Appropriate Use of Chemical Information in a Best Professional Judgment Triad Weight of Evidence Evaluation of Sediment Quality[1]

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Abstract

There is increasing support for the use of a best professional judgment, non-numeric, triad weight of evidence approach for evaluating aquatic sediment quality. This approach is based on an integrated use of sediment toxicity/source of bioaccumulatable chemicals, organism assemblages and chemical information to determine the potential for constituents in sediments to be adverse to the beneficial uses of the waterbody in which the sediments are located. This triad approach is a far more reliable approach for evaluating whether a chemical constituent(s) associated with a sediment is adverse to sediment/water quality than a chemical-specific numeric sediment quality guideline. Significant problems occur, however, with the use of this approach by some 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 sediment quality evaluation because it incorporates information into the triad that is not related to the impact of the chemicals on aquatic-life-related beneficial uses. The chemical information that should be used in a triad evaluation includes the chemical forms and concentrations of the constituents of concern in the sediments that can be toxic to aquatic life or that can lead to bioaccumulation in higher-trophic-level organisms that are a threat to these organisms or those who use aquatic life as food. Sediment TIE information and information about the cause of toxicity or the amount of a bioaccumulatable chemical in a bioavailable form in the sediments should be used as the chemical component of a triad.

Introduction

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 there are a number of forms of weight of evidence, the approach that should be followed is a best professional judgment (BPJ) evaluation of aquatic life toxicity/bioaccumulation, aquatic organism assemblage information and chemical information. While there are some who attempt to develop numeric weight of evidence approaches in which arbitrary scale factors are assigned to each of the three components of the triad, such approaches are technically invalid, since the arbitrary scaling that is used for characterizing each of the parameters bears no relationship to the significance of the magnitude of each of these factors in relating the presence of a chemical constituent in a water or sediments to its impact on the water quality-beneficial uses of a waterbody.

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Significant problems occur, however, with the use of the BPJ approach by some 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 sediment quality evaluation since it incorporates information into the triad that is not related to the impact of the chemicals on aquatic-life-related and other 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 in this paper.

Organism Assemblages

Organism assemblage information on the numbers, types and characteristics of aquatic life and, as appropriate, terrestrial organisms such as fish-eating birds present at a potentially impacted site is a key component of the information base that needs to be obtained/critically reviewed in assessing the water quality impacts of chemicals on the beneficial uses of a waterbody. It should be understood, however, that a variety of physical (flow, temperature, sunlight, sediment, 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.

Toxicity/Bioaccumulation

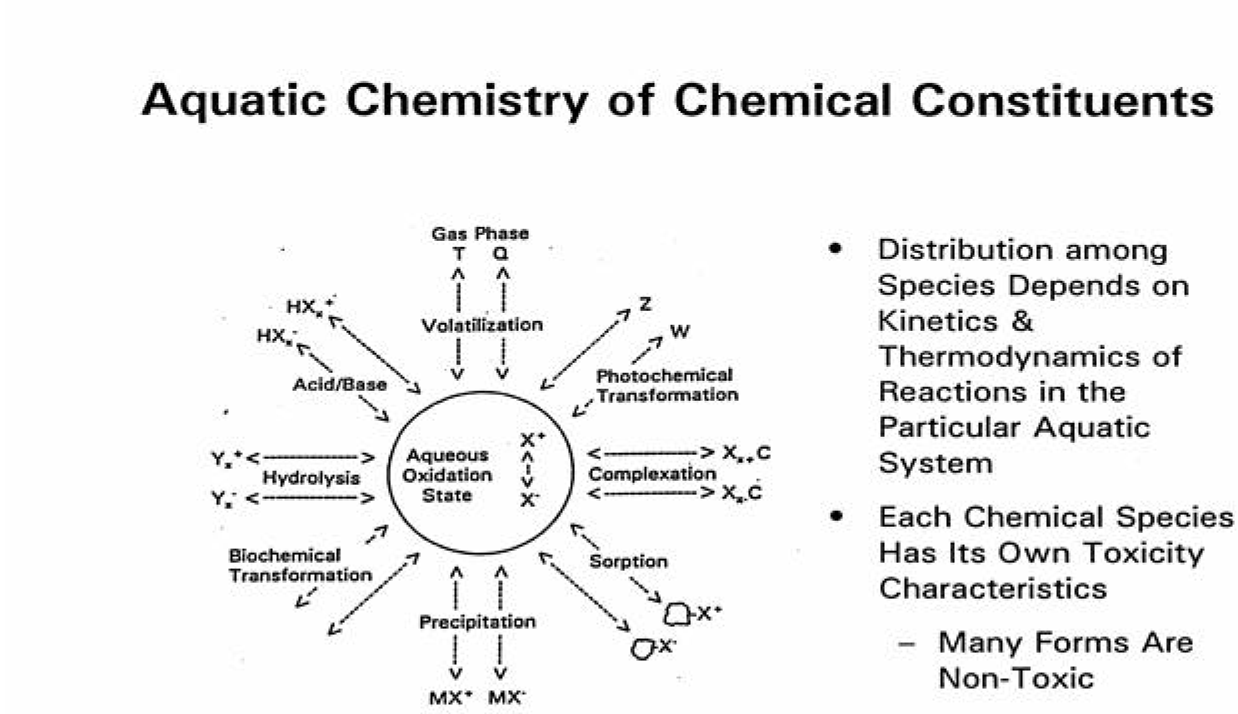
Aquatic life toxicity and/or bioaccumulation of potentially hazardous chemicals in aquatic organism tissue that is a threat to human health or higher-trophic-level organisms that use aquatic life as food are key components of a BPJ weight of evidence approach. However, as discussed by Lee and Jones-Lee (1996a), finding aquatic life toxicity in a water column or in sediments should not be interpreted to mean that this toxicity represents a significant impairment of the beneficial uses of the waterbody that are of concern to the public. It is not possible to relate laboratory-based sediment toxicity to water quality impairment. Many sediments have natural toxicity due to low dissolved oxygen, ammonia and hydrogen sulfide, yet have excellent fisheries and high water quality.

