standards pursuant to this paragraph, such State shall adopt criteria based on biological monitoring or assessment methods consistent with information published pursuant to section 1314(a)(8) of this title. Nothing in this section shall be construed to limit or delay the use of effluent limitations or other permit

Examples of narrative criteria include "surface waters shall be virtually free from . . . petroleum derived oils," or "levels of oils or petrochemicals in sediment which cause deleterious effects to the biota should not be allowed."[48] Aquatic life criteria may also take the form of numeric or narrative biocriteria.[49] Rather than focusing on the concentration or the chemical composition of a pollutant itself, biocriteria focus on how populations and communities of organisms are affected by pollutants.[50]

The EPA is required to develop its recommended criteria "for water quality accurately reflecting the latest scientific knowledge" and without consideration of the criteria's economic impact.[51] Although the EPA-developed criteria are not binding regulations imposed on states, the CWA directs states to adopt the EPA's criteria recommendations, modify the EPA's recommendations "to reflect site-specific conditions," or create criteria based on "other scientifically defensible methods."[52] Because the EPA has approval authority over state water quality standards, if a state deviates from the EPA criteria

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conditions based on or involving biological monitoring or assessment methods or previously adopted numerical criteria.

48. U.S. ENVTL. PROT. AGENCY, QUALITY CRITERIA FOR WATER 208 (1986), https://www.epa.gov/sites/production/files/2018-10/documents/quality-criteria-water-1986.pdf. As long as the EPA approves, states may adopt numeric criteria, narrative criteria, biological criteria, or criteria based on whole effluent toxicity testing. *See* 40 C.F.R. § 131.11(b); *see also* WHOLE EFFLUENT TOXICITY, *supra* note 29; U.S. ENVTL. PROT. AGENCY, BIOLOGICAL WATER QUALITY CRITERIA, https://www.epa.gov/wqc/biological-water-quality-criteria (last visited Feb. 14, 2020).

49. 33 U.S.C. § 1314.

50. *See* Robert W. Adler, *Coevolution of Law and Science: A Clean Water Act Case Study*, 44 COLUM. J. ENVTL. L. 1, 22 (2019) ("Biocriteria measure aquatic ecosystem health directly, by comparing the health of aquatic organisms and the diversity and composition of species in the water body compared to unpolluted waters.").

51. 33 U.S.C. § 1314; *see also* 40 C.F.R. 131.11 ("Such criteria must be based on sound scientific rationale and must contain sufficient parameters or constituents to protect the designated use. For waters with multiple use designations, the criteria shall support the most sensitive use."); *see, e.g.*, Recommended Aquatic Life Ambient Water Quality Criteria for Cadmium—2016, 81 Fed. Reg. 19176–77 (Apr. 4, 2016) ("Water quality criteria . . . are based solely on data and the latest scientific knowledge on the relationship between pollutant concentrations and environmental and human health effects. Section 304(a) criteria do not reflect consideration of economic impacts or the technological feasibility of meeting pollutant concentrations in ambient water.").

52. 33 U.S.C. § 1313; 40 C.F.R. § 131.11 (allowing development of site-specific criteria); 40 C.F.R. § 131.13 (allowing for WQS variances); 40 C.F.R. § 131.14 (describing water quality standard procedures).

recommendations then the state must justify its reasoning to the EPA.[53] Where states seek to adopt criteria different than those recommended by the EPA, the state must persuade the EPA that its proposed criteria protect the water's designated use.[54] Therefore, not only do EPA criteria recommendations profoundly influence state water quality standards by providing a baseline to which state water quality standards are compared, they also provide much of the scientific support that states rely on when they create their own water quality standards.[55] Even then, states are free to promulgate their own criteria that are different from the EPA recommendations as long as the EPA agrees that the criteria are scientifically defensible.[56]

iii. Criteria Affect CWA Enforcement and Regulatory Objectives

Because water quality criteria are an essential element of state water quality standards and are a foundational scientific basis of state water quality standards, criteria are especially important to the CWA's protective regulatory mechanisms in at least six ways. First, water quality criteria constrain state authority to grant permits for point source discharges under NPDES because NPDES permits should not be issued if they

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53. 40 C.F.R. §§ 131.11, 131.20-22; *see also* WATER QUALITY STANDARDS HANDBOOK CHAPTER 3, *supra* note 20, at 3

> The EPA recommends states and authorized tribes develop a record describing the scientific justification for their adopted criteria and the public participation process. If a state or authorized tribe relies on 304(a) criteria recommendations (or other up-to-date EPA guidance documents), they may reference and rely on the data in those documents and may not need to create duplicative or new material for inclusion in their records.

54. 40 C.F.R. §§ 131.20–22; *see also* WATER QUALITY STANDARDS HANDBOOK CHAPTER 3, *supra* note 20, at 3.

> In the case where a state has chosen not to adopt a new criterion or update a criterion for a parameter for which the EPA has provided new or updated CWA section 304(a) criteria recommendations, the EPA's provision at 40 CFR 131.20(a) requires states and authorized tribes to provide an explanation for why it is choosing not to adopt new or revised criterion at that time.

55. *See, e.g.*, Power & Hicks, *supra* note 40, at 1101 ("Obviously, EPA's recommended water quality criteria play an important role in shaping state water quality standards. Accordingly, unless EPA promptly revises its water quality criteria guidelines to keep up with the latest scientific knowledge, states are virtually certain to fall far behind in revising their own water quality standards.").

56. *See supra* note 48 and accompanying text.

would cause water quality criteria violations.[57] In this way, water quality criteria restrict the number and characteristics of NPDES permits to match a water body's capacity to assimilate pollutants without becoming impaired. Therefore, water quality criteria can provide a legal cause of action against the government for excessive NPDES permitting to dischargers.[58] Second, water quality criteria violations also provide a legal cause of action against a NPDES permit holder that causes a water quality standard violation.[59]

Third, criteria inform how NPDES regulates point source pollutants because NPDES permit writers partly rely on criteria to determine the scope of effluent limitations, water quality standard compliance requirements, and related water quality monitoring requirements that are included in the permits.[60] Accordingly, a permitee could theoretically avoid liability for discharging a harmful pollutant if no criterion exists for the pollutant because it is unlikely that the pollutant would be written into the NPDES permit. A harmful discharge might result if a facility's pollutant removal procedures and technologies are not effective against the pollutant. Permittees and regulators might not monitor for pollutants not subject to criteria. And, under many circumstances the permitee would not be legally obligated to eliminate or minimize the harmful pollutant discharge even if monitoring identified it in the effluent.[61] Fourth, a state's authority to regulate non-point sources under the CWA's total maximum daily load program (TMDL) is triggered when waters are non-compliant with water quality criteria and associated water quality standards.[62]

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57. *See supra* note 26 and accompanying texts.

58. *See, e.g.*, 33 U.S.C. § 1365 (permitting citizen suit against unlawful CWA violation); 33 U.S.C. § 1313(d) (describing the total maximum daily load program); 40 C.F.R. § 122.4 (describing EPA regulations prohibiting the issuance of NPDES permits that cause water quality standard violations); *see also* Friends of Pinto Creek v. U.S. E.P.A., 504 F.3d 1007, 1009 (9th Cir. 2007) (vacating a NPDES permit issued to a mining operation because the NPDES permit would have increased copper discharges into a creek that was already out of compliance with the applicable water quality standard for copper).

59. *See, e.g.*, 33 U.S.C. § 1342 (describing NPDES); 33 U.S.C. § 1365 (describing citizen suit authority).

60. *See also* NPDES MANUAL, *supra* note 21, at 1–7 (covering point source discharges).

61. *See* 33 U.S.C. § 1342(k) (describing the NPDES permit shield).

62. 33 U.S.C § 1313(d); *see also* Pronsolino v. Nastri, 291 F.3d 1123, 1125–26 (9th Cir. 2002); U.S. ENVTL. PROT. AGENCY, IMPAIRED WATERS AND TMDLS,

Fifth, water quality criteria play an important role in government transparency and information dissemination because criteria describe how and when pollutants adversely affect water quality.[63] This transforms the concept of pollution from an abstract idea to a preventable or reversible condition. Similarly, water quality criteria improves awareness of water quality, which can enhance public uses and economic value of high-quality waters that are water quality standard compliant while also incentivizing voluntary corrective actions for non-compliant waters.[64]

Sixth, criteria are an influential component of the CWA's cooperative federalism structure.[65] For example, CWA § 401 certifications grant states substantial authority over federal permits, licenses, or other activities that could cause water quality standard violations.[66] Under CWA § 401 states may add

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https://www.epa.gov/tmdl/overview-identifying-and-restoring-impaired-waters-under-section-303d-cwa (last visited Jan. 6, 2020).

> Under Section 303(d) of the Act, states are required to evaluate all available water quality-related data and information to develop a list of waters that do not meet established [water quality standards] (impaired) and those that currently meet [water quality standards], but may exceed it in the next reporting cycle (threatened). States then must develop a TMDL for every pollutant/waterbody combination on the list. An essential component of a TMDL is the calculation of the maximum amount of a pollutant that can occur in waterbody and still meet [water quality standards]. Within the TMDL the state allocates this loading capacity among the various point sources and non-point sources . . . . This process ensures that polluted waters continue to be monitored and assessed until applicable water quality standards are met.

63. *See, e.g.*, U.S. Envtl. Prot. Agency, Water Quality Standards Regulatory Revisions, 80 Fed. Reg. 51019, 51019 (revising existing criteria to "increase transparency, and enhance opportunities for meaningful public engagement").

64. *Id.*

65. *Cf., e.g.*, Mark T. Pifher, *The Clean Water Act: Cooperative Federalism?*, 12 NAT. RESOURCES & ENV'T 34, 34 (1997) (challenging the extent of cooperative federalism integrated in the CWA).

66. 33 U.S.C. § 1341 (a)(1)

> Any applicant for a Federal license or permit to conduct any activity including, but not limited to, the construction or operation of facilities, which may result in any discharge into the navigable waters, shall provide the licensing or permitting agency a certification from the State . . . that any such discharge will comply with [WQS among other CWA provisions];

33 C.F.R. § 121; *see also* PUD No. 1 of Jefferson Cty. v. Washington Dep't of Ecology, 511 U.S. 700, 700 (1994)

> [P]ursuant to § 401(d) the State may require that a permit applicant comply with both the designated uses and the water quality criteria of

conditions to federal permits to protect aquatic life and even veto certain federal projects that would cause criteria exceedances.[67] States can use § 401 certifications to prevent the destruction of wetlands by blocking or conditioning U.S. Army Corps of Engineers' dredge and fill permits issued under CWA § 404.[68] Similarly, a state could condition or block an interstate natural gas pipeline that would cause criteria exceedances by denying a § 401 certification for a Federal Energy Regulatory Commission's Certificate of Public Convenience and Necessity.[69] Because criteria are an essential element of water quality standards, criteria are also fulcrums in the balance of power between federal and state governments under CWA § 401. Importantly, criteria developed from outdated science shift federal and state power dynamics away from the balance envisioned by Congress because criteria that "accurately reflect[] the latest scientific knowledge" will trigger a state's CWA § 401 authority in different situations than criteria developed from outdated science.[70]

B. AQUATIC ECOTOXICOLOGY

Aquatic ecotoxicology integrates the disciplines of aquatic ecology[71] with toxicology[72] by studying the fate and effects of

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the state standards. In granting certification pursuant to § 401(d), the State "shall set forth any ... limitations ... necessary to assure that [the applicant] will comply with any . . . limitations under [§ 303] . . . and with any other appropriate requirement of State law.

67. 33 U.S.C. § 1341 (a)(d).

68. 33 U.S.C. § 1344(f)(1)–(2).

69. *Cf., e.g.*, N.Y State Dep't of Envtl. Conservation v. Fed. Energy Regulatory Comm'n, 884 F.3d 450 (2d Cir. 2018) (allowing the state to waive its authority under § 401 such that the pipeline may proceed without a water quality certification).

70. 33 U.S.C. § 1314(a)(1).

71. *Introduction to Aquatic Ecology*, REGIONAL AQUATICS MONITORING PROGRAM, http://www.ramp-alberta.org/river/ecology/aquatic+ecology.aspx. (last visited Feb 21, 2019) ("*Ecology* is the scientific study of how organisms interact with each other and with their environment. This includes relationships between individuals of the same species, between different species, and between organisms and their physical and chemical environments. *Aquatic ecology* includes the study of these relationships in all aquatic environments.") (emphasis added).

72. Thomas F. Schrager, *What Is Toxicology*, TOXICOLOGY SOURCE, https://web.archive.org/web/20070310233247/http://www.toxicologysource.com/whatistoxicology.html (last visited Jan. 7, 2019) ("Toxicology is the study of the

pollution and other stressors on aquatic organisms in aquatic ecosystems. Because the CWA's goal is "to restore and maintain the chemical, physical, and biological integrity of the Nation's waters," aquatic ecotoxicology embodies the science of the CWA, at least with regard to aquatic life water quality criteria.[73] This section explores three important aquatic ecotoxicology subdisciplines that are particularly relevant to criteria development: (1) pollutant fate and effect; (2) species sensitivity and life histories; and (3) novel and emerging contaminants.

i. Pollutant Fate and Effect

Pollutant fate and effect describes how pollutant concentrations and toxicity change over time, place, and route of exposure based on the chemical, physical and biological characteristics of aquatic ecosystems.[74] Aquatic life is exposed to pollutants from water, diet, or interaction with sediments—often all three,[75] but the toxicity of these different exposures can vary. For example, zinc that is dissolved in water is highly toxic to fish because zinc binds to gills and impairs oxygen and ion transport across gill membranes.[76] Conversely, when zinc is in an undissolved form then it is relatively non-toxic because it does not bind to gills where zinc elicits its toxic effects.[77] Whether zinc is present in its toxic dissolved form or in a non-

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adverse effects of chemicals on living systems, whether they be human, animal, plant or microbe.").

73. 33 U.S.C. § 1251.

74. *See generally*, U.S. ENVTL. PROT. AGENCY, FATE AND EFFECTS OF POLLUTANTS ON AQUATIC ORGANISMS AND ECOSYSTEMS: PROCEEDINGS OF USA-USSR SYMPOSIUM, ATHENS, GEORGIA, OCTOBER 19–21, 1987 (1988), https://nepis.epa.gov/EPA/html/DLwait.htm?url=/Exe/ZyPDF.cgi/30001VA3.PDF?Dockey=30001VA3.PDF (providing examples of pollutant fate and effects).

75. For example, certain trace metals such as copper and zinc are often found dissolved in water, accumulated through diet, and bound to sediments. *See* Liven Bervoets & Ronny Blust, *Metal Concentrations in Water, Sediment and Gudgeon (Gobio gobio) from a Pollution Gradient: Relationship with Fish Condition Factor*, 126 ENVTL. POLLUTION 9, 9–19 (2003).

76. *See* Christer Hogstrand, Scott M. Reid & Chris M. Wood, *Ca^{2+} Versus Zn^{2+} Transport in the Gills of Freshwater Rainbow Trout and the Cost of Adaptation to Waterborne Zn^{2+}*, 198 J. OF EXPERIMENTAL BIOLOGY 337, 337–48 (1995).

77. *See* David R. Mount et al., *Dietary and Waterborne Exposure of Rainbow Trout (Oncorhynchus mykiss) to Copper, Cadmium, Lead and Zinc Using a Live Diet*, 13 ENVTL. TOXICOLOGY & CHEMISTRY 2031, 2031–41 (1994) (demonstrating that rainbow trout are highly tolerant to dietary zinc, and other metals exposure through diet compared with aqueous exposures).

toxic form depends largely on environmental conditions (e.g., pH, concentrations of organic matter and chelators).[78] These environmental conditions may change daily (e.g., from storms), seasonally (e.g., from the rainy season or spring snowmelt), and annually (e.g., from drought) with corresponding changes in zinc toxicity to fish. Importantly, most pollutants become more or less toxic as environmental conditions change.

Not all forms of a pollutant are equally toxic. For example, elemental mercury (for instance, the silver-colored liquid metal in antique thermometers) is substantially less toxic than mercury that is biotransformed into methyl-mercury by bacteria that commonly live in aquatic sediments.[79] The enhanced toxicity of methyl-mercury, in part, is attributable to the fact that methyl-mercury is far more bioavailable, and therefore more readily accumulated in organisms compared to elemental mercury.[80] In addition, methyl-mercury enters an ecosystem's food chain, where it bioaccumulates into body tissues and is absorbed much more rapidly than it is excreted from the body.[81] Some organisms accumulate thousands to millions of times more methyl-mercury in their body than the concentration found in the water that the organism occupies.[82]

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78. *See* Dagobert Heijerick, Colin Janssen, & Wim de Coen, *The Combined Effects of Hardness, pH, and Dissolved Organic Carbon on the Chronic Toxicity of Zn to D. Magna: Development of a Surface Response Model*, 44 ARCHIVES ENVTL. CONTAMINATION & TOXICOLOGY 210, 210–17 (2003).

79. *See* Michael Gochfeld, *Cases of Mercury Exposure, Bioavailability, and Absorption*, 56 ECOTOXICOLOGY & ENVTL. SAFETY 174, 175 (2003) (providing a review of mercury-based toxicity and historic exposure events); *see generally* Chad R. Hammerschmidt et al., *Biogeochemical Cycling of Methylmercury in Lakes and Tundra Watershed of Artic Alaska*, 40 ENVTL. SCI. & TECH. 1204 (2006) (describing mercury biotransformation); *see also Biotransformation*, SCIENCEDIRECT, https://www.sciencedirect.com/topics/earth-and-planetary-sciences/biotransformation. (last visited Mar. 8, 2019) ("Biotransformation is the enzyme-catalyzed conversion of one chemical into another that may be more or less toxic.").

80. *See* Gochfeld, *supra* note 79, at 174–75.

81. *Cf. id*; *See generally* Philip S. Rainbow, *Trace Metal Bioaccumulation: Models, Metabolic Availability and Toxicity*, 33 ENV'T INT'L 576 (2007).

