Clean Water Act, Water Quality Criteria/Standards, TMDLs, and Weight-of-Evidence Approach for Regulating Water Quality

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Abstract

The Clean Water Act (PL 92-500, the 1972 Amendments to the Federal Water Pollution Control Act) established a water quality standards-based approach for regulating water quality. The US EPA was to develop national water quality criteria to be used as a basis for state water quality standards. Those standards are the legally enforceable limits that are to be used to evaluate water quality impairment. It was specified in the Clean Water Act that violation of the water quality standards was to lead to the listing of the waterbody as "impaired" and trigger the establishment of a total maximum daily load (TMDL) of the pollutant in violation. Significant problems have arisen in the implementation of the Clean Water Act. The most important of these problems is use of the numeric US EPA national criteria and state water quality standards without waterbody-specific adjustment for characteristics that influence the toxicity/availability of potential pollutants. This has led to inappropriate listing of waterbodies as "impaired" and the establishment of TMDLs with inappropriate water-quality-standard goals. It is becoming recognized that a "best professional judgment" (BPJ) triad weight-of-evidence approach should be used to regulate water quality in the US. The key component of this approach is the "best professional judgment" evaluation of a triad of key parameters: aquatic life toxicity/bioaccumulation of the contaminant(s); aquatic organism assemblage information in the aquatic system of concern; and chemical kinetic/thermodynamic information pertaining to the contaminant(s) of interest and the aquatic system of concern. This evaluation by consensus of a panel of experts in a public, interactive, peer-review process is crucial for the technically valid, cost-effective control of pollutants in aquatic systems.

Key Words:
Clean Water Act, water quality criteria, water quality standards, TMDLs, weight-of-evidence

Introduction

The 1972 amendments to the federal Water Pollution Control Act (Clean Water Act – CWA) established a regulatory framework to maintain and enhance water quality in waterbodies of the US. The CWA specified that waterbodies were to be classified with respect to their beneficial uses, such as domestic water supply, propagation of fish and aquatic life, and recreation, and that the US EPA was to develop national water quality criteria for chemical and other agents that would protect the designated beneficial uses of waterbodies. The numeric chemical-

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concentration-based national water quality criteria that it eventually developed were designed to be protective in any water under worst-case exposure conditions. The US EPA criteria, in turn, were to be used by the states as the basis for water quality standards, the benchmark for control of beneficial use-impairment of waterbodies.

The way in which these CWA provisions have been implemented has been to require that a waterbody in which a water quality standard was exceeded be listed as a Clean Water Act section 303(d)-“impaired” waterbody. Such a listing requires that a program be initiated to control the sources of the constituents responsible for the water quality standard violation. This is done through a total maximum daily load (TMDL) assessment through which is determined a load that would not result in exceedance of the standard; that load is then apportioned among those discharging the constituent.

While this TMDL approach was originally adopted in 1972, it was not until the late 1990s that it began to be implemented to any significant extent. This implementation arose from environmental groups’ filing suit against the US EPA for having failed to implement the TMDL provisions of the Clean Water Act. As part of settling the lawsuit, the US EPA agreed to see to the implementation of TMDLs by the states. There is considerable controversy, however, about the appropriateness of the TMDL process as it is typically being implemented for regulating water quality due largely to the use of numeric US EPA national water quality criteria and state standards equivalent to them as the benchmark for evaluation of water quality. Following is a synopsis of how this approach came to be established and issues that remain inadequately addressed in the pursuit of the goals of the CWA. Also described is a “best professional judgment” triad weight-of-evidence approach that provides a technically valid, cost-effective framework for assessing water quality/beneficial-use impairments and their remediation.