"Chemistry"

While chemical information is the third component of a water quality triad, there is considerable confusion and misinformation on the appropriate use of chemical information in a BPJ weight of evidence water quality evaluation. Because of a general lack of understanding and appreciation of aquatic chemistry, the level of chemical information typically used in a weight of evidence evaluation is often based on a 1960s knowledge level of aquatic chemistry, where total concentrations of a few regulated constituents having water quality standards is the chemical information used. However, it has been well-known since the late 1960s that the total concentration of potentially toxic constituents in the water column and/or sediments is an unreliable basis for estimating the water quality impacts on the Clean Water Act designated beneficial uses of a waterbody.

Aquatic Chemistry. The reason that total concentrations of a selected chemical are unreliable in 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/available. This relationship is shown in the aquatic chemistry "wheel" presented in Figure 1. The forms of a chemical, and therefore its impact on the beneficial uses of a waterbody, such as aquatic life propagation or wholesomeness of aquatic life used as food, depend on the concentrations of detoxification chemicals in the water or sediments. These types of chemicals, such as organic carbon, sulfides, carbonates, hydrous oxides, clay minerals, etc., react with potentially toxic forms of potential pollutants to detoxify or make unavailable the potentially toxic constituents.

Figure 1



Typically the water quality evaluation/management field operates at the "hub" of the wheel shown in Figure 1, where little or no consideration is given to the toxic/available forms of the chemical, which are controlled by the kinetics (rates) and thermodynamics (positions of equilibrium) of the reactions that lead to the chemical species that are present at the "rim." Rarely is information available on the amounts of the active forms of detoxification components of water and/or sediments and the characteristics of the reactions that occur with the potentially toxic/available forms. Because of this situation, it is not possible to predict, based on typical chemical analyses, the toxic/available forms of potential pollutants such as heavy metals, selected organics, nutrients, etc., that impact the beneficial uses of a waterbody which are of concern to the public.

Repeatedly, it has been found that when the significant technical deficiencies in the chemical information used in a weight of evidence evaluation are discussed with those who are proceeding to conduct the evaluation using unreliable or inadequate chemical information, such as total concentration of a chemical, those responsible claim that more appropriate chemical information is too complex to understand and difficult to obtain. The chemical total concentration approach can be characterized as an unreliable, "cheap" chemical investigation that, while providing some chemical information, is obviously unreliable for use in a weight of evidence approach.