82. *See* JAMES G. WIENER ET AL., HANDBOOK OF ECOTOXICOLOGY, ECOTOXICOLOGY OF MERCURY 409–63 (Hoffman et al., eds., 2d 2003) (providing a comprehensive overview of the fate and effects of mercury in the environment); *see also* U.S. ENVTL. PROT. AGENCY, WATER QUALITY CRITERION FOR THE PROTECTION OF HUMAN HEALTH: METHYLMERCURY 6-1 (2001) https://www.epa.gov/sites/production/files/2020-01/documents/methylmercury-criterion-2001.pdf (2001) ("Methylmercury [bioaccumulation factors] for upper

Methyl-mercury also biomagnifies up the food chain through dietary transfer from prey to their predators.[83] Longer food chains cause greater biomagnification, so methyl-mercury is generally less harmful to aquatic life in relatively shorter food chains because methyl-mercury body concentrations are lower in predators of short food chains compared with long food chains.[84] As a result, methyl-mercury concentration measured in water can be an inaccurate approximation of mercury exposure because it fails, for example, to account for organism age, trophic position, and food chain length in an ecosystem.[85] Yet, under the CWA, aquatic life criteria exceedances are most often determined by measuring water concentrations without adequate consideration of biomagnification or biotransformation.[86] Importantly, many contaminants other than mercury are biotransformed, bioaccumulated, and biomagnified.[87] Most EPA-recommended criteria do not adequately consider these factors.[88]

Abiotic (i.e., non-living) factors also affect contaminant bioavailability and toxicity. For example, low dissolved oxygen concentrations can contribute to greater toxicity of a pollutant.[89]

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trophic level freshwater and estuarine fish and shellfish typically consumed by humans generally range between 500,000 and 10,000,000.”).

83. *See* W. Baeyens et al., *Bioconcentration and Biomagnification of Mercury and Methylmercury in North Sea and Scheldt Estuary Fish*, 45 ARCHIVES ENVTL. CONTAMINATION & TOXICOLOGY 498, 498–508 (2003) (explaining that methylmercury concentrations in aquatic organisms are much higher in predator species than prey species, and also higher in older individuals that have eaten more prey over their life than younger individuals).

84. *Id.* at 499.

85. *See* JAMES G. WIENER ET AL., *supra* note 82 and accompanying text.

86. *See also* AQUATIC LIFE CRITERIA TABLE, *supra* note 2.

87. Other pollutants that biomagnify include organic contaminants such as chlorinated hydrocarbons, some pesticides, dioxins, and some metals such as selenium in addition to mercury. *See* E.M. Krümmel et al., *Delivery of Pollutants by Spawning Salmon,* 425 NATURE 225, 255 (2003) (describing a field study of sockeye salmon acting as bulk-transport vectors of polychlorinated biphenyls (PCBs) from the Pacific ocean to inland spawning lakes off the southern coast of Alaska); *see also* AQUATIC LIFE CRITERIA TABLE, *supra* note 2.

88. With the exception of the USEPA aquatic life criteria for selenium. *See* U.S. ENVTL. PROT. AGENCY AQUATIC LIFE CRITERION - SELENIUM, https://www.epa.gov/wqc/aquatic-life-criterion-selenium (last visited Jan. 28, 2020) (providing a model for acceptable selenium content that incorporates biomagnification).

89. *See* R. Lloyd, *Effect Of Dissolved Oxygen Concentrations on the Toxicity of Several Poisons to Rainbow Trout (Salmo gairdnerii richardson)*, 38 J. EXPERIMENTAL BIOLOGY 447, 450 (1961) (“The most obvious reaction of fish to

Water temperature, pH, and alkalinity (i.e., pH buffering capacity) can profoundly influence pollutant toxicity.[90] Similarly, water hardness (i.e., the concentration of dissolved magnesium and calcium) can affect pollutant toxicity.[91] Setting criteria at a national scale is accordingly complicated because abiotic factors are enormously varied among the diversity of aquatic ecosystems found in the United States.

Pollutants may elicit toxic effects through direct and indirect toxic mechanisms. Direct toxicity occurs when exposure to a pollutant results in sublethal (e.g., reduced mobility, reproductive failure, behavioral changes) or lethal effects. For example, acid mine drainage that is discharged into streams is directly toxic to aquatic life, in part, because toxic metals in the drainage impair ion transport across gills or are bioaccumulated into tissues and directly cause physiological damage to exposed organs.[92]

In contrast, indirect toxicity occurs when organisms are indirectly affected by the physical, chemical, or biological interactions of a pollutant in the environment. Again, acid mine drainage provides a useful example: algae—a primary food source for many aquatic organisms—absorbs metals which may reduce algae consumption by grazing aquatic insects.[93] Because aquatic insects provide valuable ecosystem services and are prey

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a lowered oxygen content of the water is to increase the volume of water passed over the gills, and this may increase the amount of poison reaching the surface of the gill epithelium, the site at which most poisons are absorbed.").

90. For example, copper is more toxic as pH decreases. *See* James P. Meador, *The Interaction of pH, Dissolved Organic Carbon, and Total Copper in the Determination of Ionic Copper and Toxicity*, 19 AQUATIC TOXICOLOGY 13, 13–31 (1991). Conversely, ammonia becomes less toxic as pH decreases. *See* Robert V. Thurston, Rosemarie C. Russo, & German A. Vinogradov, *Ammonia Toxicity to Fishes. Effect of pH on the Toxicity of the Un-ionized Ammonia Species*, 15 ENVTL. SCI. & TECH. 837, 837–840 (1981).

91. Water quality criteria for dissolved metals (*e.g.*, cadmium, nickel, lead, zinc) use hardness-adjusted conversions factors values. *See* AQUATIC LIFE CRITERIA TABLE, *supra* note 2, at Appendix B (providing parameters for calculating freshwater of dissolved metals criteria that are dependent on water hardness).

92. *See* Rainbow, *supra* note 81, at 576–82 (2007).

93. *See* Jonathan P. Bray et al., *Periphyton Communities in New Zealand Streams Impacted by Acid Mine Drainage,* 59 MARINE & FRESHWATER RES. 1084, 1090 (2009) (encouraging more study into the palatability of acid mine drainage contaminated algae after observing "high biomass and primary production seem to occur in the absence of strong grazing pressure from invertebrates").

for many other organisms, effects of metal-contaminated algae can cascade through the food chain (a process known as a trophic cascade).[94] Less food for insects means fewer insects; fewer insects means less food for fish, birds, and bats that feed on these insects, which leads to reduced abundance of those species.[95] Another example of indirect toxicity is in acid mine drainage-polluted streams where metals precipitate from solution and fill the interstitial spaces between rocks where aquatic insects live.[96] Although the precipitated metals are not directly toxic to aquatic insects, compared to those dissolved in water, they degrade aquatic habitats, which reduces abundance of insects and disrupts food chains.[97]

A recent example of a large-scale trophic cascade caused by indirect toxicity was documented from neonicotinoid pesticides in Japan.[98] The introduction of neonicotinoids in rice paddies in the early 1990s reduced aquatic insect and plankton abundance, which effectively decimated an economically and socially important smelt and eel fishery.[99] Although the interplay between direct and indirect toxicity is enormously important for natural resource conservation, it is very difficult to characterize these relationships through traditional criteria development, so it is not typically considered by regulators.[100]

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94. *See* JAMES G. WIENER ET AL., *supra* note 82 and accompanying text.

95. *See id. Cf.* Colden V. Baxter, Kurt D. Fausch, & W. Carl Saunders, *Tangled Webs: Reciprocal Flows of Invertebrate Prey Link Streams and Riparian Zones*, 50 FRESHWATER BIOLOGY 201, 202–08 (2005) (discussing the link between aquatic insect abundance and abundance of fish and riparian birds and bats, among others).

96. *See* Diane M. McKnight & Gerald L. Feder, *The Ecological Effect of Acid Conditions and Precipitation of Hydrous Metal Oxides in a Rocky Mountain Stream*, 119 HYDROBIOLOGIA 129, 129 (1984) ("[T]he precipitation of hydrous metal oxides greatly decreased the abundance of periphyton and benthic invertebrates.").

97. *Id.* at 129–38.

98. *See* Masumi Yamamuro et al., *Neonicotinoids Disrupt Aquatic Food Webs and Decrease Fishery Yields*, 366 SCI. 620, 622 (2019)

> In Lake Shinji, neonicotinoids indirectly reduced fishery yields by decreasing the abundance of invertebrates that serve as food for smelt and eels. Nationwide decreases in fishery yields in the lakes of Japan were also probably caused by food web disruption from neonicotinoids after the widespread use of these pesticides. Neonicotinoids can also affect fish directly.

99. *Id.*

100. *See* K. S. Kim, D. H. Funk, & D. B. Buchwalter, *Dietary (Periphyton) and Aqueous Zn Bioaccumulation Dynamics in the Mayfly Centroptilum Triangulifer*, 21 ECOTOXICOLOGY 2288, 2295 (2012) (indicating that

Pollutant fate is dynamic and chemical concentrations in aquatic environments are rarely constant through time. Pollutant concentrations in water fluctuate due to seasonal variation in aquatic conditions and because pollutants move between biological and chemical compartments (e.g., water, sediment).[101] For example, seasonal increases in instream flow from snowmelt or a rainy season can either dilute pollutant concentrations or increase pollutant concentrations due to intensified nonpoint source runoff from polluted lands.[102] Similarly, violent storms can rapidly increase instream flows and mobilize instream sediments, reintroducing pollutants into the water column that were previously sequestered by sediments.[103]

Chemical characteristics of pollutants also affect their fate.[104] For example, many pollutants are lipophilic (i.e., have an affinity for non-polar compounds such as fat tissue, rather than polar compounds like water).[105] When discharged into waters, lipophilic pollutants preferentially absorb into fatty tissue within an organism contributing to enhanced

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"approaches to deriving water quality criteria have not evolved with our growing understanding."). *Contra* AQUATIC LIFE CRITERION - SELENIUM, *supra* note 88 (providing a model for acceptable selenium content that incorporates biomagnification).

101. *See*, *e.g.*, Michael C. Moncur et al., *Seasonal Cycling and Mass-Loading of Dissolved Metals and Sulfate Discharging from an Abandoned Mine Site in Northern Canada*, 41 APPLIED GEOCHEMISTRY 176, 176–77 (2014) (summarizing studies on seasonal variations in water quality).

102. *See id.* at 176–88 (describing that seasonal cycling of dissolved metals, sulfate, and pH correlated with weather patterns); William H. Clements, Nicole K. M. Vieira & Stanley E. Church, *Quantifying Restoration Success and Recovery in a Metal-Polluted Stream: A 17-year Assessment of Physicochemical and Biological Responses*, 47 J. APPLIED ECOLOGY 899, 903–04 (2010) (identifying seasonal patterns of high metals concentrations during spring snow melt).

103. *Cf.* P.B. Cunningham et al., *Assessment of the Effects of Bioturbation in Contaminated Sediments*, PROC. 1999 CONF. ON HAZARDOUS WASTE RES. at 276 (explaining that organisms such as oligochaete worms can also cause this effect via bioturbation).

104. *Cf.* U.S. ENVTL. PROT. AGENCY, CLEAN WATER ACT (CWA) COMPLIANCE MONITORING, https://www.epa.gov/compliance/clean-water-act-cwa-compliance-monitoring (last visited Jan. 7, 2019).

105. Examples of lipophilic pollutants include methyl-mercury, selenium, various hydrocarbons including many polycyclic aromatic hydrocarbons (PAHs) and polychlorinated biphenyls (PCBs). *See, e.g.*, Krümmel et al., *supra* note 87, at 255 (describing transport vectors of PCBs).

bioaccumulation,[106] or the lipophilic pollutants adsorb nto sediments containing organic matter.[107] Therefore, exposure can predominantly occurs from within the organism itself or when aquatic life interacts with sediments.[108] For lipophilic pollutants, water concentrations do not necessarily reflect environmental pollutant concentrations because the pollutants are not predominantly located in the water column.

Some pollutants such as volatile organic compounds (e.g., gasoline, benzene, other hydrocarbons and products of combustion) are extremely toxic to aquatic life, but are challenging to measure in water because they rapidly volatilize into the atmosphere and degrade.[109] These chemicals, therefore, have a short detection window using standard monitoring techniques. Although volatile pollutants are short-lived in the environment, they can cause adverse consequences that can last years after pollutant concentrations return to normal.[110] For these pollutants, regulators can easily miss exceedances and aquatic ecosystems can suffer long-term effects from short-term exposure.[111]

One of the most challenging aspects in the science of aquatic ecotoxicology is that aquatic life is typically exposed to numerous pollutants and each pollutant may interact with other pollutants altering toxic outcomes. Simply stated, pollutants behave

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106. *See* Gitte I. Petersen & Preben Kristensen, *Bioaccumulation of Lipophilic Substances in Fish Early Life Stages*, 17 ENVTL. TOXICOLOGY & CHEMISTRY 1385, 1385 (1998) (describing lipophilic pollutant bioaccumulation into fish).

107. *See* Ross D. Markwell, Des W. Connell & Albert J. Gabric, *Bioaccumulation of Lipophilic Compounds from Sediments by Oligochaetes*, 23 WATER RES. 1443, 1443–50 (1989) (describing lipophilic pollutants accumulating in sediments from water and then into aquatic macroinvertebrates).

108. *See Id.*

109. *See, e.g.*, J. H. Canton & Ronald. C. C. Wegman, *Studies on the Toxicity of Tribromoethene, Cyclohexene and Bromocyclohexane to Different Freshwater Organisms*, 17 WATER RES. 743, 745–46 (1983) (discussing rapid decreases in the water concentration of hydrocarbons from volatilization).

110. *See* Sam B. Duggan, Christopher J. Kotalik & William H. Clements, *Integrating Results of Field Biomonitoring and Mesocosm Experiments to Validate Postspill Impacts of Petroleum Hydrocarbons on Stream Benthic Communities*, 52 ENVTL. SCI. & TECH. 13584, 13596 (2018) (finding that adverse effects of a petroleum spill in a small stream remained several years after the initial spill occurred and after sediment concentrations returned to reference-like conditions).

111. *Id.*

differently in mixtures than as single compounds.[112] As a general matter, mixture toxicity is poorly understood. Even the toxicity of well-studied pollutant mixtures often diverge from expectations based on single pollutant exposures.[113] Pollutants rarely, if ever, occur alone.[114] Yet, water quality criteria are developed for individual contaminants without regard for mixture toxicity. Therefore, EPA-developed criteria do not reflect environmentally realistic exposure scenarios where organisms in natural systems are simultaneously affected by multiple pollutants and variable environmental conditions.

ii. Species Sensitivity and Life Histories

Certain organisms are more sensitive to certain pollutants.[115] Toxicity varies by the species exposed, the habitat an organism occupies, the developmental stage of the exposed organism, and an organism's intra- or intergenerational history of exposure to pollutants and non-pollutant stressors.[116]

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112. Additive effects occur when mixture toxicity is approximately equal to the summation of individual effects (*i.e.*, 1 + 1 + 1 = 3). Synergistic effects occur when mixture toxicity is greater than the sum its parts (*i.e.*, 1 + 1 + 1 = 5), and antagonist effects occur when mixture toxicity is less than the sum of its parts (*i.e.*, 1 + 1 + 1 = 1).

113. *See, e.g.*, Elizabeth M. Traudt, James F. Ranville, & Joseph S. Meyer, *Acute Toxicity of Ternary Cd-Cu-Ni and Cd-Ni-Zn Mixtures to Daphnia magna: Dominant Metal Pairs Change Along a Concentration Gradient*, 51 ENVTL. SCI. & TECH. 4471, 4471 (2017) ("Multiple metals are usually present in surface waters, sometimes leading to toxicity that currently is difficult to predict due to potentially non-additive mixture toxicity.").

114. Similarly, non-pollutant disturbances may also affect pollutant toxicity. For example, an organism that is exposed to either elevated temperatures or to a pollutant, but not both, may experience no ill effects. However, that same organism might die if it is exposed to elevated temperatures and the pollutant. Likewise, if an organism is exposed to a pollutant or a disease, the organism may survive either. But if it is exposed simultaneously, it might not survive. *See, e.g.*, James A. Servizi & Dennis W. Martens, *Effect of Temperature, Season, and Fish Size on Acute Lethality of Suspended Sediments to Coho Salmon (Oncorhynchus kisutch)*, 48 CAN. J. FISHERIES & AQUATIC SCI. 493, 495 (1991) (finding that Coho Salmon with a viral infection were more sensitive to suspended sediments than healthy cohorts). Criteria do not typically consider multiple disturbances in criteria development.

115. *See* SPECIES SENSITIVITY IN ECOTOXICOLOGY 4 (Leo Posthuma et al., eds., 2002) ("[D]ifferent species respond differently to a compound at a given concentration (i.e., different species have different sensitivities).").

116. *See Id.*

A pollutant may cause toxicity at a much lower concentration in one species versus another.[117] If a particularly sensitive species plays a disproportionately important role in an ecosystem (*i.e.*, a keystone species), then relatively low pollutant concentrations may cause an outsized adverse effect on an ecosystem.[118] Pollutants also affect individuals within a species differently. For example, smaller organisms are generally, but not always, more sensitive to pollutants compared to larger and more developmentally mature individuals.[119]

As aquatic organisms complete their life cycle, they often occupy different habitats, which may alter pollutant exposures. For example, salmon hatch from eggs laid at the bottom of shallow streams. Here, the sediment may expose young salmon fry to very different pollutants than juvenile salmon migrating to the ocean, which may be very different than adult exposure in the open ocean.[120] Toxicity also differs for aquatic insects based on life-stage, such as during the biologically stressful transition

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117. *See* David J. Soucek et al., *Acute and Chronic Toxicity of Nickel and Zinc to a Laboratory Cultured Mayfly, Neocloeon triangulifer, in Aqueous but Fed Exposures*, ENVTL. TOXICOLOGY & CHEMISTRY (forthcoming 2020) (discussing how copper and nickel are far more toxic to some species than others therefore the use of environmentally realistic exposure regimes is critical for determining species sensitivity and how this has important implications for criteria development); *see also* SPECIES SENSITIVITY IN ECOTOXICOLOGY, *supra* note 115 and accompanying text.