Early Regulatory Approach – Issues Still Needing Attention

Lee (2001) discussed a number of the significant technical shortcomings inherent in the TMDL approach adopted by the US EPA for regulating chemical constituents for the protection of water quality. For example, in the 1960s, when toxicity tests were starting to be used to evaluate the toxicity of wastewater discharges, it was often found that a portion of the heavy metals in some discharges was in forms that did not cause toxicity. This finding was in accord with what would be expected based on the aquatic chemistry of heavy metals. It was recognized that heavy metals exist in a variety of chemical forms; given the chemical nature of the forms, it could be expected that not all of them would be equally available/toxic to aquatic life, although this distinction could not be made with chemical analytical techniques. This situation was sufficiently well-known that by the early 1970s, the National Academies of Science and Engineering concluded, as part of their development of the Blue Book of Water Quality Criteria (NAS/NAE, 1973), that heavy metals in wastewater discharges could not be reliably regulated based on chemical concentrations. Rather, because of the numerous unquantifiable factors that control the manifestation of a chemical’s toxicity, they recommended a toxicity test approach be used to determine the availability of the heavy metals, either alone or in combination with other metals or other substances, in a particular water. The National Academies of Science and Engineering Blue Book Criteria were adopted by the US EPA (1976) in its 1976 Red Book Criteria, which were the first official water quality criteria developed pursuant to the Clean Water Act.

In the early 1980s, however, the US EPA abandoned the toxicity testing approach recommended by the National Academies of Science and Engineering. In its place, it adopted a policy of applying the numeric, worst-case, national water quality criteria (generally, chronic exposure, safe concentrations) to the concentrations of total recoverable metals (i.e., those forms that are measurable after strong acid digestion of the sample), rather than to the available forms, in water quality evaluation and regulation. That approach lead to overregulation of heavy metals since in some situations substantial parts of the "total recoverable" heavy metals are non-toxic/unavailable.

Some relief from the overregulation of heavy metals was provided when application of the criteria was shifted from "total recoverable" forms to "ambient-water dissolved" forms of metals (US EPA, 1995). The shift in focus at that time was not based on the finding of any new information since it had been well-established in the 1960s and 1970s that particulate forms of heavy metals in the water column were nontoxic. Focusing on dissolved forms of heavy metals corrected a long-standing problem in the implementation of the national water quality criteria into state water quality standards. That notwithstanding, the Agency has still not addressed its inappropriate application of water quality criteria for many other constituents, such as organics, to total concentrations rather than properly addressing contaminant availability.

While deficiencies in the conventional application of the water quality criteria were generally recognized, they were not addressed by the Agency primarily because the regulations that were developed were not being enforced by either the US EPA or many of the states. This ultimately led to the promulgation of the National Toxics Rule in subsequent revisions of the Clean Water Act, through which Congress mandated that states either adopt the US EPA criteria for toxics, or have them imposed upon them by the US EPA. By the early 1990s, all states had adopted US EPA criteria for "toxics." California's regulations adopting the US EPA criteria as state standards, however, were soon judged invalid through court action because California state law also requires consideration of economic impact of water pollution control regulations. Since the California State Water Resources Control Board did not comply with those state requirements, the courts determined that the regulations must be voided. Thus, for many years, California did not have water quality criteria/objectives for "toxics." Finally, in 2000, the US EPA Region 9 imposed what became known as the California Toxics Rule criteria (US EPA, 2000). They are the US EPA criteria for "toxics" that were originally adopted in the mid-1980s, or subsequent updates, such as the US EPA (1987; 1995; 1996; 1999). The most recent update of national water quality criteria occurred in 2002, when the US EPA (2002) developed its currently recommended national water quality criteria. The US EPA requires that as states update their criteria, they incorporate the 2002 criteria as the state standards.

Lee et al. (1982), Lee and Jones (1987), and Lee and Jones-Lee (1995) discussed alternative approaches for assessing and controlling the impact of contaminants on water quality that took better account of contaminant availability to affect water quality thus directing the financial resources available first toward defining those constituents that adversely impact the beneficial uses of a waterbody, and then controlling those constituents to the extent necessary to protect those uses.

Priority Pollutant List

The 1972 Clean Water Act also mandated that the US EPA develop a list of "priority pollutants" which was to include those chemicals found in water that should receive the highest attention for regulatory action. National water quality criteria were then to be developed for each of those chemicals to protect fish and aquatic life in all waters. Congress, however, did not fund the Agency adequately to carry out this mandate. Finally, when the Agency could not develop the list within the timeframe allowed, an environmental group filed suit to force the US EPA to do so. In response to that suit, in the mid-1970s, the Agency's attorneys and environmental group attorneys, with limited technical input and without public peer review, promulgated what is now known as the "Priority Pollutant" list.