Chemical Composition versus Water Quality. A fundamental problem exists in the water quality field with many of its practitioners using chemical concentrations, as typically measured in US EPA or "Standard Methods" analytical procedures, as "water quality." Water quality, by Clean Water Act requirements, is tied to the beneficial uses of a waterbody. Since it is not possible to translate chemical concentrations in either a discharge to a waterbody or within a waterbody to an impairment of beneficial uses, it is not appropriate to characterize a set of chemical analysis data as an assessment of water quality. Such data should be characterized as "water quality characteristics" that, when appropriately combined with other information, can provide inference on the relationship between a constituent(s) and the water quality characteristics of a waterbody which are of concern to the public.

A similar problem exists with respect to the term "chemistry" when referring to chemical data. Chemistry involves the evaluation of the thermodynamics and kinetics of the reactions that govern the distribution of chemical species in a waterbody (see Figure 1). A set of data on chemical concentrations is not "chemistry," but provides information on the chemical characteristics of a waterbody.

Basically, the problem is that those who use total concentrations of a potentially toxic chemical, knowingly or through ignorance, use the presence of chemical constituents, regardless of impacts, as synonymous with pollutants -- i.e., constituents which adversely impact the beneficial use of waterbodies. This is an inappropriate approach which ignores the aquatic chemistry of constituents of concern, and can readily cause massive waste of public and private funds in unnecessary chemical constituent control. This approach is also a significant deterrent to obtaining the information needed for a reliable assessment of the beneficial use impacts of the unregulated constituents -- i.e., those without water quality criteria/standards -- since the focus is on chemical concentrations rather than chemical impacts.

Association of Chemical Concentrations with Impacts. As long as regulatory agencies, environmental groups and others continue to use unreliable chemical information in a weight of evidence triad, such as total concentrations of a few chemicals, to "associate" the presence of a measured chemical constituent to a water quality impact (such as toxicity, bioaccumulatable chemicals, changes in organism assemblages, etc.), the BPJ weight of evidence approach is not a reliable tool, since one of the key components of the triad is fundamentally flawed. While toxicity and excessive bioaccumulation are readily measurable characteristics of an aquatic ecosystem, as are the numbers, types and characteristics of aquatic life in a particular system of concern, as well as the total concentrations of chemical constituents present in this system, the total concentration measurements often have no relationship to the impact of potential pollutants on beneficial uses.

Unreliability of Co-Occurrence-Based Sediment Quality Guidelines. One of the most significant examples of inappropriate use of chemical information in a water quality assessment is the use of the Long and Morgan (1991), Long, *et al.* (1995), or Long and MacDonald (1998) co-occurrence-based so-called "sediment quality guidelines." These "guidelines" are based on total concentrations of a few selected chemical constituents that co-occur with some type of biological impact/response. As discussed by Lee and Jones-Lee (1993), there is no cause-and-effect relationship established in the co-occurrence-based values. The fact that these co-occurrence-based approaches are based on total concentrations means that they are fundamentally flawed, and while there may be so-called "correlations" between toxicity and an exceedance of a sediment quality guideline, this is a coincidental situation that is an unreliable 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 due to either a constituent(s) that is not measured or a combination of constituents that, while measured, do not exceed the "sediment quality guidelines." Basically, in the co-occurrence-based approaches, "success" relies on the fact that chemical constituents derived from urban industrial areas, while having biological effects, often occur in the presence of other constituents which, while in non-toxic, non-available forms, are present in elevated concentrations. While the Long and Morgan, MacDonald, etc., "sediment quality guidelines" can, under some situations, indicate that there is potential for toxicity in sediments when several guideline values are significantly exceeded, 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 Lee and Jones-Lee (1996b), co-occurrence-based sediment quality guidelines are a cheap "chemistry" approach that gives those who have little or no understanding of aquatic chemistry and water quality issues a means of incorporating so-called "chemical information" into a weight of evidence approach without having to become knowledgeable in aquatic chemistry and toxicology relationships that are fundamental to any proper water quality assessment with respect to the cause of a water quality problem.