118. *See, e.g.*, Peter J. Ashton, *The Demise of the Nile Crocodile (Crocodylus niloticus) as a Keystone Species for Aquatic Ecosystem Conservation in South Africa: The Case of the Olifants River*, 20 AQUATIC CONSERVATION: MARINE & FRESHWATER ECOSYSTEMS 489, 489–93 (2010) (describing the decline of the Nile Crocodile, a keystone species in South Africa's rivers, largely from water pollution).

119. *See* Pete Cadmus et al., *Size-dependent Sensitivity of Aquatic Insects to Metals*, 54 ENVTL. SCI. & TECH. 955, 955 (2019) (finding that "aquatic insect body size is an important predictor of susceptibility to aqueous metals" exposure); Servizi & Martens, *supra* note 114, at 493 (finding that larger Coho Salmon were more tolerant to suspended sediments). *Contra generally* William Stubblefield et al. *Acclimation-induced Changes in the Toxicity of Zinc and Cadmium to Rainbow Trout*, 18 ENVTL. TOXICOLOGY & CHEMISTRY 2875 (1999) (finding that juvenile fish "to be approximately three times less sensitive to the toxic effects of the metals than were adult fish").

120. *See* P. S. Ross et al., *The Trouble with Salmon: Relating Pollutant Exposure to Toxic Effect in Species with Transformational Life Histories and Lengthy Migrations*, 70 CAN. J. FISHERIES & AQUATIC SCI. 1252, 1252 (2013) ("Determining the effects that pollutants have on wild salmon requires study designs that consider life history, habitat, and the real world of complex contaminant exposure.").

of metamorphosis from an aquatic larvae to winged-adults.[121] Depending on the pollutant involved, metamorphosis by aquatic insects from aquatic to terrestrial environments will increase or decrease pollutant exposure and toxicity.[122]

Pollutant exposure itself modifies pollutant toxicity. For example, pollutants are often more toxic when organisms lack an acclimation period.[123] Conversely, chronic exposure can cause intergenerational adaptation and increase pollutant tolerance over generations.[124] But adaptation may come at a cost. Adaptation to one stressor (e.g., a pollutant) can make organisms more susceptible to other stressors—even transgenerationally.[125] Pollutant exposure can also shift community dynamics causing the local extirpation of sensitive species with an accompanying increase in abundance of pollution-tolerant species.[126] This community-level shift can

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121. *See* J. S. Wesner et al., *Metamorphosis Enhances the Effects of Metal Exposure on the Mayfly, Centroptilum triangulifer*, 48 ENVTL. SCI. & TECH. 10415, 10415–22 (2014) (examining the effect of contaminants on larval aquatic insects).

122. *See* Johanna. M. Kraus et al., *Metamorphosis Alters Contaminants and Chemical Tracers in Insects: Implications for Food Webs*, 48 ENVTL. SCI. & TECH. 10957, 10957–65 (2014) (describing a meta-analysis of pollutant transfer associated with metamorphosis in aquatic insects).

123. *See* Stubblefield et al., *supra* note 119, at 2875–81 (1999) (studying the acclimation response of Rainbow Trout to lethal and sublethal zinc and cadmium levels).

124. For example, chronic metal exposure in mountain streams can increase pollution tolerance in aquatic insects relative to populations with no previous exposure history. *See* William H. Clements, *Metal Tolerance and Predator–prey Interactions in Benthic Macroinvertebrate Stream Communities*, 9 ECOLOGICAL APPLICATIONS 1073, 1073–84 (1999) (investigating prey interactions based on direct and indirect effect of cadmium, copper, and zinc); *see also* Judith S. Weis & Peddrick Weis, *Tolerance and Stress in a Polluted Environment*, 39 BIOSCIENCE 89, 89–95 (describing costs of intergenerational embryonic tolerance to methylmercury in Killifish populations).

125. *See generally* Donna R. Kashian et al., *The Cost of Tolerance: Sensitivity of Stream Benthic Communities to UV-B and Metals*, 17 ECOLOGICAL APPLICATIONS 365 (2007); Clements, Vieira, & Church, *supra* note 102, at 899–910 ("We have previously reported results of mesocosm experiments showing that despite tolerance to metals, macroinvertebrate communities from contaminated sites in the Arkansas River were more sensitive to acidification . . . UV-B radiation . . . and stonefly predation . . . compared to communities from reference streams.").

126. *See generally* Clements, Vieira, & Church, *supra* note 102 (reporting optimistic results of a long-term ecosystem restoration effort, but recognizing that lasting effects remain); Duggan, Kotalik, & Clements, *supra* note 110, at 13584–90 (finding that adverse effects of a petroleum spill in a small stream

alter ecosystem services,[127] prey availability, and impede the aquatic ecosystem from returning to a pre-pollution condition after the pollution source is removed.[128] The vast complexity of nature poses enormous challenges to criteria development.

iii. Novel and Emerging Contaminants

The EPA currently lists sixty pollutants or classes of pollutants on its table of National Recommended Aquatic Life Criteria.[129] However, "[o]ne hundred million unique chemicals have been produced in the past [sixty] years, at a rate of about [ten] million per year in the past decade."[130] Not all of these chemicals are toxic and not all reach waterways, but each year chemicals that were once thought to be non-toxic are found to have toxic effects, and many reach waterways.[131] Moreover, the EPA-recommended criteria do not exist for many pollutants that are specifically designed for biologically reactivity such as illicit drugs or pharmaceuticals.[132] In fact, most modern wastewater

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remained several years after the initial spill occurred and after sediment concentrations returned to reference-like conditions).

127. *See* J. Bruce Wallace et al., *The Impact of Repeated Insecticidal Treatments on Drift and Benthos of a Headwater Stream*, 179 HYDROBIOLOGIA 135, 145–46 (1989) (investigating how successive, seasonal insecticide treatment shifts community structure).

128. *See* Brian A. Wolff, Sam B. Duggan, & William H. Clements, *Resilience and Regime Shifts: Do Novel Communities Impede Ecological Recovery in a Historically Metal-contaminated Stream?*, 56 J. APPLIED ECOLOGY 2698, 2698–2709 (2019) (observing long-term differences in community composition following upstream metal contamination).

129. *See* AQUATIC LIFE CRITERIA TABLE, *supra* note 2 (listing "the most up to date criteria for aquatic life ambient water quality criteria").

130. G. Allen Burton, Jr. et al., *Slipping Through the Cracks: Why Is the U.S. Environmental Protection Agency Not Funding Extramural Research on Chemicals in Our Environment?*, 51 ENVTL. SCI. & TECH. 755, 755 (2016).

131. *See generally* Dana W. Kolpin et al., *Pharmaceuticals, Hormones, and Other Organic Wastewater Contaminants in U.S. Streams*, 36 ENVTL. SCI. & TECH. 1202 (2002) (finding that despite limited knowledge of "the potential toxicological effects" of the contaminants analyzed, they were found in "80% of the 139 streams sampled for this study").

132. *See, e.g.*, Jen Christensen, *Your Drain on Drugs: Amphetamines Seep into Baltimore Streams*, CNN, (Aug. 26, 2016), https://www.cnn.com/2016/08/25/health/meth-fish-baltimore/index.html ("A new study suggests that aquatic life in Baltimore is being exposed to drugs, and it's having an impact. And these aren't soft drugs; they include methamphetamine and amphetamine. They're messing with the growth and development of organisms in local streams."); *see also* Cary Inst. of Ecosystem Studies, *Drug Pollution Concentrates in Stream Bugs, Passes to Predators in Water and on Land*, SCIENCEDAILY (Nov. 6, 2018),

treatment plants lack the technology needed to remove the legal and illegal drugs contained in human body-waste that is discharged into waterways through sewers.[133] For example, the anti-anxiety drug oxazepam can alter fish behavior and feeding at environmentally relevant water concentrations.[134] Other common chemicals such as personal care products can cause intersex in fish exposed to wastewater effluent.[135] An ecosystem experiment on an entire lake demonstrated that such effects can collapse a fishery because reproduction stops when an entire fish population expresses female traits.[136] Additionally, nearly all major U.S. waterways are contaminated with per- and polyfluoroalkyl substances ("PFAS") compounds, but these chemicals were only recently identified as hazardous [137] Water quality criteria have not yet been developed for PFAS.[138] An alarming diversity of synthetic chemicals are continuously

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https://www.sciencedaily.com/releases/2018/11/181106171825.htm ("Sixty-nine pharmaceutical compounds have been detected in stream insects, some at concentrations that may threaten animals that feed on them . . . Drug concentrations were the highest in invertebrates collected downstream of wastewater treatment facilities or in heavily populated areas with potential septic tank leakage.").

133. *See* Jelena Radjenovic, Mira Petrovic, & Damiá Barceló, *Analysis of Pharmaceuticals in Wastewater and Removal Using a Membrane Bioreactor*, 387 ANALYTICAL BIOANALYTICAL CHEMISTRY 1365, 1365 (2006) ("When they enter a wastewater-treatment plant, xenobiotics are not usually completely mineralized. They are either partially retained in the sludge, or metabolized to a more hydrophilic but still persistent form and, therefore, pass through the wastewater-treatment plant. . . and end up in the receiving waters.").

134. *See* T. Brodin et al., *Dilute Concentrations of a Psychiatric Drug Alter Behavior of Fish from Natural Populations*, 339 SCI. 814, 815 (2013).

135. *See* Burton, Jr., *supra* note 130, at 755.

136. *See generally* Karen A. Kidd et al., *Collapse of a Fish Population After Exposure to a Synthetic Estrogen*, 104 PNAS 8897, 8897–8901 (2007) (finding that chronic exposure of a fish species to a synthetic estrogen led to "a near extinction of this species from the lake").

137. *See* Lutz Ahrens & Mirco Bundschuh, *Fate and Effects of Poly- and Perfluoroalkyl Substances in the Aquatic Environment: A Review*, 33 ENVTL. TOXICOLOGY & CHEMISTRY 1921, 1921 (2014) ("Polyfluoroalkyl and perfluoroalkyl substances (PFASs) are distributed ubiquitously in the aquatic environment, which raises concern for the flora and fauna in hydrosystems.").

138. *See* AQUATIC LIFE CRITERIA TABLE, *supra* note 2. *But see* M. Elias et al., Developing Protective Aquatic Life Values for Data-Limited Chemicals—Considerations for PFAS, Presentation at the Society for Environmental Toxicology and Chemistry North America Meeting (Nov. 2019), https://toronto.setac.org/wp-content/uploads/2019/10/Toronto-abstract-book-web.pdf (describing the EPA effort to develop water quality criteria for PFAS).

discharged into nearly all aquatic environments, but relatively few have EPA-developed criteria.[139]

C. EPA CRITERIA DEVELOPMENT UNDER THE 1985 GUIDANCE DOCUMENT

In 1985, many of the nation's leading aquatic toxicologists, ecologists, chemists, and experts from other disciplines, completed the "Guidelines for Deriving Numerical National Water Quality Criteria for the Protection of Aquatic Organisms and Their Uses."[140] The 1985 guidelines were intended to create an "objective, internally consistent, appropriate[,] and feasible" method for establishing numeric aquatic life water quality criteria.[141] The guidelines favor precision, standardization, and repeatability, and, therefore, have established single-species laboratory experiments as the required data source to derive and develop criteria.[142]

The EPA continues to use the 1985 guidelines for aquatic life criteria development today, thirty-five years after they were initially established. This standardized process derives acute and chronic numeric water quality criteria for freshwater and

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139. *See* Kolpin, *supra* note 131, at 1208 ("However, many of the 95 [contaminants examined] do not have such guidelines or criteria determined.").

140. 1985 GUIDELINES, *supra* note 6, at 2 ("These National Guidelines have been developed on the theory that effects which occur on a species in appropriate laboratory tests will generally occur on the same species in comparable field situations."); *see also* WATER QUALITY STANDARDS HANDBOOK CHAPTER 3, *supra* note 20, at 14–15

> These guidelines describe an objective way to estimate the highest concentration of a substance in water that will not present a significant risk to the aquatic organisms in the water. This EPA method relies primarily on acute and chronic laboratory toxicity data for aquatic organisms from eight taxonomic groups reflecting the distribution of aquatic organisms' taxa that are intended to be protected by water quality criteria. Acute criteria are derived using short-term (48- to 96-hour) toxicity tests on aquatic plants and animals. Chronic criteria can be derived using longer-term (7-day to greater than 28-day) toxicity tests, if available, or by using an acute-to-chronic ratio procedure if there are insufficient chronic data. If justified, acute and chronic aquatic life criteria may be related to other water quality characteristics such as pH, temperature, or hardness. Separate criteria are typically developed for freshwater and saltwater organisms. Other information from mesocosms (controlled field experiments) and field data are considered when available and as appropriate. The Aquatic Life Guidelines recommend that criteria are lowered to protect commercially or recreationally important species, where appropriate.

141. 1985 GUIDELINES, *supra* note 6, at 1.

142. *Id.* at 11–14.

saltwater life.[143] "[A]cute criteria[] protect against mortality or effects that occur due to a short-term exposure to a chemical," whereas "chronic criteria [] protect against mortality, growth and reproductive effects that may occur due to a longer-term exposure to a chemical."[144] The 1985 guidelines anticipate that criteria would be the highest concentrations of a pollutant that aquatic life can be exposed to without adversely affecting ninety-five percent of aquatic life.[145]

The 1985 guidelines rely on surrogate species (i.e., species that we define here as proxies for the distribution of species sensitivity to pollutants in aquatic ecosystems and are suitable for laboratory testing) to develop criteria.[146] Because of difficulties sampling or culturing native animals, and the tremendous diversity of aquatic life, it is logistically infeasible to sample and conduct toxicity tests on every relevant species in natural ecosystems. Therefore, surrogate species are used to represent the pollutant sensitivity of all the nation's aquatic life. The 1985 guideline's "minimum data requirements" mandate

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143. *Id*. at 29

> The criterion is stated as: The procedures described in the "Guidelines for Deriving Numerical National Water Quality Criteria for the Protection of Aquatic Organisms and Their Uses" indicate that, except possibly where a locally important species is very sensitive, (1) aquatic organisms and their uses should not be affected unacceptably if the four-day average concentration of (2) does not exceed (3) µg/L more than once every three years on the average and if the one-hour average concentration does not exceed (4) µg/L more than once every three years on the average. Where (1) = insert "freshwater" or "saltwater;" (2) = insert name of material; (3) = insert the Criterion Continuous Concentration; (4) = insert the Criterion Maximum Concentration.

144. *See* WATER QUALITY STANDARDS HANDBOOK CHAPTER 3, *supra* note 20, at 15. Both acute and chronic criteria have three components: (1) magnitude, the maximum concentration of a pollutant; (2) duration, how long the maximum concentration of a pollutant can occur and; (3) frequency, how often the maximum exposure concentration can occur. *Id.*

145. 1985 GUIDELINES, *supra* note 6, at 1

> Because aquatic ecosystems can tolerate some stress and occasional adverse effects, protection of all species at all times and places is not deemed necessary. If acceptable data are available for a large number of appropriate taxa from an appropriate variety of taxonomic and functional groups, a reasonable level of protection will probably be provided if all except a small fraction of the taxa are protected, unless a commercially or recreationally important species is very sensitive. The small fraction is set at 0.05 because other fractions resulted in criteria that seemed too high or too low in comparison with the sets of data from which they were calculated.

146. *Id*.

the use of toxicity testing data from surrogate species representing at least eight taxonomic families when developing acute criteria, and three families for chronic criteria.[147]

For acute toxicity testing of a particular pollutant, single-species forty-eight-hour or ninety-six-hour toxicity tests estimate lethal concentrations that kill fifty percent of the test organism's population (LC50).[148] All available lethality data for aquatic organisms that meet the specification of the 1985 guidelines are then ranked from most to least sensitive to the pollutant.[149] This ranking of sensitivity is often referred to as a species sensitivity distribution.[150] Using the fifth percentile of data representing the most sensitive organisms, or more typically the four most sensitive organisms, a final acute value is estimated that would protect all organisms but that fifth percentile from experiencing fifty percent mortality.[151] However, because the sensitivity data represents LC50s (pollutant

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147. *Id.* at 12

> Results of acceptable acute tests . . . at least one species of freshwater animal in at least eight different families such that all of the following are included: a) the family Salmonidae in the class Osteichthyes; b) a second family in the class Osteichthyes, preferably a commercially or recreationally important warmwater species . . . ; c) a third family in the phylum Chordata . . . ; d) a planktonic crustacean . . . ; e) a benthic crustacean . . . ; f) an insect . . . ; g) a family in a phylum other than Arthropoda or Chordata . . . ; h) a family in any order of insect or any phylum not already represented.

But see Buchwalter, Clements, & Luoma, *supra* note 7, at 286

> In North America, there are an estimated 11,000 species of freshwater invertebrates and approximately 1200 species of fresh water fish. In particular, requiring only a single species of aquatic insect to generate a criterion value is highly questionable, given that there are at least 8600 different species in North America.

148. 1985 GUIDELINES, *supra* note 6, at 11–19. When lethality cannot be easily demonstrated, but an indicator of morbidity such as immobilization is apparent, then an effects concentration (EC50) is utilized rather than a LC50. *Id.* at 8.

149. *Id.*; *see also Id.* at 28

> If the available data indicate that one or more life stages [of a given species] are at least a factor of two more resistant than one or more other life stages of the same species, the data for the more resistant life stages should not be used in the calculation of the Species Mean Acute Value because a species can only be considered protected from acute toxicity if all life stages are protected.

150. *See* Michael Bock, STATISTICAL TOOLS TO EVALUATE SPECIES SENSITIVITY DISTRIBUTIONS AND CALCULATE FINAL ACUTE AND CHRONIC VALUES, RAMBOL ENVIRON (2015), https://www.epa.gov/sites/production/files/2016-01/documents/07_bock_ssd_v5_secure.pdf.