Despite the intention to focus on water quality problems, in actuality the "Priority Pollutant" list has proven to be detrimental to properly defining the constituents that are significantly adverse to the beneficial uses of waterbodies. The list was not properly peer-reviewed for its inclusion and prioritization of pollutants of real water quality significance. Instead, the list focused primarily on what are known as rodent carcinogens – i.e., those constituents that, at high concentrations over extended periods of exposure, cause cancer in rats, but do not necessarily have a great significance to water quality. Large amounts of public resources have been devoted to analyzing for and then developing control programs for many of the rodent carcinogens, especially the chlorinated solvents, while neglecting many pollutants of greater water quality significance.

In looking at this situation, Dr. Christian Daughton, Chief, Environmental Chemistry Branch, US EPA National Exposure Research Laboratory, indicated that there are more than 22 million organic and inorganic substances, with nearly 6 million commercially available. The current water quality regulatory approach addresses fewer than 200 of those chemicals as potential water pollutants, i.e., the "priority pollutants." He stated, *"Regulated pollutants compose but a very small piece of the universe of chemical stressors to which organisms can be exposed on a continual basis." (*Daughton, 2004).

Implementation of TMDLs

The establishment of TMDLs focuses on achieving water quality standards in receiving water. This focus led to a review of the TMDL-based water pollution control program by the National Research Council (NRC). The NRC's review (NRC, 2001) discussed technical deficiencies in the US EPA's TMDL program. Waterbodies have been placed inappropriately on the Clean Water Act section 303(d) list of impaired waterbodies on the basis of unreliable evaluation. TMDL goals of achieving worst-case water quality standards for total concentrations, are often inappropriate goals for solving real, significant, water quality / use-impairment problems in a technically valid, cost-effective manner. Most importantly, there is inadequate time and inadequate funding available to support the development of TMDLs as they are being administered through the US EPA and state regulatory agencies.

The first step toward establishing a more appropriate TMDL process should be an assessment of the appropriateness of the water quality standards that were used to establish the 303(d) listing and the standards that are used as TMDL goals to correct water quality impairment. Since a considerable part of the TMDL program is directed toward sources such as agricultural runoff and urban runoff that frequently contain constituents that are, in substantial proportion, nontoxic, and unavailable, it is important that the US EPA and the states refocus TMDL programs on controlling toxic, available forms, as opposed to total concentrations of constituents.

BPJ Triad Weight-of-Evidence

Because of the technical inappropriateness and unreliability of using overly simplistic, even though administratively expedient, indicators of impact, increasing attention is being given to the use of a triad "weight-of-evidence" approach as a regulatory tool for water quality impact assessment and management. While this approach has been configured in a number of ways with varying degrees of technical validity, a well-accepted, technically appropriate format is a "best professional judgment" (BPJ) evaluation of a triad of key parameters: aquatic life toxicity/bioaccumulation of the contaminant(s); aquatic organism assemblage information in the aquatic system of concern; and chemical kinetic/thermodynamic information pertaining to the contaminant(s) of interest and the aquatic system of concern. These components are described below.

Toxicity/Bioaccumulation. The availability of most chemical contaminants to aquatic life cannot be determined through chemical analysis; the availability can be affected by the character of the ambient water, the nature of the exposure conditions, and the sensitivity of the organisms of concern. Further, routine chemical analysis does not cover all potential toxicants that may be present. Therefore, a key component of a BPJ weight-of-evidence evaluation for water quality impact assessment and management is aquatic life toxicity testing and/or bioaccumulation testing of aquatic organism tissue for potentially hazardous chemicals that are a threat to human health or higher-trophic-level organisms that use aquatic life as food. The importance of utilizing the BJP triad framework for the interpretation of the results of this testing is illustrated by the fact that, as discussed by Lee and Jones-Lee (1996a), finding aquatic life toxicity in laboratory tests of ambient water or sediment cannot be assumed to mean that that toxicity represents a significant impairment of the beneficial uses of the waterbody that is of concern to the public. It is not necessarily possible to equate laboratory-based water column or sediment toxicity with water quality impairment. For example, many sediments have natural toxicity due to low dissolved oxygen, ammonia and hydrogen sulfide, yet the waterbodies associated with them have excellent fisheries and high water quality. The other aspects of the triad must be used with this information to make a best professional judgment regarding the significance of the toxicity and bioaccumulation information.