The state of California Water Resources Control Board (WRCB, 1998) adopted the Bay Protection and Toxic Cleanup Program (BPTCP) Water Quality Control Policy for Guidance on Development of Regional Toxic Hot Spot Cleanup Plans, which allows the Regional Water Boards to use elevated concentrations of constituents in sediments as a basis for identifying Principal Responsible Parties (PRPs) for a sediment "Superfund" ("Aquafund") to pay for clean-up of contaminated sediments that are designated as a "toxic hot spot." Further, this same "association" approach is supported under the WRCB BPTCP Policy to allow the Regional Water Boards to amend NPDES wastewater discharge permits for dischargers to limit the concentrations of a constituent that is present in elevated concentrations in the sediment or water column without investigating whether the elevated concentrations of the constituent are, in fact, causing adverse impacts to the beneficial uses of a waterbody.

Lee (1998a,b) and Lee and Jones-Lee (1998) have provided detailed discussions on the technically invalid approaches that the WRCB adopted in the BPTCP policy. They point out that this policy can readily lead to inappropriate designation of "toxic hot spots" and PRPs and inappropriate modifications of NPDES permits that can cause large-scale unnecessary expenditure of public and private funds in the name of water pollution control that will have little or no impact on the beneficial uses of the waterbodies in which the sediments of concern are located.

There have been a number of notable examples of inappropriate approaches that have developed from the inappropriate application of co-occurrence-based sediment quality guidelines. One of the most notorious of these is the Santa Monica Bay Restoration Project, where the regulatory agencies from the local LA Regional Water Board, through the US EPA, endorsed having the public in the LA region spend $42 million over five years to control, on a mass-emission strategy basis, the concentrations of heavy metals and other constituents commonly present in urban area and highway stormwater runoff. This policy was justified based on finding lead in Santa Monica Bay sediments at concentrations above a co-occurrence-based sediment quality guideline.

It was suggested to these regulatory agencies (Lee and Jones-Lee, 1994), prior to the adoption of the Bay Restoration Plan, that the lead in the Santa Monica Bay sediments may be in an inert, non-toxic form, as frequently occurs in marine sediments. It was further suggested that before any restoration plan of this type is adopted (one that causes the public to make such a massive expenditure in the name of water pollution control and Santa Monica Bay restoration), toxicity testing should be done on the sediments to determine whether the lead present at elevated concentrations is in a toxic/available form and, if it is, whether it is a significant cause of impairment of the beneficial uses of Santa Monica Bay. These recommended approaches were ignored by the regulatory agencies, including the US EPA, and these agencies and environmental groups blindly accepted the exceedance of a single co-occurrence-based sediment quality guideline as sufficient reason to cause the public to spend $42 million over five years in controlling the input of 22 constituents of concern to stormwater runoff in the Los Angeles region.

US EPA Region 9 (2002) has proposed to use co-occurrence-based sediment quality guidelines as the basis for establishing organochlorine pesticide and PCB excessive bioaccumulation TMDL targets for controlling excessive bioaccumulation in edible fish taken from the Upper Newport Bay in Orange County, California. However, as discussed by Lee and Jones-Lee (2002), this approach is technically invalid for a variety of reasons, including the fact that there is no relationship between the total concentrations of DDT, chlordane and PCBs in a sediment and the bioaccumulation of these chemicals in lower- and upper-trophic-level forms of aquatic life. Further the so-called "biological effects" which are used in the co-occurrence relationships were not based on bioaccumulation. US EPA Region 9's approach for controlling excessive bioaccumulation of organochlorine pesticides and PCBs in Upper Newport Bay fish is obviously technically invalid and should be abandoned.

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 (1992), and Lee and Jones-Lee (1993; 1996a,c; 2000, 2002), the co-occurrence approaches are technically invalid and unreliable for assessing cause and effect which can be used as the basis for a regulatory program. O'Connor, in an assessment based on the NOAA Status and Trends, as well as US EPA EMAP databases, stated that,

> *"All these criteria are better than random selections in identifying toxic sediment but they are not reliable. They are all more often wrong than right and should not be used, by themselves, to imply anything about biological significance of chemical data."*