151. 1985 GUIDELINES, *supra* note 6, at 14.

concentrations that kill fifty percent of all organisms exposed), the final acute value is divided by two as an additional precaution.[152] This precautionary factor of two is somewhat arbitrary, but "is intended to result in a concentration that will not severely adversely affect too many of the organisms."[153]

Toxicity tests for developing chronic criteria utilize longer exposure times than acute testing—typically seven days or more—and measure long-term mortality, as well as sublethal effects including growth and reproduction.[154] A chronic criterion is determined by either taking the mean of the "no observed effect concentration" and "lowest observed effect concentration," or concentrations that change a chronic endpoint by twenty percent (EC20), or through other methods when available data are unreliable.[155] Similar to acute criteria, chronic criteria may be adjusted lower when necessary to account for various water characteristics such as temperature, pH, hardness, or when "other data" (e.g., from mesocosms, dietary exposures, field observations, etc.) demonstrate that a criterion is not protective.[156]

Under most circumstances, all toxicity testing data for developing criteria come from aqueous pollutant exposures.[157] However, exposures may only utilize a single pollutant—

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152. *Id*. at 11–19. For contaminants where toxicity is affected by certain water chemistry parameters, values are further adjusted using laboratory-derived equations. For example, trace metals are adjusted using a hardness-adjusted model. *See* AQUATIC LIFE CRITERIA TABLE, *supra* note 2.

153. 1985 GUIDELINES, *supra* note 6, at 9

> Instead of being equal to the Final Acute Value, the Criterion Maximum Concentration is now equal to one-half the Final Acute Value. The Criterion Maximum Concentration is intended to protect 95 percent of a group of diverse genera, unless a commercially or recreationally important species is very sensitive. However, a concentration that would severely harm 50 percent of the fifth percentile or 50 percent of a sensitive important species cannot be considered to be protective of that percentile or that species. Dividing the Final Acute Value by 2 is intended to result in a concentration that will not severely adversely affect too many of the organisms.

154. *Id*. at 19–25; *see also* WATER QUALITY STANDARDS HANDBOOK CHAPTER 3, *supra* note 20, at 15 ("Chronic criteria can be derived using longer-term (7-day to greater than 28-day) toxicity tests, if available, or by using an acute-to-chronic ratio procedure if there are insufficient chronic data.").

155. 1985 GUIDELINES, *supra* note 6, at 19–25.

156. *Id*.; *see also* WATER QUALITY STANDARDS HANDBOOK CHAPTER 3, *supra* note 20, at 15.

157. *See* Buchwalter, Clements, & Luoma, *supra* note 7, at 286.

mixture toxicity data are not accepted.[158] Additionally, dietary exposure (i.e., food source contamination) data are not required for criteria development and typically expressly excluded from criteria development.[159] Nevertheless, the 1985 guidelines' rigid acceptable data requirements are made more flexible because "other data" may be incorporated into criteria development in certain circumstances.[160]

Although the 1985 guidelines are currently EPA's default criteria development method, quasi-modernized approaches using additional chemical and biological data to adjust for site-specific conditions are employed for certain pollutants.[161] For example, copper uses a biogeochemical model (i.e., biotic ligand model or "BLM") for its EPA-recommended criterion that incorporates site-specific water chemistry values to determine

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158. 1985 GUIDELINES, *supra* note 6, at 11 ("Data on technical grade materials may be used if appropriate, but data on formulated mixtures and emulsifiable concentrates of the material of concern should not be used.").

159. *See* Buchwalter, Clements, & Luoma, *supra* note 7, at 286 ("Examples of studies that have been routinely or expressly excluded from at least some WQC include observations from nature, data from field experiments, dietary exposures, advanced approaches to toxicity testing (e.g., mesocosms), and the use of buffering free ion concentrations.").

160. 1985 GUIDELINES, *supra* note 6, at 18

> [M]uch judgment will usually be required to derive a water-quality criterion for aquatic organisms and their uses" and that "[a]ll necessary decisions should be based on a thorough knowledge of aquatic toxicology and an understanding of these Guidelines and should be consistent with spirit of these Guidelines, i.e., to make best use of the available data to derive the most appropriate criteria.;

Id. at 28

> Pertinent information that could not be used in earlier sections might be available concerning adverse effects on aquatic organisms and their uses. The most important of these are data on cumulative and delayed toxicity, flavor impairment, reduction in survival, growth, or reproduction, or any other adverse effect that has been shown to be biologically important. Especially important are data for species for which no other data are available. Data from behavioral, biochemical, physiological, microcosm, and field studies might also be available . . . Such data might affect a criterion if the data were obtained with an important species, the test concentrations were measured, and the endpoint was biologically important.

see also WATER QUALITY STANDARDS HANDBOOK CHAPTER 3, *supra* note 20, at 15 ("Other information from mesocosms (controlled field experiments) and field data are considered when available and as appropriate.").

161. 1985 GUIDELINES, *supra* note 6, at 23 ("[W]hen enough data are available to show that chronic toxicity to at least one species is related to a water quality characteristic, that relationship should be taken into account"); *see also id* at 28 (discussing "other data").

the criterion value.[162] This model is more accurate in deriving criteria protective of aquatic life compared to merely adjusting for water hardness alone as is done with many other metals.[163] Although biogeochemical models have been developed for other metals (*e.g.,* zinc, lead, cadmium), the EPA has only adopted biogeochemical models for copper and aluminum criteria.[164]

Another example is the current selenium criterion adopted in 2016 that uses "other data" because the earlier criterion was underprotective.[165] Selenium toxicity is profoundly influenced by changes in its chemical form and trophic transfer across the food chain.[166] Because of the complexity of selenium toxicity, a

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162. U.S. ENVTL. PROT. AGENCY, AQUATIC LIFE AMBIENT FRESHWATER QUALITY CRITERIA–COPPER 2007 REVISION (Feb. 2007), https://www.epa.gov/sites/production/files/2019-02/documents/al-freshwater-copper-2007-revision-factsheet.pdf.

> The BLM requires ten input parameters to calculate a freshwater copper criterion (a saltwater BLM is not yet available): temperature, pH, dissolved organic carbon (DOC), calcium, magnesium, sodium, potassium, sulfate, chloride, and alkalinity. The BLM is used to derive the criteria rather than as a post-derivation adjustment as was the case with the hardness-based criteria. This allows the BLM-based criteria to be customized to the particular water under consideration.

163. *See* AQUATIC LIFE CRITERIA TABLE, *supra* note 2; *see also* Soumya Niyogi & Chris M. Wood, *Biotic Ligand Model, a Flexible Tool for Developing Site-Specific Water Quality Guidelines for Metals*, 38 ENVTL. SCI. & TECH. 6177, 6177 (2004) ("The biotic ligand model . . . is a mechanistic approach that greatly improves our ability to generate site-specific ambient water quality criteria. . . for metals in the natural environment relative to conventional relationships based only on hardness.").

164. *See* U.S. ENVTL. PROT. AGENCY, FACT SHEET: AQUATIC LIFE AMBIENT FRESHWATER QUALITY CRITERIA FOR ALUMINUM IN FRESHWATERS (2018) https://www.epa.gov/sites/production/files/2018-12/documents/aluminum-criteria-final-factsheet.pdf (applying a multiple linear regression model to the aluminum criterion); U.S. ENVTL. PROT. AGENCY, FACT SHEET, AQUATIC LIFE AMBIENT FRESHWATER QUALITY CRITERIA-COPPER 2007 REVISION (2017) https://www.epa.gov/sites/production/files/2019-02/documents/al-freshwater-copper-2007-revision-factsheet.pdf (applying the biotic ligand model to the copper criterion).

165. *See* AQUATIC LIFE CRITERION - SELENIUM, *supra* note 88; U.S. ENVTL. PROT. AGENCY, AQUATIC LIFE AMBIENT WATER QUALITY CRITERION FOR SELENIUM IN FRESHWATER 2016-FACT SHEET, https://www.epa.gov/sites/production/files/2016-06/documents/se_2016_fact_sheet_final.pdf [hereinafter SELENIUM FACT SHEET].

166. *See* AQUATIC LIFE CRITERION - SELENIUM, *supra* note 88 ("Selenium is a nutritionally essential element for animals in small amounts, but toxic at higher concentrations. Selenium bioaccumulates in the aquatic food chain and chronic exposure in fish and aquatic invertebrates can cause reproductive

combination of biogeochemical models and laboratory-based dietary exposures were used to develop criterion based on both water and tissue concentrations, with fish tissue concentrations being the ultimate criterion.[167]

D. THE RISE AND STALL OF THE EPA'S CRITERIA MODERNIZATION EFFORT

The EPA ostensibly recognized that its water quality criteria development guidelines did not reflect the latest science. In 2015, the EPA initiated a broad criteria modernization effort and made substantial progress towards issuing new guidelines.[168] However, in spring 2019, the EPA abandoned the broad modernization effort without public explanation.[169]

In 2015, the EPA held a meeting on "Revising U.S. EPA's Guidelines for Deriving Aquatic Life Criteria" where world experts in aquatic ecology, environmental toxicology, and ecological risk assessment gathered to discuss revising the 1985 guidelines.[170] In 2016, the EPA supplemented its Scientific Advisory Board ("SAB") Ecological Processes and Effects Committee with scientific experts on water quality to review a new EPA document entitled "Scope and Approach for Revising USEPA's Guidelines for Deriving National Water Quality Criteria to Protect Aquatic Life" that would inform the scientific basis of future EPA criteria development policies.[171]

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impairments (e.g., larval deformity or mortality). Selenium can also adversely affect juvenile growth and mortality.").

167. SELENIUM FACT SHEET, *supra* note 165 ("EPA recommends that when implementing the criterion, the fish tissue elements take precedence over the water column elements, except in certain circumstances.").

168. *See* U.S. ENVTL. PROT. AGENCY, EPA ACTIVITIES RELATED TO REVISING THE AQUATIC LIFE GUIDELINES, https://www.epa.gov/wqc/aquatic-life-criteria-and-methods-toxics#sab (last visited Jan. 12, 2020)

> EPA has begun the process of revising the existing Guidelines used to derive National Ambient Water Quality Criteria for the protection of aquatic life. EPA will consider new and alternative methods for deriving aquatic life criteria to inform revision of EPA's existing guidance using the newest most appropriate science available.

169. Interview by Sam B. Duggan with anonymous source, May 20, 2019.

170. INVITED EXPERT MEETING ON REVISING U.S. EPA'S GUIDELINES FOR DERIVING AQUATIC LIFE CRITERIA, *supra* note 8.

171. *See* U.S. ENVTL. PROT. AGENCY, REQUEST FOR NOMINATIONS OF EXPERTS TO AUGMENT THE SCIENCE ADVISORY BOARD ECOLOGICAL PROCESSES AND EFFECTS COMMITTEE TO PROVIDE ADVICE ON METHODS FOR DERIVING WATER QUALITY CRITERIA FOR THE PROTECTION OF AQUATIC LIFE (2016), https://www.govinfo.gov/content/pkg/FR-2016-08-30/pdf/2016-20851.pdf; *see*

In 2017, the EPA publicly suggested that it tentatively planned to utilize a two-pronged approach to ensure that the EPA's future water quality criteria reflected the "current state-of-the-science."[172] Prong one would "updat[e] and refin[e] methods for deriving state-of-the-science criteria" by replacing the 1985 guidance document with a new one that would apply the latest science to EPA criteria development for certain chemicals where robust data sets existed.[173] Prong two would

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also U.S. ENVTL. PROT. AGENCY, SCOPING AND APPROACH FOR REVISING GUIDELINES FOR DEVISING NUMERICAL WATER QUALITY CRITERIA TO PROTECT AQUATIC LIFE, https://yosemite.epa.gov/sab/sabproduct.nsf/fedrgstr_activites/1985%20WQ%20Criteria%20Guidelines%20Revision!OpenDocument&TableRow=2.0#2 (last updated May 7, 2018)

> EPA's Office of Water (OW) has requested early SAB advice on a draft scoping document, entitled "Scope and Approach for Revising USEPA's Guidelines for Deriving National Water Quality Criteria to Protect Aquatic Life." This draft document provides an overview of the framework EPA proposes to use for the phased revision of the 1985 Guidelines for Deriving Numerical Water Quality Criteria for the Protection of Aquatic Organisms and Their Uses by outlining the planned scope and approach of the Guidelines revision process and introducing new and alternative methods to be considered for deriving aquatic life criteria based on the latest and most appropriate science available. The agency is planning on developing other documents to support the revision and will bring these to the SAB for peer review.

172. U.S. ENVTL. PROT. AGENCY, UPDATE ON US EPA'S REVISION TO THE 1985 GUIDELINES FOR DERIVING AQUATIC LIFE CRITERIA, https://cfpub.epa.gov/si/si_public_record_report.cfm?Lab=NCEA&dirEntryId=336630 (updated June 14, 2017); *see also* M. Elias et al., USEPA's 1985 Guidelines for Deriving Aquatic Life Criteria—Update on the Status of the Guidelines Revision Process, Presentation at the Society of Environmental Toxicology and Chemistry North America Meeting (Nov. 2018), *available at* https://www.setac.org/store/ViewProduct.aspx?id=13373145

> USEPA's Office of Water is in the process of revising its 1985 Guidelines for Deriving Numerical National Water Quality Criteria for the Protection of Aquatic Organisms and Their Uses (Stephan et al. 1985). . . EPA is undertaking a comprehensive revision process that will result in the development of two separate methods documents: 1) a Comprehensive Guidelines Document, intended to directly update and expand on approaches presented in the 1985 Guidelines, and will describe methods that provide criteria for chemicals requiring a more detailed level of evaluation, and 2) a Streamlined Guidelines Document, which will focus on criteria development methods that are resource-conserving and can be used to develop scientifically-robust criteria, even when supporting data are more limited.

173. M. ELIAS ET AL., UPDATE ON US EPA'S REVISION TO THE 1985 GUIDELINES FOR DERIVING AQUATIC LIFE CRITERIA 1 (2017), HTTPS://CFPUB.EPA.GOV/SI/SI_PUBLIC_RECORD_REPORT.CFM?LAB=NCEA&DIRENTRYID=336630 ("The first track reflects that for a smaller group of chemicals,

create a new guidance document for "developing criteria more rapidly for the broader protection of aquatic life from the potential adverse effects of the large number of chemicals released into the aquatic environment . . . even when data is more limited."[174]

Progress towards modernizing criteria development slowed beginning in October 2017, when the EPA announced a new policy that prohibited scientists who receive EPA grants from serving on the SAB.[175] Rapidly, the SAB shifted membership from prominent academic scientists to industry representatives and others with a previously antagonistic relationship with the EPA.[176] In May 2018, the newly reshuffled SAB disbanded the

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criteria development may be scientifically complex, and deriving robust criteria for these chemicals may require detailed investigation.").

174. *Id.* ("The second track reflects the recognition that extensive testing of all chemicals is infeasible and there is a need to efficiently derive criteria using approaches that estimate safe environmental concentrations with limited empirical data.").

175. U.S. ENVTL. PROT. AGENCY, STRENGTHENING AND IMPROVING MEMBERSHIP ON EPA FEDERAL ADVISORY COMMITTEES (Oct. 31, 2017), https://www.epa.gov/sites/production/files/2017-10/documents/final_draft_fac_directive-10.31.2017.pdf; *see also* Robert G. McLusky, *Courts Reject Challenges to Directive Prohibiting EPA Grant Recipients from Participation on Federal Advisory Committees*, JACKSONKELLY PLLC (Mar. 26, 2019), https://www.jacksonkelly.com/energy-environment-blog/courts-reject-challenges-to-directive-prohibiting-epa-grant-recipients-from-participation-on-federal-advisory-committees; Jennifer Sass, *The Industry-Friendly Science Advisory Board Act of 2017*, NAT'L RESOURCES DEF. COUNCIL (Mar. 30 2017), https://www.nrdc.org/experts/jennifer-sass/industry-friendly-science-advisory-board-act-2017.

176. *See* Rebecca Beitsch, *Watchdog Finds EPA Skirted Rules When Appointing Industry Leaders to Science Advisory Board*, THE HILL (July 15, 2019), https://thehill.com/policy/energy-environment/453178-watchdog-finds-epa-skirted-rules-when-appointing-industry-leaders ("A report from the Government Accountability Office (GAO) found the EPA did not follow the process for selecting the 'best qualified and most appropriate candidates' for two important committees that advise on environmental regulations and also 'did not ensure that all appointees met ethics requirements.'"); *see also* Warren Cornwall, *Trump's EPA has Blocked Agency Grantees from Serving on Science Advisory Panels. Here is What it Means*, SCI. MAG. (Oct. 31, 2017), https://www.sciencemag.org/news/2017/10/trump-s-epa-has-blocked-agency-grantees-serving-science-advisory-panels-here-what-it; *see also* Umair Irfan, *The EPA is Taking Unprecedented Steps to Oust Scientists who Receive its Grants*, VOX (Nov. 1, 2017), https://www.vox.com/energy-and-environment/2017/10/27/16552766/epa-science-advisory-board-scientific-counselors.