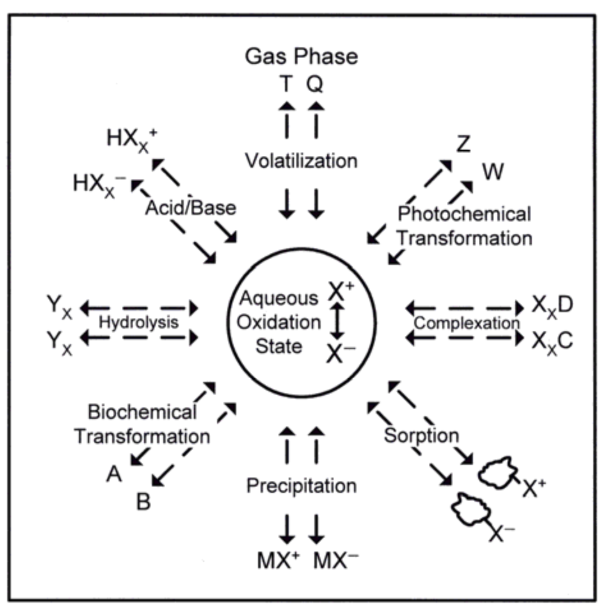
Organism Assemblage. Organism assemblage information includes description of the numbers, types, and characteristics of aquatic life and, as appropriate, terrestrial organisms such as fish-eating birds, present at a potentially impacted site. Insight into whether or not water quality has been adversely affected can be gained from understanding how the organism assemblage at the location compares with that which might be expected to be supported there. However, a variety of physical (flow, temperature, sunlight, sediment, and habitat alteration, etc.), non-potential-pollutant chemical (TDS, nutrients, organic constituents, hardness, alkalinity, etc.) and biological (reproductive cycles, disease, predation, etc.) factors other than chemical potential pollutants can affect the numbers, types and characteristics of aquatic life in a waterbody's water column or sediments. Therefore, it is critical that this information be considered in the context of a BPJ evaluation in assessing the water quality impacts of chemicals on the beneficial uses of a waterbody.

Chemical Information. Chemical concentration has been one of the most convenient, yet most misunderstood and misused, pieces of information in water quality evaluation and management. Unfortunately, chemical information and "chemistry" have often been considered to be a laundry list of total concentrations of a few regulated constituents having water quality standards, that are mechanically applied to discharges, ambient water, or sediment. This occurs despite the fact that for half a century it has been known that the total concentration of a potentially toxic constituent in the water column and/or sediments is an unreliable basis for estimating the impacts of that contaminant on the beneficial uses of a waterbody. Thus, the administratively expedient application of such values directly can distort the significance of that chemical contaminant to water quality.

The reason the total concentration of a selected chemical is unreliable for assessing water quality/use impairments is that many chemical constituents exist in aquatic systems in a variety of chemical forms, only some of which are toxic or available to affect aquatic life. The aquatic "chemistry," i.e., the kinetics (rates) and thermodynamics (positions of equilibrium) of reactions that a chemical can undergo in a natural water system, is illustrated in the aquatic chemistry "wheel" presented in Figure 1.

Figure 1.