EPA's Ecological and Effects Committee,[177] a committee tasked with identifying the latest science of criteria development.[178] Then, in spring 2019, at a meeting in the EPA's Office of Water, the criteria modernization project was functionally killed by a verbal announcement that EPA resources were being diverted from the project and allocated elsewhere.[179] EPA staff that were spearheading the broad criteria modernization effort then shifted to other projects such as the laudable but narrow focus of developing criteria for perfluorooctane sulfonate ("PFOS") and perfluorooctanoic acid ("PFOA") pollutants.[180] Unfortunately, the EPA's efforts to update the 1985 guidelines document to reflect the latest science are not currently moving forward despite the EPA's seeming acknowledgment that its

177. *See* U.S. ENVTL. PROT. AGENCY, COMMITTEES AND MEMBERSHIP, https://yosemite.epa.gov/sab/sabproduct.nsf/WebBOARD/CommitteesandMembership?OpenDocument (last updated June 21, 2018)

> On May 31, 2018, the Science Advisory Board unanimously voted to restructure its supporting standing committees from seven to four . . . The SAB approved retiring the Ecological Processes and Effects Committee (EPEC), the Environmental Economics Advisory Committee (EEAC) and the Environmental Engineering Committee (EEC). When issues arise in these three areas, the current make-up of the Board sufficiently represents expertise to oversee work on these subject matters and convene panels as statutorily authorized. For any future advisory requests on ecology, economics or engineering, the SAB Staff Office plans to create ad hoc panels chosen specifically for the topic under consideration;

SCOPING AND APPROACH FOR REVISING GUIDELINES FOR DEVISING NUMERICAL WATER QUALITY CRITERIA TO PROTECT AQUATIC LIFE, *supra* note 171; *but see* U.S. ENVTL. PROT. AGENCY, SAB AD HOC COMMITTEES AND PANELS, https://yosemite.epa.gov/sab/sabproduct.nsf/webBOARD/SABAdHocCommitteesandPanels?OpenDocument (last updated Apr. 1, 2020) (stating that the EPA is "currently forming SAB Ad Hoc Committees and Panels or augmenting existing Standing Committees to address" aquatic life water quality criteria methods). Interestingly, as of July 6, 2020, the aforementioned reference to forming a SAB Ad Hoc Committee to address aquatic life water quality criteria methods is no longer visible on the EPA website. *Id.* (last updated May 14, 2020).

178. The CWA requires that the EPA develop "criteria for water quality that accurately reflect *the latest scientific knowledge*." 33 U.S.C. § 1314(a)(1) (emphasis added).

179. Interview by Sam B. Duggan with anonymous source, May 20, 2019.

180. *See, e.g.*, M. Elias et al., *supra* note 138 (describing the EPA effort to develop water quality criteria for PFAS to the Society of Environmental Toxicology and Chemistry at the annual North America meeting); A. Jarvis et al., Reviewing Current Toxicity Literature to Evaluate Data to Support the Development of Draft PFOS and PFOA Aquatic Life Ambient Water Quality Criteria, Presentation at the Society for Environmental Toxicology and Chemistry North America Meeting (Nov. 2019), https://toronto.setac.org/wp-content/uploads/2019/10/Toronto-abstract-book-web.pdf (same).

recommended criteria for aquatic life no longer reflect the latest science as is required by the CWA.[181]

II. INTEGRATING THE LATEST SCIENCE INTO AQUATIC LIFE WATER QUALITY CRITERIA

Water quality criteria are foundational to many CWA programs (e.g., NPDES, TMDL, § 401 state certifications, and state water quality standards). Because criteria are regulatory definitions of water quality, they also provide a quantitative and qualitative basis for taking water quality related actions under the CWA. Similarly, criteria define success under the Clean Water Act's primary goal because criteria describe the water quality conditions needed "to restore and maintain the chemical, physical, and biological integrity of the Nation's waters."[182] Therefore, water quality criteria grounded in outdated science undermine CWA programs and its remedial purpose.

The CWA requires that the EPA develop and periodically revise criteria to reflect the "latest scientific knowledge."[183]Although criteria developed under the EPA's 1985 guidelines may have reflected the latest science thirty-five years ago, they no longer do.[184] Likewise, an emphasis on discrete numeric criteria may have reflected the latest science in the past, but as we explain in this section, current science suggests that discrete numeric criteria should be supplemented with flexible narrative criteria. By not developing criteria that reflect the latest science, the EPA may be violating the plain text of the CWA.

This section describes why the EPA may be out of compliance with the CWA and offers suggestions for attaining compliance. First, the EPA should update the 1985 guidance document for deriving numeric criteria to incorporate the last thirty-five years of scientific advancement. Second, each numeric criterion should be reinforced by a companion narrative criterion. Third, the EPA should develop a single catch-all

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181. 33 U.S.C. § 1314(a)(1).
182. 33 U.S.C. § 1251.
183. 33 U.S.C. § 1314(a)(1).
184. *Cf.* DeForest et al., *supra* note 7, at 1124 ("[Criteria] for several chemicals are more than 30 years old—meaning that 30+ years of data are not considered in these [criteria] —and many chemicals still do not have [criteria].").

narrative criterion as a gap-filler for all pollutants not directly regulated by other water quality criteria.

A. THE 1985 GUIDELINES DO NOT REFLECT THE LATEST SCIENCE

The EPA's current criteria development procedures do not reflect the latest science. Here, we explain why the 1985 guidance is not the latest science and offer suggestions for modernizing the 1985 guidance. The science of aquatic ecotoxicology has progressed substantially in the past thirty-five years. Since 1985, scientists have solved many mysteries within the field and discovered others. It is now unquestionable that the sole requirement of single-species toxicity tests—the hallmark of the 1985 guidelines—fail to predict many important instances of toxicity in natural systems and wholly neglect the emergent properties that define aquatic ecosystems under stress from pollutants.[185]

The 1985 guidelines rely on the responses of an extremely limited number of different species, many of questionable environmental relevance, to represent the vast range of sensitivity to pollutants observed among all biodiversity of aquatic life in the United States.[186] Because it is impossible to conduct toxicity tests on all relevant species, particularly those that are threatened, endangered, or difficult to culture in laboratories, species sensitivity distributions serve an important purpose and should not be abandoned. However, it is now abundantly clear that sensitivity of aquatic life cannot be characterized by solely using species sensitivity distributions of LC50s alone.[187] The manner which the 1985 guidelines

185. In ecology, emergent properties are complexities of naturally phenomena that are not fully described by lower level processes. In other words, the whole is greater than the sum of its parts. For example, the responses of a fish population to a given pollutant is not explained by the response of a single fish cell or a single fish—the emergent properties that are not explained from reductionism (i.e., single species toxicity tests) includes interspecies interactions, rates of immigration and emigration from habitats, birth rates, predation success, disease resistance, ecosystem services, etc. *Cf.* ERNST MAYR, THE GROWTH OF BIOLOGICAL THOUGHT 64–67 (1982) (discussing the emergent properties in hierarchical biological organization).

186. 1985 GUIDELINES, *supra* note 6, at 1.

187. *See* Kevin V. Brix, David K. DeForest, & William J. Adams, *The Sensitivity of Aquatic Insects to Divalent Metals: A Comparative Analysis of Laboratory and Field Data*, 409 SCI. TOTAL ENV'T 4187, 4187–97 (2011)

establishes a species sensitivity distribution according to a minimum data requirement that only requires toxicity data from eight surrogate species grossly underrepresent important and environmentally relevant toxic outcomes. For aquatic insects in particular, there are nearly 9000 species in North America.[188] Insects are also disproportionately critical for supporting aquatic food webs and providing functional ecosystem services.[189] Yet just one aquatic insect species is required in criteria development.[190] Furthermore, aquatic insects are only exposed as larvae, which excludes metamorphosis to adults, a process necessary for nearly all aquatic insects to reproduce.[191]

Traditional single species exposures also underrepresent the complexity of pollutant fate and effects in nature. Interspecies relationships are glaringly absent from consideration in the 1985 guidelines.[192] And exposures must occur in an aqueous form.[193] Therefore, non-aqueous exposures are not typically incorporated into criteria development even though exposure to contaminated food and polluted sediment is commonplace in aquatic ecosystems. Indirect toxic effects and toxicity from physical stressors (e.g., from fine sediment, or metal precipitates) are not estimated.[194] Also, pollutant mixtures are not included in criteria development despite the fact that pollutants in almost all aquatic ecosystems occur in complex and dynamic mixtures.[195]

(providing LC50 estimates for metals among different aquatic insect species and providing hypotheses for the vast range of species sensitivities).

188. ECOLOGY AND CLASSIFICATION OF NORTH AMERICAN FRESHWATER INVERTEBRATES (James H. Thorp & Alan P. Covich eds., 3d 2009) (classifying aquatic insects in North America).

189. *See, e.g.*, Craig R. Macadam & Jenni A Stockan, *More Than Just Fish Food: Ecosystem Services Provided by Freshwater Insects*, 40 ECOLOGICAL ENTOMOLOGY 113, 113–23 (2015).

190. 1985 GUIDELINES, *supra* note 6, at 12.

191. 1985 GUIDELINES, *supra* note 6, at 14.

192. 1985 GUIDELINES, *supra* note 6, at 2 ("These National Guidelines have been developed on the theory that effects which occur on a species in appropriate laboratory tests will generally occur on the same species in comparable field situations.").

193. *Id.* at 10.

194. 1985 GUIDELINES, *supra* note 6.

195. 1985 GUIDELINES, *supra* note 6, at 11 ("Data on technical grade materials may be used if appropriate, but data on formulated mixtures and emulsifiable concentrates of the material of concern should not be used."); *see also supra* note 112 and accompanying texts.

The 1985 guidelines only requires relatively short-term exposures compared to those observed in nature, but longer exposure durations that allow pollutant accumulation in exposed organisms to approach steady-state are needed to observe the greatest consequences of pollutant toxicity.[196] The exposure duration problem is compounded because most acute and many chronic tests only capture a portion of an organism's life cycle.[197] Therefore, particularly sensitive developmental stages, such as newly hatched individuals and life stages present during metamorphosis and reproduction, are often overlooked.

The 1985 guidelines only require single species toxicity tests.[198] More environmentally realistic exposures, such as field experiments and mesocosm testing,[199] may be applied under the 1985 guidelines as "other data" to supplement single species toxicity testing results, but these approaches are not required and are rarely used in criterion development.[200] Yet, these approaches can integrate many emergent properties that occur in polluted ecosystems such as changes in interspecies relationships (e.g., competition, predation) and toxicant effects on food resources that indirectly affect other organisms.[201] Importantly, these experimental approaches can also offer control and replicability, allowing for standardization that is

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196. "Steady-state" in aquatic toxicology refers to the concentration of a contaminant in an organism's body once uptake and depuration rates reach equilibrium. Steady-state is important because it is used to quantify bioconcentration factors of pollutants and establishes how long it takes for an organism's body burden of pollutants to reach a long-term maximum. *See* Poteat & Buchwalter, *supra* note 7, at 887–88 (describing how steady-state models determine metal body burdens in metal exposed aquatic insects).

197. 1985 GUIDELINES, *supra* note 6, at 19–20 (accepting results from life-cycle toxicity tests).

198. *Id.* at 2 ("These National Guidelines have been developed on the theory that effects which occur on a species in appropriate laboratory tests will generally occur on the same species in comparable field situations.").

199. *See* Christopher Kotalik, Contaminants and Ecological Subsidies: The Land-Water Interface, Mesocosms To Evaluate Aquatic-Terrestrial Contaminant Linkages Using Aquatic Insect Emergence: Utility for Aquatic Life Criteria Development (2020) (unpublished manuscript) (on file with author) ("Here, we define 'mesocosms' as experimental systems that integrate the abiotic and biotic components of natural aquatic communities under controlled conditions.").

200. *See, e.g.*, Buchwalter, Clements, & Luoma, *supra* note 7, at 287–88, 289–90 (applying field data and mesocosm experiments for criteria development).

201. *See Id.* at 290.

important for developing criteria.[202] Despite the advantages, field experiments and mesocosm are rarely utilized for criteria development.

The EPA has also deemphasized the use of field data from the development of water quality criteria.[203] Surprisingly, most criteria are developed, in large part, without integrating data collected from the aquatic ecosystems that criteria intend to protect. Certain data such as pollutant accumulation, pollutant transfer through food webs, and many other emergent properties are best collected from natural settings impacted by pollutants rather than through reductionist laboratory experiments.[204]

It can be argued that biocriteria and WET testing are solutions to the problems associated with the 1985 guidelines. Yes, biocriteria are useful for directly estimating biological sensitivity to pollution in actual aquatic ecosystems and quantifying ecological divergence from reference conditions.[205] However, establishing and interpreting biocriteria requires substantial expertise in local aquatic conditions because monitoring results may be complicated by numerous extraneous factors that are not directly related to pollutants (e.g., seasonality, disease, invasive species, boom and bust population cycles, etc.).[206] WET testing also offers some improvements in

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202. *See* Christopher A. Mebane, Travis S. Schmidt & Laurie S. Balistrieri, *Larval Aquatic Insect Responses to Cadmium and Zinc in Experimental Streams*, 36 ENVTL. TOXICOLOGY & CHEMISTRY 749, 749–62 (2017) (applying a modern experimental stream approach to generate metals toxicity results in a similar manner as the traditional single-species toxicity testing approach and in a manner suitable for criteria development).

203. *But see* Susan M. Cormier, Glenn W. Suter II, & Lei Zheng, *Derivation of a Benchmark for Freshwater Ionic Strength,* 32 ENVTL. TOXICOLOGY & CHEMISTRY 263, 263–71 (2013); Cormier et al., *supra* note 8, at 490–504.

204. *See, e.g.,* A. Robin Stewart et al., *Food Web Pathway Determines How Selenium Affects Aquatic Ecosystems: A San Francisco Bay Case Study*, 38 ENVTL. SCIENCE & TECHNOLOGY 4519, 4519–26 (2004) (applying food web modelling to characterize effects of selenium in San Francisco Bay and offering support for this approach over traditional evaluations of contaminant impacts alone).

205. *See* WATER QUALITY STANDARDS HANDBOOK CHAPTER 3, *supra* note 20, at 19–20.

206. *See* William H. Clements, Chris W. Hickey, & Karen A. Kidd, *How Do Aquatic Communities Respond to Contaminants? It Depends on the Ecological Context*, 31 ENVTL. TOXICOLOGY & CHEMISTRY 1932, 1932–40 (2012) (explaining that toxicity can vary widely according to ecological context (*i.e.*, ecosystem characteristics), yet, "observations about context dependency could

experimental exposure realism by directly monitoring the toxicity associated with polluted effluent mixtures collected from or near point-source discharges.[207] However, pollutant composition, characteristics, concentration, and, importantly, pollutant toxicity may change during transport from the field to laboratory.[208] Additionally, WET testing suffers from similar limitations as other reductionist single-species toxicity tests utilized by the 1985 guidelines (e.g., unrealistic exposure scenarios, short testing durations, limited endpoints, few surrogate species, etc.).[209] Although thoughtfully implemented biocriteria can overcome many of the deficiencies in the 1985 guidelines, WET testing requires similar fundamental changes that the 1985 guidelines need.

Updating guidelines for developing water quality criteria is not a novel undertaking. The EPA lags behind other regulatory bodies around the world that have updated their equivalent guidelines multiple times to reflect scientific advancements. Australia and New Zealand adopted their first guidelines in 1992,[210] and they updated their guidelines in 2000[211] on the basis that "new and improved techniques were available for establishing guideline values and for monitoring and

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be used to test hypotheses about ecological mechanisms responsible for differences in sensitivity among communities.").

207. *See* WHOLE EFFLUENT TOXICITY, *supra* note 29.

208. *Cf.* Pete Cadmus et al., *The Use of Field and Mesocosm Experiments to Quantify Effects of Physical and Chemical Stressors in Mining-Contaminated Streams*, 50 ENVTL. SCIENCE & TECH. 7785, 7825–33 (2016) (describing a sophisticated WET test that took advantage of the fact that dissolved metals precipitate from solution when effluent is transported from a point source to the laboratory).

209. *See* WHOLE EFFLUENT TOXICITY, *supra* note 29.

210. *See ANZECC (1992) Water Quality Guidelines*, AUSTL. GOV'T INITIATIVE, https://www.waterquality.gov.au/anz-guidelines/resources/previous-guidelines/anzecc-1992 (last visited Apr. 4, 2020) ("This was the first joint guidance for Australia and New Zealand that was developed by the Australia and New Zealand Environment and Conservation Council (ANZECC) and released in 1992.").

211. *See ANZECC & ARMCANZ (2000) Water Quality Guidelines*, AUSTL. GOV'T INITIATIVE, https://www.waterquality.gov.au/anz-guidelines/resources/previous-guidelines/anzecc-armcanz-2000 (last visited Apr. 4, 2020) (describing how these guidelines were prepared in 2000 and superseded by revised Water Quality Guidelines released in 2018).

assessment."[212] They again revised their guidelines in 2018, with draft values set to become available in 2020.[213] In Europe, the Water Framework Directive set out guidelines in 2000,[214] amended these guidelines in 2008,[215] and also undergoes a periodic evaluation ("fitness check") to determine if the Water Framework Directive policies are "fit for purpose" based on "[policy] effectiveness, efficiency, coherence, [and] relevance."[216] In Canada, guidelines were initially adopted in 1987, and were updated in 1991 and 2007.[217]

The 1985 guidelines were, at one time, cutting-edge and were adopted by numerous countries across the world. Yet, while other countries have since acknowledged trends in science, and modernized their guidelines to reflect the latest science, the United States has not. Although criteria may be applied somewhat differently in the United States than in other

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212. *History of the Water Quality Guidelines*, AUSTL. GOV'T INITIATIVE, https://www.waterquality.gov.au/anz-guidelines/about/history (last visited Feb. 29, 2020).

213. *See Deriving Guideline Values for Water Quality*, AUSTL. GOV'T INITIATIVE https://www.waterquality.gov.au/anz-guidelines/guideline-values/derive (last updated Dec. 24, 2019) ("Guideline values for aquatic ecosystems can be derived using: reference site data, laboratory-effects data, field-effects data, multiple lines of evidence based on two or more of these data."); *Pathway for Toxicant Default Guideline Value Publication*, AUSTL. GOV'T INITIATIVE, https://www.waterquality.gov.au/anz-guidelines/guideline-values/default/draft-dgvs#draft-default-guideline-values (last updated Nov. 13, 2019) ("Draft DGVs should become available from early 2020.").

214. *See* Council Directive 2000/60/EC, 2000 O.J. (L 327) (EC) (creating the guidelines).

215. *See* Council Directive 2008/105/EC, 2008 O.J. (L 348) (EC) (amending the guidelines).

216. *See European Commission, Executive Summary of the Fitness Check of the Water Framework Directive, Groundwater Directive, Environmental Quality Standards Directive and Floods Directive*, at 1, SEC (2019) 438 final (Dec. 12, 2019), https://ec.europa.eu/environment/water/fitness_check_of_the_eu_water_legislation/documents/SWD_2019_440_F1_SWD_FITNESS_CHECK_EXECUTIVE_SUMMARY_EN_V4_P1_1058675.pdf.

217. *See* Doug Spry, *An Overview of Canadian Water Quality Guidelines*, U.S. ENVTL. PROT. AGENCY (Sept. 14, 2015), https://www.epa.gov/sites/production/files/2016-01/documents/03_spry_canadianwaterqualitygdlns-final-rev_secure.pdf (providing an overview of Canadian water quality guidelines); *see also Invited Expert Meeting on Revising U.S. EPA's Guidelines for Deriving Aquatic Life Criteria,* U.S. ENVTL. PROT. AGENCY, https://www.epa.gov/wqc/invited-expert-meeting-revising-us-epas-guidelines-deriving-aquatic-life-criteria (last visited Jan. 9, 2019) (describing the meeting at which Doug Spry presented).

countries, the science of developing criteria is the same across the globe. If the 1985 guidelines lag behind the science for developing criteria in other nations, then they also lag behind the latest scientific knowledge in the United States.

i. Suggestions for Updating the 1985 Guidelines

As the seminal ecologist and a founder of the modern ecotoxicology discipline, John Cairns instructed, "[i]f environmental toxicology is to come of age, it must begin to ask more searching questions, develop broader hypotheses involving natural systems, and develop models that are validated in landscapes, not laboratories."[218] In this section, we reiterate recommendations from scientific literature and from commentators, with some modification and additions of our own. We provide specific recommendations for modernizing the criteria development process according to scientific advancements made since 1985 and list some policy recommendations that may better facilitate criteria development. Importantly, we do not advocate for complete abandonment of single species testing, rather, these recommendations are meant to build upon the 1985 guidelines and to advance the criteria development process to better reflect the latest scientific knowledge.

Here, we have not attempted to prioritize this rather expansive list of recommendations, and we do not suggest that the EPA implement these recommendations all at once. Rather, it would be more beneficial for the EPA to select and prioritize recommendations that it determines to most closely "reflect the latest scientific knowledge" and implement those recommendations. Over time, the EPA could implement more recommendations as they are justified and feasible. In fact, the CWA envisions such as process.[219]

a. Scientific Suggestions for Updating the 1985 Guidelines

* Develop methods for incorporating field data into criteria development, particularly when organisms appear more

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218. John J. Cairns Jr., *Paradigms Flossed: the Coming of Age of Environmental Toxicology*, 11 ENVTL. TOXICOLOGY AND CHEMISTRY: AN INT'L J. 285, 286 (1992).

219. 33 U.S.C. § 1314(a)(1) ("[The EPA] shall develop. . . (*and from time to time thereafter revise*) criteria for water quality that accurately reflect the latest scientific knowledge.") (emphasis added).

sensitive to a pollutant in the wild than in the laboratory or vice versa. This may require a weight of evidence approach. [220] Alternatively, criteria primarily based on field observations are also possible.[221] For example, the EPA-developed field-based benchmarks for conductivity in Central Appalachian streams.[222] This framework provides a model for expansion to different groups of contaminants and different locations.

* Explicitly acknowledge that pollutants almost always occur in mixtures.[223] Criteria development should, at a minimum, attempt to model common mixture interactions.[224] Biogeochemical models for metal mixtures exist and offer a template for addressing pollutant mixtures that may cause additive, antagonistic, or synergistic toxicity.[225] Mixture toxicity is a particular thorny problem and the current use of WET

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220. *See, e.g.*, Cormier et al., *supra* note 8, at 490

> Final selection of a criterion uses a weight-of-evidence comparison that engenders confidence because causal associations are confirmed on the basis of different assumptions, independent data sets, and varied statistical methods, thereby compensating for the concerns raised by individual studies and methods. Thus, it becomes possible to specify criteria for agents with biological or physical modes of action, as well as those with chemical modes of action, to best achieve environmental goals.

221. *Cf.* Susan M. Cormier & Glenn W. Sutter, *Sources of Data for Water Quality Criteria*, 32 ENVTL. TOXICOLOGY & CHEMISTRY 254, 254 (2013)

> [N]early all water quality criteria . . . have been derived using standard laboratory toxicity tests . . . But now it is time to avail ourselves of all sources of knowledge. The U.S. EPA's initial application [of field data to criteria setting], a benchmark value for dissolved ions measured as specific conductance, has withstood a series of intense reviews and has guided environmental decisions. The true judge of the method's value, though, rests in whether it is used for other pollutants and whether it inspires new and useful science. In any case, we expect that information from the laboratory, field, and modeling will contribute in the future to a wider range of approaches to criteria setting.

222. *See* Cormier, Suter, & Zheng, *supra* note 203, at 263–71 (detailing methodology and justifications for deriving a field-based benchmark for conductivity in streams).

223. *See supra* note 112 and accompanying texts.

224. *See* DeForest et al., *supra* note 7, at 1125 ("More explicitly tackle the challenges of setting mixtures criteria.").

225. *See* Kevin J. Farley, et al., *Metal Mixture Modeling Evaluation project: 2. Comparison of Four Modeling Approaches*, 34 ENVTL TOXICOLOGY AND CHEMISTRY 741, 741–53 (2015).; *see also* Christer Hogstrand, Scott M. Reid & Chris M. Wood, *Ca^{2+} Versus Zn^{2+} Transport in the Gills of Freshwater Rainbow Trout and the Cost of Adaptation to Waterborne Zn^{2+}*, 198 J. OF EXPERIMENTAL BIOLOGY 337, 337–48 (1995).

testing and other similar testing procedures in NPDES permits does not sufficiently address the problem.

* Provide methods for developing criteria using more environmental realistic exposure scenarios such as field and mesocosm experiments.[226] These approaches better approximate community and population level responses in nature by incorporating indirect effects, incorporating emergent properties, and embracing the natural variability of complex systems that define aquatic ecosystems.[227] The EPA required mesocosm testing from 1988 to 1992 for pesticide registration under the Federal Insecticide, Fungicide, and Rodenticide Act,[228] and significant literature and technical guidance exists to run these experiments.[229]

* Develop methods for modifying or validating criteria derivations using mesocosm experiments, ecosystem experiments, and field observations.[230]

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226. *See* Buchwalter, Clements, & Luoma, *supra* note 7, at 287–88, 289–90 (proposing field data and mesocosm experiments for criteria development).

227. *See Id.* at 286 (describing why it is necessary to update the traditional approach); Susan M. Cormier, Lei Zheng, & Colleen M. Flahery, *Field-Based Method for Evaluating the Annual Maximum Specific Conductivity Tolerated by Freshwater Invertebrates*, 633 SCI. TOTAL ENV'T 1637, 1637–46 (2018) (providing "a method for developing an acute value to complement a chronic benchmark or criterion derived from field data"); William H. Clements, *Small-Scale Experiments Support Causal Relationships Between Metal Contamination and Macroinvertebrate Community Responses*, 14 ECOLOGICAL APPLICATIONS 954, 954–67 (2004) (providing an example of an experimental approach that incorporates these different considerations).

228. *See* U.S. ENVTL. PROT. AGENCY, QUESTIONS AND ANSWERS: IMPROVEMENTS TO EPA'S PROGRAM TO PREVENT ADVERSE ENVIRONMENTAL EFFECTS OF PESTICIDES (1992) (explaining that the EPA rescinded the mesocosm testing requirement on the basis that "they do not provide substantial information for making risk decisions beyond that already revealed by lower tiered [e.g., single-species laboratory testing] studies").

229. *See* JOHN CAIRNS ET AL., ECOLOGICAL TOXICITY TESTING: SCALE, COMPLEXITY, AND RELEVANCE 1–223 (John Cairns Jr. & B. R. Niederlehner, eds., 2004) (offering technical guidance for mesocosm experimental setup, design, statistical analyses, among other important considerations); GRANEY ET AL., AQUATIC MESOCOSM STUDIES IN ECOLOGICAL RISK ASSESSMENT (R. L. Graney et al., eds., 1993) (offering similar technical guidance for mesocosm experimental setup, design, statistical analyses, among other important considerations).

230. *See* G. Allen Burton et al., *Making Ecosystem Reality Checks the Status Quo*, 31 ENVTL. TOXICOLOGY AND CHEMISTRY 459, 459–68 (2012).

* Propose methods for and require dietary exposures when developing criteria.[231] For example, the latest EPA selenium criteria included dietary exposure data.[232] The inclusion of mesocosm and field exposures in criteria development would inherently include dietary exposures, but dedicated dietary trials might also be necessary for certain pollutants.[233]

* Report body size and developmental stage of aquatic organisms used in all single species testing, mesocosm experiments, and field results. Encourage toxicity testing for all body sizes and developmental life stages.

* Consider aquatic-terrestrial linkages in criteria development.[234] Pollutant export and aquatic subsidies link terrestrial systems with aquatic systems.[235] Mesocosm and field experiments can estimate such linkages.[236] Similarly, consider

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231. *See* Kim, Funk, & Buchwalter, *supra* note 100, at 2295

> [I]nsects dominate freshwater ecosystems and are heavily relied upon in ecological monitoring programs. We know from the literature that insects are generally unresponsive to traditional toxicity assays utilizing aqueous exposures only, and generally acquire much of their metal exposures from their diets. In light of these factors, we think it is valid to ask whether water quality criteria based solely on toxicity tests using aqueous exposures can be adequately protective of aquatic communities. Our understanding of trace metal bioaccumulation and toxicity have improved greatly in the last few decades, while approaches to deriving water quality criteria have not evolved with our growing understanding. Methods to incorporate dietary exposures into toxicity testing are here and ready be used to develop scientifically defensible water quality standards.

232. *See* U.S. ENVTL. PROT. AGENCY, AQUATIC LIFE AMBIENT WATER QUALITY CRITERION FOR SELENIUM–FRESHWATER (2016), https://www.epa.gov/sites/production/files/2016-07/documents/aquatic_life_awqc_for_selenium_-_freshwater_2016.pdf ("The toxicity studies relevant to the derivation of the fish tissue selenium criterion elements involve . . . extended duration dietary exposure.").

233. Buchwalter, Clements, & Luoma, *supra* note 7, at 288–89 (criticizing that the traditional approach fails to consider dietary exposure).

234. *See generally* Kraus et al., *Cross-Ecosystem Impacts of Stream Pollution Reduce Resource and Contaminant Flux to Riparian Food Webs*, 24 ECOLOGICAL APPLICATIONS 235, 234–43 (2014).

235. *See id.* (describing a field study assessing the relationship of metal concentrations in mountain streams to metal export and insect emergence (i.e., subsidies) to linked forest environments). *Cf.* Krümmel et al., *supra* note 87, at 255 (describing a field study of sockeye salmon acting as bulk-transport vectors of polychlorinated biphenyls (PCBs) from the Pacific ocean to inland spawning lakes off the southern coast of Alaska).

236. *See* Christopher Kotalik, Contaminants and Ecological Subsidies: The Land-Water Interface, Mesocosms To Evaluate Aquatic-Terrestrial Contaminant Linkages Using Aquatic Insect Emergence: Utility for Aquatic

toxic effects of pollutants on aquatic-dependent organisms (i.e., waterfowl, riparian obligate species).[237]

* Incorporate bioavailability models into criteria development.[238]

* Provide methods for integrating bioaccumulation, biomagnification, biotransformation, toxic intermediaries, and trophic transfer of pollutants into criteria. The latest EPA aquatic life criteria for selenium was developed using field data that model bioaccumulation.[239] These relationships will generally be best estimated using field data.[240]

* Develop models to predict aquatic ecosystems resistance and recovery following aquatic life criteria exceedances. The 1985 guidelines already describe allowable frequency and duration for when acute and chronic criteria exceedances can occur;[241] however, this is generalized for all contaminants and for all aquatic ecosystems. Specific frequencies and durations of criteria exceedances should be developed for specific pollutants.

Life Criteria Development (2020) (unpublished manuscript) (on file with author) (describing the use of aquatic insect emergence collected during mesocosm testing to predict aquatic contaminant effects on aquatic-dependent terrestrial organisms); Kraus et al., *supra* note 234, at 235–43 (studying the effects of aquatic contaminants via resource linkages).

237. *See* Baxter, Fausch & Saunders, *supra* note 95, at 201 ("Emergence of adult insects from streams can constitute a substantial export of benthic production to riparian consumers such as birds, bats, lizards, and spiders, and contributes 25–100% of the energy or carbon to such species.").

238. *See* Christopher A. Mebane et al., *Metal Bioavailability Models: Current Status, Lessons Learned, Considerations for Regulatory Use, and the Path Forward*, 39 ENVTL. TOXICOLOGY & CHEMISTRY 60, 60–84 (2020) (providing an overview of bioavailability models); *see also* William J. Adams, et al., *Bioavalibility Assessment of Metals in Freshwater Environments: A Historical Review*, 39 ENVTL. TOXICOLOGY & CHEMISTRY 48, 48–59 (2019) (discussing the science of bioavailability and its incorporation into regulatory practice).

239. *See* SELENIUM FACT SHEET, *supra* note 165 (using bioaccumulation modeling). *Cf.* AQUATIC LIFE CRITERION - SELENIUM, *supra* note 88 ("Selenium bioaccumulates in the aquatic food chain and chronic exposure in fish and aquatic invertebrates can cause reproductive impairments (*e.g.*, larval deformity or mortality).").

240. *See* Nico W. Van den Brink et al., *Use of Terrestrial Field Studies in the Derivation of Bioaccumulation Potential of Chemicals*, 12 INTEGRATED ENVTL. ASSESSMENT & MGMT. 135, 135–45 (2016) (reviewing methods for estimating bioaccumulation of pollutants in the field); *see also* Raphael A. Lavoie, *Biomagnification of Mercury in Aquatic Food Webs: A Worldwide Meta-Analysis*, 47 ENVTL. SCI. & TECH. 13385, 13385–94 (2014) (describing a large-scale analysis of mercury biomagnification).

241. 1985 GUIDELINES, *supra* note 6, at 4–9.

* Consider the effects of dynamic exposures that change over time.[242]

* Consider legacy effects of pollutants (e.g., altered community structure, alternative stable states, costs of tolerance) that may adversely impact aquatic life even after pollutant concentrations return to acceptable levels.[243]

* Consider integrating functional aquatic ecosystem responses (e.g., rates of primary production, nutrient cycling, and decomposition) and related ecosystem services into criteria development.[244]

* If hypothesis testing statistics are utilized to test for pollutant effects, derive criteria using statistical methods that minimize type II error, not just type I error. Type II error rate should also be reported for all hypothesis testing results.[245] It is better to err on the side of caution, and to protect against type II error because erroneously concluding that a pollutant has no adverse effect on aquatic life when it actually causes toxicity (i.e., a false negative) may result in environmental degradation that may be difficult to reverse after the fact.

* Provide methods for addressing indirectly toxic pollutants. Stream mesocosms offer appropriate experimental conditions to evaluate these relationships.[246]

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242. *See supra* notes 101, 102, 103 and accompanying texts.

243. *See* Duggan, Kotalik, & Clements, *supra* note 110, at 13584–90 (describing a petroleum spill affected stream that despite petroleum hydrocarbon concentrations returning to pre-spill concentrations, communities were significantly impaired years after the spill); *see also* William H. Clements, & Jason R. Rohr, *Community Responses to Contaminants: Using Basic Ecological Principles to Predict Ecotoxicological Effects*, 28 ENVTL. TOXICOLOGY & CHEMISTRY 1789, 1789–1800 (2009) ("A better understanding of pollution-induced community tolerance, and of the costs of this tolerance, should facilitate identifying contaminant impacted communities, thus forecasting the ecological consequences of contaminant exposure and determining the restoration effectiveness."); Kashian et al., *supra* note 125, at 365–75 (arguing "that the greater susceptibility of chronically disturbed communities to UV-B and other novel stressors represents a potential cost of tolerance").

244. *See, e.g.*, Macadam & Stockan, *supra* note 189, at 113–23 (2015).

245. In hypothesis testing, type I error is the rejection of the null hypothesis when it is actually true, which is commonly referred to as a "false positive." Type II error is not rejecting the null hypothesis when the alternative hypothesis is true, which is commonly referred to as a "false negative."

246. *See* Kotalik, *supra* note 236 (describing the indirect toxicity of pollutants such as effects on food resources (e.g., algae) that can be incorporated into mesocosm testing); *see also* Christopher J. Kotalik, Pete Cadmus, & William H. Clements, *Indirect Effects of Iron Oxide on Stream Benthic*

* Provide methods for establishing toxicity data for species that may be inappropriate for toxicity testing such as threatened or endangered species, species of heighten public concern, and species that are difficult utilize in toxicity tests but have substantial ecosystem value.[247]

* Reevaluate and consider amending the 1985 guideline's minimum data requirements—the "[eight]-family rule" for acute criteria and the "three-family rule" for chronic criteria.[248] This requirement that criteria must be derived by utilizing toxicity data from eight (acute criteria) or three (chronic criteria) species representing different taxonomic families can be both an unreasonable hurdle for developing criteria when pollutants are data poor, and may limit the data considered in criteria development for data rich pollutants.

* Provide methods for incorporating risk assessment principles into criteria development.[249]

Communities: Capturing Ecological Complexity with Controlled Mesocosm Experiments, 53 ENVTL. SCIENCE & TECH. 11532, 11532–40 (2019) (describing a mesocosm study examining indirect iron toxicity to aquatic insects); *see, e.g.*, Cormier et al., *supra* note 8, at 490–504 (using criterion assessment methodology to argue "it is possible to specify criteria for agents with biological or physical modes of action, as well as those with chemical modes of action, to best achieve environmental goals").

247. *See* DeForest et al., *supra* note 7, at 1125 ("Add a framework for evaluating the protectiveness of [criteria] relative to [threatened and endangered] species. It should include procedures for identifying surrogate organisms and applying tools such as the USEPA's Interspecies Correlation Estimation (ICE) model . . . ").

248. *See id.* ("Reconsider the "8-family rule" in terms of taxa requirements and the opportunity to provide flexibility by region or water-body type. Lessons learned, such as the sensitivity of unionid mussels and snails to certain chemicals, are informative."); *see also* J. Cairns, *The Myth of the Most Sensitive Species*, 36 BIOSCIENCE 670, 670–72 (1986).