Aquatic Chemistry of Chemical Constituents



- Distribution among Species Depends on Kinetics & Thermodynamics of Reactions in the Particular Aquatic System
- Each Chemical Species Has Its Own Toxicity Characteristics

  Many Forms Are Non-Toxic

As illustrated, chemicals can undergo oxidation/reduction, volatilization, photochemical, complexation, sorption/desorption, precipitation, hydrolysis, and acid/base reactions in natural water systems. Many of these reactions alter the availability of the chemical to affect aquatic life. While measurement of the total concentration of a chemical includes essentially all of these forms, the amount of the "available" forms of the chemical present depends in part on the nature of the chemical and the types and amounts of materials in the water and/or sediment that act to "detoxify" the chemical, i.e., render it non-toxic or unavailable to affect aquatic life through these reactions. These types of materials include organic carbon, sulfides, carbonates, hydrous oxides, clay minerals, and others. The amount of available forms also depends on the rates of reaction, the extent to which these reactions occur, and the comparative availability among the forms.

There is no simplistic method by which to reliably quantitatively account for these interactions by mathematical manipulation or chemical analysis. It is for this reason that chemical concentration information, especially total concentrations of chemicals, should not be used alone in assessing water quality or impairment of water quality. The disregard for the aquatic chemistry of contaminants and for the nature and duration of organism exposure in aquatic systems makes the application of worst-case, numeric water quality criteria typically overly restrictive for the protection of beneficial uses of waterbodies. While chemical concentration information can raise issues to consider and sources that may be worthy of further investigation, it is unreliable for reaching a conclusion about "water quality" or beneficial use impairment. It is for this reason that the aquatic toxicity/bioaccumulation and organism assemblage information are also critical parts of the triad evaluation and the need for objective, technically informed, best professional judgment is clear.

Co-Occurrence-Based Sediment Quality Guidelines: Caution

The issue of sediment quality criteria and guidelines warrants special attention in this discussion. Reliable evaluation and regulation of the impacts of contaminants in sediment systems is substantially more complex and more ill-defined than in ambient waters. While it has been long-understood that there is no relationship between the total concentrations of chemical contaminants in sediments and toxicity, bioaccumulation, or adverse impact on beneficial uses of a water, chemical concentration is simple and numeric, and lends itself to easy decision-making. In an attempt to make simple chemical analysis relevant, some have developed and advanced the use of co-occurrence-based "sediment quality guidelines" (Long and Morgan, 1991; Long et al., 1995; Long and MacDonald, 1998). A group of sediments was evaluated for having some type of biological impact. Then the concentrations of a few selected contaminants in those sediments exhibiting an "impact" were examined. Basically, then, for each contaminant, the lowest concentration associated with an "impacted" sediment was said to be adverse, a cause for concern in any sediment, and the basis for a "sediment quality guideline." No consideration was given to the actual cause of the "impact" reported, to the fact that total concentration is not related to impact, to a number of chemical and conditions that are well-understood to cause sediment toxicity, or to sediments having that or higher concentrations of the contaminant without exhibiting adverse impacts. The only basis for the so-called "guideline" concentration was the "co-occurrence" of the contaminant in the sediment with some biological impact attributed to that sediment. It is entirely expected that chemical constituents derived from urban industrial areas, while having biological effects, often occur in the presence of other constituents which, while in nontoxic, unavailable forms, are present in elevated concentrations.

Co-occurrence-based approaches exemplify inappropriate use of chemical information in a water quality assessment but nonetheless are popularized because of their ease of application. As discussed by Lee and Jones-Lee (1993, 1996b, 2004a), there is no cause-and-effect relationship established in the co-occurrence-based values. While there may be so-called "correlations" between toxicity and an exceedance of a sediment quality guideline, this is coincidental and unreliable for an assessment of the cause of the biological impacts. The fact that a chemical constituent exceeds a particular "sediment quality guideline" does not mean that that constituent is in any way related to biological effects, such as toxicity, bioaccumulation and/or changes in organism assemblages. The actual cause of the biological response can readily be either a constituent(s) that is not measured or not considered in the scheme, or a combination of constituents that, while measured, do not, individually or summed, exceed the "sediment quality guidelines." Thus there can be no expectation that funds spent to achieve "sediment quality guideline" values will result in any improvement in sediment/water quality or that sediments targeted by the exceedance of guideline values are, in fact, of the greatest concern.