249. *See* Glenn W. Sutter II & Susan M. Cormier, *What Is Meant by Risk-Based Environmental Quality Criteria*, 4 INTEGRATED ENVITL. ASSESSMENT & MGMT. 486, 486 (2008)

> Risk assessment offers several advantages as a basis for criterion development. Unlike the National Research Council's expert judgment, it is procedurally transparent and consistent. However, unlike the algorithmic approach of Stephan et al. (1985), which provides a standard methodology for data selection and analysis, it is flexible enough to incorporate differences in goals, information availability, and analytical methods. This flexibility is particularly important as criteria are derived for unconventional pollutants, like nutrients and suspended sediments, and as novel types of field data and laboratory data become available.

See also Glenn Suter, *Specifying the Dimensions of Aquatic Life Benchmark Values in Clear, Complete, and Justified Problem Formulation*, 14 INTEGRATED

* Provide methods for addressing issues of context dependency and multiple disturbance that may affect toxicity (e.g., adaptation, acclimation, sensitive versus tolerant community composition, disease, invasive species, water level/flow, drought, extreme cold or heat, climate change, mixtures, etc.).[250] Weight-of-evidence approaches and the application of risk assessment principles could help address these complexities.[251]

* Provide methods for developing a single national recommended narrative catch-all criterion. Provide methods for developing narrative companion criteria to supplement numeric criteria. Provide methods for defining the terms in the narrative criteria. Provide methods for establishing interpretation, monitoring, implementation, and enforcement guidelines for the narrative criteria. Consider requiring that all states adopt a narrative catch-all criterion and companion criteria.

* Consider broadly utilizing biocriteria.[252] This might include a requirement that all states adopt biocriteria. It is worth noting that many, if not most, of the problems identified in this Article could be solved through the appropriate use of biocriteria.

ENVTL. ASSESSMENT AND MGMT. 631, 633–34 (2018) (describing the potential use of human-health risk assessment methods in criteria development for aquatic life). *Cf.* Glen Suter, Susan Cormier & Mace Barron, 13 INTEGRATED ENVTL. ASSESSMENT AND MGMT. 1045, 1050 (2017) ("Regulatory agencies have relied on standard methods for deriving benchmark values, such as Stephan et al. (1985), because their application is objective and consistent for all pollutants. A similar standard of fairness may be achieved by following a consistent [weight-of-evidence] framework and methodology to maximize objectivity and consistency."). Narrative criteria could also be used to make criteria more risk based rather than algorithmic.

250. *See* Clements et al., *supra* note 206 at 1932 ("Similar to the way in which aquatic toxicologists assess abiotic factors associated with contaminant bioavailability, observations about context dependency could be used to test hypotheses about ecological mechanisms responsible for differences in sensitivity among communities.").

251. *See* Cormier et al., *supra* note 8, at 490–504 (providing an overview of using weight of evidence to develop water quality criteria).

252. *See* Adler, *supra* note 50, at 1–66; Adler, *supra* note 25, at 803–06; Robert W. Adler, *Filling the Gaps in Water Quality Standards: Legal Perspectives on Biocriteria*, *in* BIOLOGICAL ASSESSMENT AND CRITERIA, TOOLS FOR WATER RESOURCE PLANNING AND DECISION MAKING 345, 358 (Wayne S. Davis & Thomas P. Simon, eds., 1995); Robert W. Adler, *The Two Lost Books in the Water Quality Trilogy: The Elusive Objectives of Physical and Biological Integrity*, 33 ENVTL. L. 29, 70–75 (2003) (surveying sources on broadly considering biocriteria in the context of setting water quality standards).

b. Other Suggestions for Updating the 1985 Guidelines

* Adopt at least two frameworks for developing criteria. First (i.e., tier 1), when data for a particular pollutant are abundant and time restraints for criterion development are not severe, the criterion should be developed through an exhaustive synthesis of all available and relevant data. This framework should emphasize environmental realism over other considerations. Second (i.e., tier 2), when data for a particular pollutant are limited or when time restraints for criterion development are pressing, criterion development should be streamlined and should emphasize the precautionary principle[253] over other considerations.[254]

* Provide guidelines for independent researchers on the best practices for constructing experiments and studies that the EPA would be likely to incorporate into their criteria development process. Also, indicate that the EPA would not automatically exclude data merely because an independent researcher did not follow the guidelines.

* Define and provide guidance on the definition of CWA's phrase requiring the EPA to develop "criteria for water quality that accurately reflect the latest scientific knowledge."[255]

* Provide methods for determining when a criterion must be revised because it no longer reflects the latest science.

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253. *See* David Kriebel et al., *The Precautionary Principal in Environmental Science*, 109 ENVTL. HEALTH PERSP. 871, 871 (2001) (listing the precautionary principle's four central components: "taking preventive action in the face of uncertainty; shifting the burden of proof to the proponents of an activity; exploring a wide range of alternatives to possibly harmful actions; and increasing public participation in decision making").

254. *See* M. Elias & C. Bergeron, *USEPA's 1985 Guidelines for Deriving Aquatic Life Criteria—Update on the Status of the Guidelines Revision Process*, *in* ABSTRACT BOOK: SETAC NORTH AMERICA 39TH ANNUAL MEETING 335 (2018) https://www.setac.org/store/ViewProduct.aspx?id=13373145 (explaining that such a framework was considered by the EPA); *see also* DeForest et al., *supra* note 7, at 1125

> Adopt 2 tiers of criteria ('rapid' and 'detailed'). The former could be derived efficiently from existing databases . . . . Modern programming allows for rapid, targeted retrieval of data. The latter should encourage more robust evaluation of toxicity data and frameworks for considering alternative exposure routes and endpoints, evaluating threatened and endangered . . . species, using interspecies and interchemical extrapolation, and 'other' endpoints.

255. 33 U.S.C. § 1314(a)(1).

* Provide a framework for rapidly revising a criterion when a determination is made that the criterion no longer reflects the latest science.

* Provide methods for periodically revising the criteria development guidelines.

* Provide methods for prioritizing the development or revisions of certain criteria over others. For example, developing criteria for emerging pollutants, common pollutant mixtures, narrative companion criteria, and a narrative catch-all criterion could be prioritized over revising criteria that already exist.

* Provide methods for encouraging data collection for pollutants that have limited data availability.

* Provide methods for encouraging private entities to share toxicity data with the EPA to assist with criteria development even when the private toxicity data is proprietary or otherwise private.

B. THE EPA SHOULD DEVELOP NARRATIVE CRITERIA TO SUPPLEMENT ALL EPA-RECOMMENDED NUMERIC CRITERIA

The CWA's regulatory framework is inextricably linked with the science of aquatic ecotoxicology. But the science contains many unknowns. Particularly in natural settings, expectations of toxic effects on aquatic life often diverge from expectations derived from laboratory experimentation because nature is infinitely complex, persistently dynamic, and fundamentally different than experimental conditions in laboratories.

Under the CWA, the EPA must develop criteria that accurately reflect the latest science.[256] Although current science can undoubtedly predict that extremely high concentrations of pollutants will cause adverse effects on aquatic organisms and extremely low concentrations will not, predictions between the extremes are much more difficult and subject to error. Yet, water quality criteria are developed to predict between the extremes—each criterion is a regulatory determination of the threshold between protecting aquatic life from pollutants and pollutants causing unacceptable toxic effects. Not only would this threshold be difficult for the latest science to describe for a single species

256. 33 U.S.C. § 1314(a)(1) (providing for the development and publication of "criteria for water quality accurately reflecting the latest scientific knowledge").

under dynamic natural conditions, but EPA-recommended criteria attempt to extrapolate the threshold across the vast diversity of aquatic organisms, across all the nation's waterways, and across the breadth of interactions among various biotic and abiotic factors.

We assert that the latest science is clear in at least one regard: it is impossible to accurately predict the threshold between protecting aquatic life from pollutants and pollutants causing unacceptable toxic affects by relying exclusively on a discrete numeric criterion because even if such a threshold exists, the threshold changes.[257] Instead, the latest science shows that discrete numeric criteria must be given more flexibility.[258] Therefore, we suggest that each EPA numeric criterion recommendation should be reinforced by a flexible companion narrative criterion, and all numeric criteria for aquatic life should be further protected by a single catch-all narrative criterion.[259]

i. A Narrative Companion Criterion for Every Numeric Criterion

The latest science counsels against over relying on numeric criteria. Although the CWA requires the EPA to recommend numeric criteria for certain pollutants, the EPA may also supplement numeric criteria with narrative criteria.[260] A narrative criterion should supplement each numeric criterion.

For example, the current EPA-recommended criterion for acute exposure to the pesticide diazinon in freshwater is 0.17 μg/L.[261] Alternatively, we propose a numeric criterion with a

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257. *Cf.* Andrew J. Huggett, *The Concept and Utility of 'Ecological Thresholds' in Biodiversity Conservation*, 124 BIOLOGICAL CONSERV. 301, 301–10 (2005) (describing the challenges associated with identifying ecological thresholds).

258. *Cf.* Adler, *supra* note 9 ("[I]t would seem that individual numeric water quality criteria are, at best, necessary but not sufficient to attain aquatic ecosystem health . . . Congress envisioned that water quality standards would address factors other than concentrations of individual pollutants.").

259. *Cf.* 33 U.S.C. § 1251(a)(1) ("[I]t is the national policy that the discharge of toxic pollutants in toxic amounts be prohibited.").

260. 33. U.S.C. 1314; *see also* 40 C.F.R. 131.11.

261. The national acute criteria for diazinon reads,

> The procedures described in the "Guidelines for Deriving Numerical National Water Quality Criteria for the Protection of Aquatic Organisms and Their Uses" (Stephan et al. 1985) indicate that, except possibly where a locally important species is very sensitive, freshwater

narrative companion. For example, 0.17 µg/L or concentrations of diazinon itself, or in combination with other perturbations, adversely affect aquatic life compared to reference conditions.[262] Not only does a dual numeric and narrative criteria framework allow for regulatory flexibility that is needed to adjust to the uncertain consequences of pollutants in natural systems, but it could also future-proof [263] criteria against changing environmental conditions (e.g., climate change, disease, land use changes) that could affect a pollutant's toxicity and make numeric criteria less environmentally relevant than when they were originally developed. Additionally, narrative companion criteria could future-proof criteria against scientific advances that may demonstrate that a pollutant is more toxic than previously thought.

For these reasons, numeric criteria with narrative companions more accurately reflect the latest science than the current system. Importantly, the EPA should also rigorously define each term in each narrative companion criteria and promulgate guidance for interpreting and enforcing the criteria.

> aquatic organisms and their uses should not be affected unacceptably if the one-hour average concentration does not exceed 0.17 µg/L more than once every three years on the average and if the four-day average concentration of diazinon does not exceed 0.17 µg/L more than once every three years on the average.

U.S. ENVTL. PROT. AGENCY, AQUATIC LIFE AMBIENT WATER QUALITY CRITERIA, DIAZINON 28 (2005) https://www.epa.gov/sites/production/files/2019-03/documents/ambient-wqc-diazinon-final.pdf.

262. There are an infinite number of potential narrative companion criteria that the EPA could utilize that would be more or less protective of aquatic life and more or less difficult to regulate. This narrative companion criteria is only intended to serve as an example. Another example is, 0.17 µg/L or amounts of diazinon, its breakdown products, metabolites, or transformation products, that by itself or in conjunction with any other biotic or abiotic factor, cause statistically significant health, behavioral, or distribution changes in a population or community of aquatic organisms at any life stage compared to expectations based on natural conditions. Another example is, 0.17 µg/L or amounts of diazinon that cause physiological harm to aquatic life. Similarly, the companion criteria could be an explicit biocriteria. It should also be noted that this Article envisions that narrative companion criteria would act as a one-way ratchet allowing for stricter CWA enforcement than could otherwise be achieved with a numeric criteria alone—not looser enforcement.

263. *See* Alexandra Klass, *Future-Proofing Energy Transport Law*, 94 WASH. U. L. REV. 827, 828 n.1 (defining "[f]uture-proofing [as] the process of anticipating the future and developing methods of minimizing the negative effects while taking advantage of the positive effects of shocks and stresses due to future events")(quoting *Principles of Future-Proofing: Research on Future-Proofing the Built Environment*, http://principlesoffutureproofing.com).

If the EPA utilized dual numeric and narrative criteria framework, the EPA would more fully comply with mandates from the CWA that require criteria to reflect the latest science, but also require numeric criteria for certain pollutants.

ii. A National Narrative Catch-All Criterion

Reinforcing numeric criteria with narrative companions are not enough. Neither is the CWA's broad no "toxic pollutants in toxic amounts" policy.[264] The EPA should consider developing a catch-all narrative criterion for aquatic life to serve as a gap-filler for all toxic scenarios that are not explicitly regulated by other criteria. Overreliance on a piecemeal approach to regulating pollution on a pollutant-by-pollutant basis is unjustified.[265] The latest science cannot adequately predict which pollutants may elicit toxic effects in combination with other biotic and abiotic factors. Pollutant mixtures may elicit toxic effects on aquatic life even though no single pollutant exceeds a particular criterion. The EPA cannot develop criteria fast enough to keep pace with scientific advances, the diversity of existing pollutants, or the creation of new and emerging pollutants. Unlike the narrative companion criteria that reinforce specific numeric criteria, this catch-all criterion would provide umbrella protection for all aquatic life from all pollutants—its role is preventing unexpected or unregulated adverse effects of pollutants from slipping through regulatory gaps and escaping enforcement actions to the detriment of aquatic life.

Although many states have catch-all criteria in one form or another,[266] states often craft these using unenforceable, vague

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264. 33 U.S.C. § 1251(a)(1) ("[I]t is the national policy that the discharge of toxic pollutants in toxic amounts be prohibited."). However, this policy does lend support for the EPA developing supplemental narrative criteria.

265. Although the CWA requires the development and publication of "information on methods for establishing and measuring water quality criteria for toxic pollutants on other bases than pollutant-by-pollutant criteria, including biological monitoring and assessment methods," 33 U.S.C. § 1314(a)(8), the EPA itself does not develop such criteria except for relatively narrow classes of pollutants (e.g., oil and grease, bacteria, PCBs)). *Cf. supra* note 48 and accompanying texts.

266. *See, e.g.*, MINN. R. 7050.0150

> For all class 2 waters, the aquatic habitat, which includes the waters of the state and stream bed, shall not be degraded in any material manner, there shall be no material increase in undesirable slime growths or aquatic plants, including algae, nor shall there be any significant

language with inadequately defined terms and states often only apply catch-all criteria to a narrow scope of designated uses that can leave important aquatic resources unprotected.[267] The EPA should leverage its expertise and national leadership role to recommend specific language for a catch-all narrative criterion for adoption by the states. Moreover, the EPA also should rigorously define each term in the catch-all criterion and promulgate guidance for its interpretation and enforcement.

Similar to narrative companion criteria, there are many possibilities for crafting an EPA-recommended catch-all criterion that could be more or less protective and more or less difficult to enforce. This Article does not attempt to provide the best language, but example language is provided.

The catch-all criterion could contain technical and expansive language. For example, waters including aquatic sediments and hyporheic waters shall be free of pollutants including their breakdown products, metabolites, transformation products, and any mixture thereof, that individually or in combination with any other biotic or abiotic factor, cause statistically significant pollutant loading, pollutant transfer, or statistically significant health, behavioral, or distribution changes to a sub-population, population or community of aquatic organisms at any life stage.[268] The catch-all criterion could contain less technical language by mirroring one of the several suggestions that EPA offers in its Water Quality Standards Handbook:

> All waters shall be free from toxic, radioactive, conventional, non-conventional, deleterious or other polluting substances in amounts that

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> increase in harmful pesticide or other residues in the waters, sediments, and aquatic flora and fauna; the normal aquatic biota and the use thereof shall not be seriously impaired or endangered, the species composition shall not be altered materially, and the propagation or migration of aquatic biota normally present shall not be prevented or hindered by the discharge of any sewage, industrial waste, or other wastes to the waters.

267. *See e.g.*, OHIO ADMIN CODE 3745-1-04 (describing Ohio's "free from" narrative criterion); *Cf.* City of Taunton v. United States EPA, 895 F.3d 120, 133 (1st Cir. 2018) (discussing how Massachusetts failed to translate a narrative criteria into an enforceable standard so the EPA was forced to); Fla. Wildlife Fed'n, Inc. v. Jackson, 853 F. Supp. 2d 1138, 1146–51, 1156–60 (N.D. Fla. 2012), *appeal dismissed*, 737 F.3d 689 (11th Cir. 2013) (explaining that a Florida narrative criteria was invalid because it was unenforceable).

268. A catch-all criterion could draw from the seminal ecologist Aldo Leopold—water quality should "tend[] to preserve the integrity, stability and beauty of the biotic community." ALDO LEOPOLD, *supra* note 1, at 224.

> will prevent attainment [of water quality which provides for the protection and propagation of fish, shellfish, and wildlife.]; (2) [waters should not] cause injury or [toxicity] to . . . , or produce adverse physiological responses in humans, animals, or plants; (3) [waters should not] produce undesirable or nuisance aquatic life [or the lack of desirable aquatic life]. . . .[269]

The catch-all criterion could also rise from the language of CWA's primary goal—waters shall be free from pollutants in amounts that do not "restore and maintain the chemical, physical, and biological integrity of the Nation's waters."[270] If the EPA defined each term with sufficient rigor and provided states with adequate guidance for interpretation, implementation, and enforcement, such a criterion could turn the CWA's unenforceable and aspirational goal into an enforceable and substantive mandate because CWA compliance would be measured, in part, by adherence to the CWA's primary goal. The EPA should, however, develop only one catch-all narrative criterion for recommendation to the states—the criterion that the EPA determines is the most accurate reflection of the latest science.

iii. The Benefits of Supplementing Numeric Criteria with Narrative Criteria Outweigh the Criticisms

Just like numeric criteria, narrative criteria can serve as the basis for establishing CWA requirements.[271] However, regulators, industry, and interest groups have historically disfavored narrative criteria because narrative criteria are flexible standards that lack the regulatory certainty of bright-

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269. WATER QUALITY STANDARDS HANDBOOK CHAPTER 3, *supra* note 20, at 5–6.

270. 33 U.S.C. § 1251(a).

271. Examples include state water quality standards, CWA § 401 state water quality certification, and NPDES permit obligations including water quality-based effluent limitations. Narrative criteria exceedances may also trigger TMDL requirements. *See, e.g.*, WATER QUALITY STANDARDS HANDBOOK CHAPTER 3, *supra* note 20, at 5–6. ("Such narrative criteria can serve as the basis for establishing pollutant or chemical-specific [water quality-based effluent limitations] for wastewater or stormwater discharges where the state or authorized tribe has not adopted chemical specific numeric criteria for a specific pollutant."). *Cf.* Northwest Envtl. Advocates v. Envtl. Prot. Agency, 855 F. Supp. 2d 1199, 1213–16 (D. Or. 2012) (holding that where numeric criteria are possible, narrative criteria can supplement, but not supplant numeric criteria); Nat'l Resources Def. Council, Inc. v. Envtl. Prot. Agency, 770 F. Supp. 1093, 1100 (E.D. Va. 1991), *aff'd*, 16 F.3d 1395 (4th Cir. 1993) ("The accepted definition of water quality criteria does not compel numerical standards . . . .").

line rules provided by numeric criteria.[272] For example, if a numeric criterion for pollutant X is 1.0 μg/L, a measurement of 1.1 μg/L would be a criteria exceedance. Alternatively, determining compliance with a narrative criterion requires the quasi-subjective analysis of an expert. For example, if the narrative criterion is, no pollutant X in amounts that do not "restore and maintain the chemical, physical, and biological integrity of the Nation's waters," then an expert would need to demonstrate that pollutant X was causing those effects before a regulatory agency could enforce a criteria exceedance. Notwithstanding valid concerns about regulatory certainty and enforcement challenges, the EPA should embrace the supplemental value of narrative criteria and develop recommended narrative water quality criteria (i.e., companions and a catch-all) for aquatic life and provide states with relevant guidance for interpretation, implementation, and enforcement.

Consider an analogy discussed in the U.S. District Court for the Northern District of Florida's decision in *Florida Wildlife Federation., Inc. v. Jackson*: "a state could adopt a numeric speed limit—70 [mph]—or a narrative standard—don't drive too fast. Or . . . both—don't drive over 70, and don't drive too fast for conditions."[273] Any thoughtful person can appreciate the definitiveness of a numeric speed limit, and the value of the narrative speed limit. Also, anyone who has received a speeding ticket for driving at the numeric speed limit during a storm can attest to its enforceability even though compliance is based on a quasi-subjective analysis by a police officer. By supplementing a numeric speed limit with a narrative speed limit, the law creates a robust rule that is both definite and flexible. It also better reflects the law's purpose—preventing car accidents—and the science of driving that demonstrates increased risk of car accidents under certain environmental conditions. Moreover, any uncertainty with narrative speed limits is not overly burdensome for drivers because the law presumes that the numeric speed limit applies unless road conditions negate the protective value of the numeric speed limit. Then, and only then, does the narrative speed limit apply.

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272. *See, e.g.*, Oliver A. Houck, *Cooperative Federalism, Nutrients, and the Clean Water Act: Three Cases Revisited*, 44 ENVTL. L. REP. NEWS & ANALYSIS 10426, 10432 (2014) (describing challenges for implementing narrative criteria).

273. Fla. Wildlife Fed'n. Inc., 853 F. Supp. 2d at 1138.

Likewise, the narrative water quality criteria proposed in this Article would only apply when numeric criteria, or other permit conditions, are not adequately protecting aquatic life. Then, and only then, would the narrative criteria become enforceable against regulated parties. For example, imagine a government agency suspects that a chemical manufacturer's effluent discharge is causing adverse effects to aquatic life even though the manufacturer is complying with the numeric criteria listed in its NPDES permit. If the NPDES permit included relevant companion narrative criteria or the catch-all criterion, then the government could enforce new restrictions on the NPDES permit, but only after expert analysis demonstrates the effluent's toxic effects in the receiving waters.[274] This demonstration would require the expert to overcome a presumption that the numeric criteria is protective for aquatic life by establishing a cause-and-effect relationship between the chemical manufacturer's discharge and the adverse environmental effects. This would be a difficult burden, but it is a tool that government—or a concerned citizens group—should have in order to enforce the goals of the CWA.[275]

The EPA should recommend supplemental narrative companion criteria and a catch-all criterion not only because they provide needed regulatory flexibility, but also because the CWA explicitly requires that the EPA recommend water quality criteria that are "accurately reflecting the latest scientific

274. *See supra* Section I.A.i. (providing background on the regulatory framework for NPDES permits).

275. Without narrative supplementation of numeric criteria, dischargers can sometimes legally discharge pollutants that cause toxic effects to aquatic life as long as the discharger is complying with the plain language of its NPDES permit including relevant numeric criteria. If a discharger is NPDES permit compliant, the government or a concerned citizens group cannot typically enforce new restrictions on the discharge to limit toxic effects until the NPDES permit gets reissued by the state, which could be many years into the future. *See* 33 U.S.C. § 1342 (k) (describing the NPDES permit shield). But, if the NPDES permit included an appropriate supplemental narrative criteria then new restrictions could be enforced. On the other hand, a discharger could not game the flexibility of the narrative criteria and increase pollution by demonstrating compliance with the narrative criteria when it was out of compliance with the numeric criteria because the numeric criteria corresponds to a maximum allowable concentration of the pollutant. *See also* 33 U.S.C. § 1342(o) (describing that under the CWA's anti-backsliding provision, a NPDES permit may not be renewed, reissued, or modified if it contains effluent limitations which are less stringent than the comparable effluent limitations in the previous permit).

knowledge."[276] Numeric criteria, without narrative supplementation, do not reflect the latest scientific knowledge. Because numerous variables in waterbodies interact in unpredictable ways, enforcing CWA violations based on exceedances of specific pollutant concentrations (i.e., numeric criteria) does not necessarily protect a waterway from a pollutant, just as enforcing a numeric speed limit does not ensure driver safety.[277] This is because it is likely impossible to capture the complexities of nature in discrete numeric criteria values alone. Modern science cannot adequately predict the toxicity of pollutant mixtures which may be more or less toxic than the sum of their parts. Pollutant mixtures may elicit toxic effects even though no single pollutant exceeds the numeric water quality criteria. And, numeric criteria cannot be developed fast enough to keep pace with scientific advances, the diversity of existing pollutants, or the development of novel pollutants. Although numeric criteria provide definitiveness and regulatory certainty desired by industry, environmentalists, and governments alike, they do not necessarily support the CWA's goal "to restore and maintain the chemical, physical, and biological integrity of the Nation's waters."[278] Therefore, the latest science indicates that narrative criteria should supplement numeric criteria to fill gaps that are created by the inherent rigidity of numeric criteria.

As noted above, narrative water quality criteria are assailed on several grounds. For example, opponents assert that numeric criteria are stronger standards, and are easier to measure and monitor than narrative criteria which can be difficult to define, enforce, and write into permits.[279] Indeed, numeric criteria are bright-line rules that typically require mere chemical analysis of water samples for criteria enforcement.[280] On the other hand, enforcing narrative criteria requires more time-consuming interpretation, and a quasi-subjective analysis by an expert.[281]

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276. 33 U.S.C. § 1314(a)(1).

277. Fla. Wildlife Fed'n. Inc., 853 F. Supp. 2d at 1145–46.

278. 33 U.S.C. § 1251(a).

279. *See, e.g.*, Houck, *supra* note 272 (describing challenges for implementing narrative criteria).

280. *See* Adler, *supra* note 25, at 804–05.

281. *See id.* (implying that the use of multiple types of criteria in conjunction with each other can be superior to reliance on a single type of criteria because each type of criteria has pros and cons).

The EPA largely agrees with these arguments, and its general distaste for narrative criteria is apparent given that the agency is increasingly requiring that states promulgate numeric criteria while also invalidating or discouraging state narrative criteria.[282] For example, the EPA invalidated a Florida narrative criterion for nutrients as functionally unenforceable because compliance review was "costly and time consuming (sic) because the relationship between nutrient levels and biological impairment is very complex and often difficult to separate from other factors."[283]

Arguments that narrative criteria are unenforceable are misplaced. Courts routinely create enforceable obligations from flexible standards lacking bright-line rules. For example, the axiomatic "reasonableness" standard creates enforceable obligations for a variety of legal claims.[284] Courts even consider the "reasonableness" standard to be an objective standard.[285] Moreover, the reasonableness standard was developed to address problems similar to those presented here—courts and legislatures found it impossible to exhaustively define legal compliance with various laws because human actions are too numerous and complex to predict, so "reasonableness" is used as a proxy for legality. The causes and effects of water pollution suffer from the same problems of numerosity and complexity as human behavior. In situations where numerosity and complexity interact, bright-line rules are not always preferable.[286]

Additionally, arguments that the regulatory burdens of enforcing narrative criteria are too costly are overstated.[287] Narrative criteria will likely be substantially less expensive to

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282. *See, e.g.*, Fla. Wildlife Fed'n. Inc., 853 F. Supp. 2d at 1146–51, 1156–60 (indicating that the use of narrative criteria at the exclusion of a numeric criteria can be problematic).

283. 2 Treatise on Environmental Law § 3.03, Lexis (2018).

284. Other examples include proximate cause, reasonable doubt, etc.

285. *See*, *e.g*., Graham v. Connor, 490 U.S. 386, 397 (1989) (describing an objective reasonableness standard in criminal law).

286. *See also* Adler, *supra* note 50, at n.22 (2019) (describing and providing examples of how "[b]iocriteria have, in fact, moved from assessment to regulatory targeting to regulation and enforcement.").

287. *See* Treatise on Environmental Law, *supra* note 283 at § 3.03 (stating that the EPA has argued narrative criteria are costly).

develop than numeric criteria,[288] and improvements in water quality and ecosystem services from enforcing narrative criteria will likely offset associated regulatory costs.[289]

Similarly, the industrial sector is understandably concerned that narrative criteria create challenges for enforcement and compliance that could increase business costs.[290] Narrative criteria, as proposed in this Article, could also effectively force many polluters to spend additional money on treatment technologies and procedures to reduce pollutants while simultaneously increasing water quality monitoring costs. There is likely truth to this concern, but it is fair to charge dischargers for the negative externalities associated with their products.[291] And if certain products end up costing more money, the marketplace will decide if those extra costs are justified for any given product. Moreover, these industry costs will be equitably or directly proportionate to the adverse consequences of the discharge itself. Arguments that this will hurt the broader economy err because such an argument would necessarily ignore the economic benefits of clean water, healthy and functional aquatic ecosystems, associated ecosystem services, and direct benefits to industries that are dependent on thriving aquatic ecosystems.[292]

Another argument against implementing a system of supplemental narrative criteria is that it might lead to a flood of litigation that would exacerbate regulatory uncertainty and costs.[293] However, all new regulatory frameworks have uncertainty. Over time, litigation itself enhances regulatory

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288. *Cf.* Power & Hicks, *supra* note 40, at 1100–02 (describing the onerous process of promulgating criteria).

289. *See* Allison J. Mitchell, Note, *Establishing an "Injury-in-Fact" Through Valuations of Ecosystem Services: Putting It in Terms Federal Courts Understand*, 20 MINN. J. L. SCI. & TECH. 439, 456–61 (2019) (describing methods for valuing ecosystem services).

290. *See* Power & Hicks, *supra* note 40, at 1107–09 (discussing the costs of compliance).

291. *Cf.* Mississippi Comm'n on Nat. Res. v. Costle, 625 F.2d 1269, 1277 (5th Cir. 1980) ("The interpretation that criteria were based exclusively on scientific data predates the [CWA's] 1972 amendments. Water Quality Criteria vii (1968). Furthermore, when Congress wanted economics and cost to be considered, it explicitly required it. See 33 U.S.C. §§ 1311(b)(2)(A), 1312(b), 1314(b) (1976).").

292. *But see* Power & Hicks, *supra* note 40, at 1115–16 (arguing that stringent criteria and "[e]nd-of-pipe effluent limits" can be unduly burdensome to the economy causing economic waste).

293. *See id.* at 1108 (discussing the costs of litigation).

certainty as the courts flesh out the nuance of the framework. Moreover, courts are well-versed in working with flexible standards such as reasonableness, foreseeability, and proximate cause.

Critics may also argue that EPA-developed narrative companion criteria and a catch-all criterion are unnecessary because the CWA allows states—with EPA approval—to adopt criteria which may be different than EPA recommendations and may include narrative companions and catch-all criteria.[294] The CWA also allows states to create site-specific criteria and variances that attempt to account for specific environmental conditions at specific locations.[295] The use of biocriteria and WET testing is also available to states.[296] Although this is true, states can lack the resources or the political will needed to develop and implement CWA programs that embrace the complexity of natural systems to ensure that the chemical, physical, and biological integrity of state waterways are protected from pollutants. Moreover, extensive use of site-specific criteria and variances exacerbate regulatory burdens by creating a hodgepodge of rules that apply to certain pollutant discharges from particular dischargers into specific waters. And, WET testing, like all types water quality criteria, can be more misleading than helpful unless it is applied in a manner that is consistent with the latest science. Furthermore, no state outmatches the EPA's regulatory and scientific expertise or national leadership regarding CWA program development and implementation.[297] Simply put, the EPA is the best agency to develop narrative companion criteria, a catch-all criterion and associated guidance. The current regulatory tools used by states to supplement EPA-recommended water quality criteria are not sufficient to protect and restore the nation's waters, at least in many states.

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294. *See supra* Section I.A.ii.

295. 40 C.F.R. § 131.20(c); *see also* Water Quality Standards Regulatory Clarifications, 78 Fed. Reg. 54,518, 54,531 (Sept. 4, 2013).

296. BIOLOGICAL WATER QUALITY CRITERIA, *supra* note 48; *See* 40 C.F.R. § 131.11(b); *see also* WHOLE EFFLUENT TOXICITY, *supra* note 29; Adler, *supra* note 25.

297. *See, e.g.*, *EPA Research Supports States*, U.S. Envtl. Prot. Agency, https://www.epa.gov/research/epa-research-supports-states ("EPA researchers are conducting innovative, anticipatory research and applying their expertise to a range of environmental challenges including helping states and communities make informed decisions about environmental issues they face.").

By developing narrative companion criteria and a catch-all criterion as official recommendations, the EPA pressures the states to adopt these recommendations or justify why they choose not to through the use of a "sound scientific rationale."[298] In the absence of EPA narrative criteria recommendations, it is much easier for states to ignore factors that can make numeric criteria not protective enough (e.g., mixture interactions, sublethal effects, novel chemicals, emergent properties). If the EPA-developed the narrative criteria recommendations this Article proposes, states would be required, at a minimum, to at least explain why they think the inherent gaps of numeric criteria are worth leaving unfilled or the state would risk losing its CWA regulatory authority delegated to it by the EPA. The effect would be more thoughtful state water quality standards.

Importantly, it is also well within the EPA's technical expertise to create guidelines to assist states in adopting supplemental narrative criteria that would create enforceable obligation on regulated parties even if compliance is determined by the subjective analysis of an expert. These guidelines are also needed to prevent interest groups (e.g., industry or environmentalists) from gaming narrative criteria enforcement mechanisms. The EPA has never officially defined what constitutes a violation of a narrative criterion. It should. The EPA should also reverse its trend of invalidating narrative criteria by encouraging states to supplement numeric criteria with EPA-developed narrative criteria, and parties regulated under the CWA should be required to comply with both.

CONCLUSION

At some level, most CWA programs utilize water quality criteria to determine CWA compliance. However, the CWA requires the EPA to develop criteria reflecting the latest science. For the foregoing reasons we believe the EPA is not meeting this obligation. As a result, the EPA may be violating the plain language of the CWA.

The EPA has broad discretion to determine what the latest science is. Although this Article offers thoughts, based on the scientific literature, for what the latest science may be, it does not intend to exhaustively describe the latest science. Suggestions for updating the 1985 guidelines and for

298. 40 C.F.R. § 131.11.

supplementing numeric criteria with narrative statements are merely suggestions based on the authors' opinions. This Article does, however, explain that the EPA is not currently developing criteria reflecting the latest science. It also asserts that the EPA knows this.

A three-part solution for attaining compliance with the CWA's latest science mandate is offered.[299] First, the EPA should resume the process of publishing revisions to the 1985 guidelines. Second, a flexible narrative companion criterion should be attached to each EPA-recommended numeric criterion. Third, the EPA should develop a single catch-all narrative criterion.

It is likely not hyperbole to declare that "[n]ature is not only more complex than we think. It is more complex than we can think."[300] If true—it likely is true—regulators must reconsider the relevance of rigorously controlled laboratory studies and reductionist science to natural systems, and also consider new ways of thinking about enforcing the CWA.[301]

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299. 33 U.S.C. § 1314(a)(1).

300. Frank E. Egler, THE WAY OF SCIENCE: A PHILOSOPHY OF ECOLOGY FOR THE LAYMAN 21 (1970).

301. *Cf.* E-mail from Robert W. Adler, Professor, University of Utah, S.J. Quinney College of Law (Sept. 9, 2019, 10:30 AM CST) (on file with author):

> I do have a different perspective to suggest, although it is perhaps a naïve one . . . . We now know of tens of thousands more pollutants than scientists envisioned in 1972. We are chasing our collective tails. But the [CWA] itself sought to bypass that by achieving zero discharge by a deadline now long past. Perhaps if we refocus on zero discharge the massive scientific challenge of trying to address every possible pollutant or combination of pollutants through [water quality standards] will diminish. (Yes, there will still be air deposition, runoff, etc., but the magnitude of the problem I suspect would diminish dramatically.) I know many will simply call that unrealistic, but that's because they continue to focus on end-of-pipe treatment feasibility rather than [fundamental process] changes.