Some try to skirt the fundamental technical flaws in the approach by limiting its use to "screening" sediments. However, using a patently unreliable "screening" tool can do nothing but provide patently unreliable results, which will serve to misdirect concern, responsibility, and funds for remediation, and leave real problem areas unaddressed. While sediments that exceed one or more "sediment quality guidelines" may, in fact, merit further investigation or remediation, the guideline values are meaningless for making that assessment; under no circumstances should anyone assume that the exceedance of a guideline value represents a cause-and-effect relationship that can be used to determine the likely cause of a biological response. As discussed by O'Connor (1999a,b; 2002), O'Connor and Paul (2000), O'Connor et al. (1998), Engler (pers. comm.), DiToro (2002), Chapman (2002), Burton (2002), Lee and Jones-Lee (1993; 1996a,b; 2004a), the co-occurrence approaches are obviously technically invalid and unreliable for assessing cause-and-effect. A reliable evaluation and regulatory program must be based on reliable assessments of the cause of the adverse effect.

Recommended Approach for Incorporation of Chemical Information into a BPJ Triad Weight-of-Evidence Water Quality Evaluation

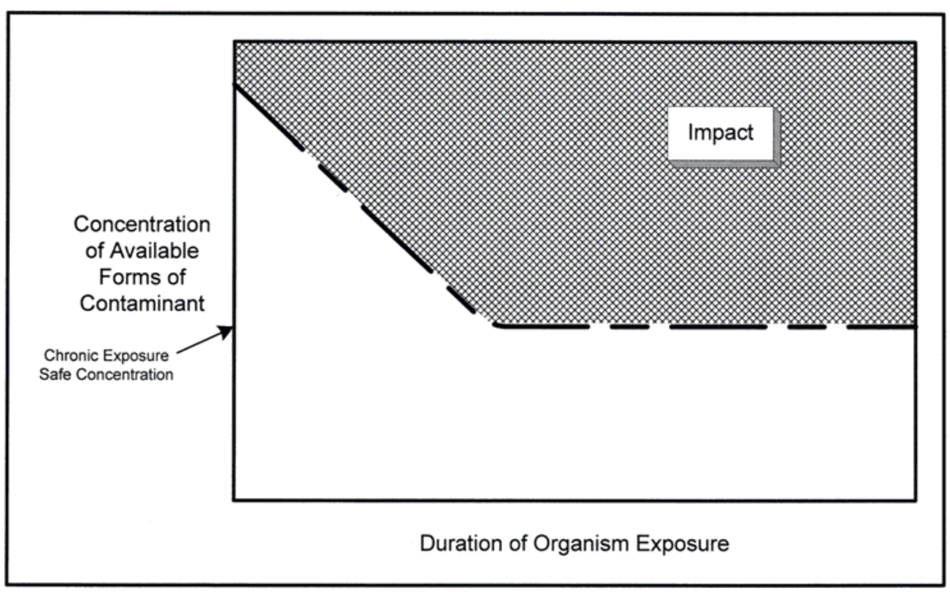
The recommended approach for the use of chemical concentration information in a BPJ triad weight-of-evidence evaluation of the cause of a water quality impairment begins with the reliable definition of the water quality/use impairment that is of concern. The existence of a contaminant in total concentrations greater than a worst-case-based standard/guideline is not, in itself, an adverse impact unless that contaminant is causing adverse impacts to the beneficial uses of the waterbody. Thus, for example, before measuring the concentrations of copper, lead, zinc and cadmium that typically occur in street and highway stormwater runoff at concentrations above US EPA worst-case-based water quality criteria and state water quality standards based on those criteria, the chemical impact evaluation approach determines whether the water or sediment of concern is toxic. Jones-Lee and Lee (1998) describe an Evaluation Monitoring approach that has been developed to focus on chemical impacts rather than chemical concentrations.

If toxicity is found in laboratory tests of a water or sediment, then an assessment should be made as to whether that toxicity translates to an adverse impact on the waterbody's beneficial uses, such as fisheries, survival or reproduction of desired aquatic life, etc. It should not be assumed that toxicity measured in a standard toxicity test necessarily translates to a toxicity that is significantly altering the numbers, types, and characteristics of desirable forms of aquatic life in a waterbody. This is especially true for situations such as urban area and highway stormwater runoff, where there can be short-term pulses of toxicity associated with a runoff event that are not of sufficient magnitude or duration to exceed the critical magnitude/duration coupling needed to be adverse to important forms of aquatic life in a waterbody.

Figure 2 shows a typical relationship between duration of exposure and toxicity; as illustrated, the manifestation of a toxicity response to available forms of a contaminant depends on the duration of exposure. Elevated concentrations of a toxicant can be tolerated by aquatic life, provided that the duration of exposure of this toxicity is shorter than the critical, or threshold, toxicity/duration of exposure coupling for that contaminant and organism in the ambient water. Exposure durations of aquatic life can be affected by the intermittent nature of the introduction of the contaminant, the rate and nature of dilution in the ambient water, avoidance or attraction behavior of the organism, etc.

Figure 2.

Critical Concentration/Duration of Exposure Relationship



If measured toxicity is determined to potentially affect the beneficial uses of the waterbody, then a toxicity identification evaluation (TIE) should be conducted to evaluate the cause of the toxicity (US EPA, 1991; 1993; Lee and Jones-Lee, 2002). The TIE process defines the availability of contaminants present and can elucidate the potential availability of the toxicity-causing contaminant(s) from its various sources. This, then, can direct control toward those sources that are contributing significantly to the toxicity. Not only is this approach more technically sound, but it also addresses the issue of potential impacts of unrecognized, unmeasured, and/or unregulated pollutants that has been the subject of increasing importance in water quality management.

Summary and Conclusion

The federal Clean Water Act and amendments have directed the development of water quality criteria and standards and a framework for identifying and addressing beneficial use impairments in the waters of the country. In the quest for administratively simple means by which to evaluate and regulate water quality and sediment quality, worst-case-based criteria and standards for a select group of chemicals have been developed. These are applied to the concentrations of contaminants in ambient waters as a means of judging water quality. This approach is known to be unreliable for evaluating or regulating water quality because it does not properly account for the beneficial uses of the water; the nature, behavior and forms of chemical contaminants; or the unrecognized and unregulated pollutants.

The BPJ triad weight-of-evidence approach described herein provides a technically sound foundation and approach for assessing water quality impacts, causes of the impacts, and directions for controlling the impact. It is not as administratively expedient as simple comparison of chemical concentration data; however, that simplistic approach is not reliable for determining impairments or effecting control of real water quality problems. The BPJ triad weight-of-evidence approach requires the allocation of sufficient funds to determine the characteristics of the constituents/conditions of concern, with particular emphasis on properly defining toxicity and water quality cause-and-effect relationships. It also requires that individuals knowledgeable in aquatic chemistry, aquatic toxicology and water quality provide guidance on, and appropriate interpretation of the results of, the kinds of chemical and toxicity studies that are needed to appropriately incorporate chemical information into assessing the water quality significance of chemical constituents in impacting the beneficial uses of a waterbody.

Numeric weight-of-evidence approaches in which arbitrary scale factors are assigned to each of the three components of the triad are technically invalid, because the scaling factors do not represent the relationship between a chemical constituent in a water or sediment and its impact on the water quality-beneficial uses of a waterbody.

Significant problems can occur with the use of the BPJ approach in incorporating chemical information into the triad. The use of total concentrations of constituents and/or the exceedance of a co-occurrence-based so-called sediment quality guideline is technically invalid. Such an approach can distort the triad water/sediment quality evaluation since it incorporates information into the triad that is not related to the impact of the chemicals on aquatic-life-related beneficial uses.

The BPJ weight-of-evidence approach should be based on the consensus of a panel of experts who, in a public, interactive, peer-review process, consider the information available, define what additional information is needed, and then render an opinion as to the integrated assessment of the information available on the significance of a particular chemical constituent in impacting the beneficial uses of a waterbody. The characteristics of the components of a BPJ weight of evidence approach which focuses on the appropriate use of chemical information are discussed further by Lee and Jones-Lee (2004b).

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