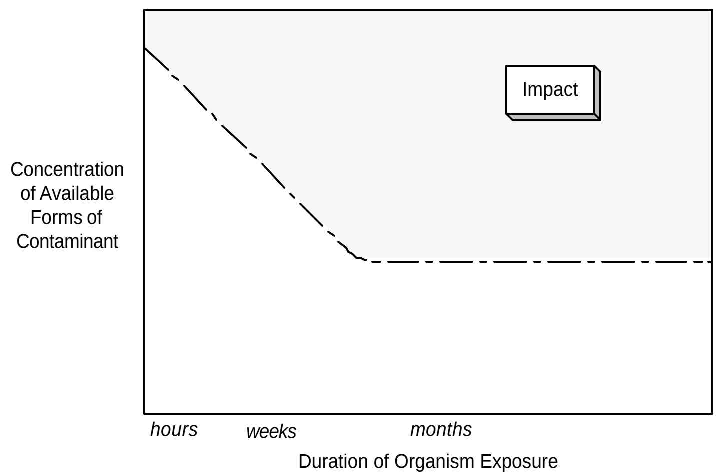
Co-occurrence-based approaches for estimating sediment toxicity provide a method by which total concentration chemical data can be used by those who are either unknowledgeable or unwilling to admit their technical deficiencies in aquatic chemistry and toxicology as applied to water quality evaluation and management. They should not be used in sediment quality evaluation or in a BPJ weight of evidence evaluation.

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

The recommended approach for the use of chemical information in a BPJ weight of evidence evaluation on the cause of a water quality impairment involves reliably defining the water quality/use impairment that is of concern. Basically, adopting this approach requires that the emphasis in water pollution control programs be shifted from focusing on chemical concentrations that exceed worst-case-based standards/guidelines to reliably assessing chemical impacts on the beneficial uses of a waterbody. Rather than measuring 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 these criteria, the chemical impact evaluation approach determines whether the water or sediment of concern is toxic. If it is toxic, then, through toxicity identification evaluations (TIEs), an assessment is made as to the cause of this toxicity. 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, then an assessment should be made as to whether this toxicity is significantly adverse to the waterbody's beneficial uses. It should not be assumed that toxicity measured in a standard toxicity test necessarily translates to 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 and duration to exceed the critical magnitude and duration needed to be adverse to important forms of aquatic life in a waterbody. Figure 2 shows the relationship between duration of exposure and toxicity that typically occurs, where high concentrations of standard laboratory-measured toxicity can be tolerated by some forms of aquatic life, provided that the duration of exposure of this toxicity is short, compared to the critical toxicity/duration of exposure relationships that exist in ambient waters for aquatic life.

Figure 2
Critical Concentration/Duration of Exposure Relationship



Under the total concentration "association" approach, the elevated copper, zinc, lead and sometimes cadmium in urban area and highway stormwater runoff above US EPA worst-case-based water quality criteria/standards is assumed to be toxic, and it is also assumed that this toxicity is significantly adverse to the beneficial uses of the waterbody. This "association"-based identification of copper, zinc, lead and cadmium as significant "pollutants" derived from urban area and highway stormwater runoff could cost the public large amounts of funds in treating the runoff waters to remove these metals so that their concentrations do not exceed worst-case-based water quality criteria/standards by any amount more than once every three years.

As an example of the high costs of eliminating exceedances of worst-case-based water quality criteria/standards, it is estimated that to control the concentrations of these heavy metals in urban area street and highway stormwater runoff in the Los Angeles area so that they do not cause exceedances of water quality standards, it will cost the public in excess of $50 billion for collection and treatment works. This expenditure would be made under conditions where studies in the San Francisco Bay region, Sacramento, Stockton and Orange County, California, have shown that the heavy metals in urban area street and highway stormwater runoff are in non-toxic forms (Lee and Taylor, 1999). While urban street and highway stormwater runoff in these areas is toxic to *Ceriodaphnia* (a freshwater zooplankton), this toxicity is due to the organophosphate pesticides diazinon and chlorpyrifos, which are not regulated based on water quality standards. The adoption of Evaluation Monitoring, which makes use of a BPJ weight of evidence approach, can be highly effective in focusing water quality evaluation and management resources on real, significant water quality problems.

The approach that should be followed in using chemical information to assess the potential for a particular chemical to cause a water quality impact involves the appropriate use of TIEs to define whether a particular constituent that occurs at concentrations above a water quality standard is in a toxic/available form, and/or to determine the chemical(s) that cause the toxicity in water or sediments. This 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. Those with limited aquatic chemistry/toxicology expertise and experience sometimes comment that, since there are no "standard" TIE procedures for determining the cause of toxicity in sediments, it is not possible to identify the cause of toxicity in sediments. Identification of the cause of toxicity in sediments requires that individuals knowledgeable in aquatic chemistry, aquatic toxicology and water quality provide guidance on and appropriate interpretation 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.

Addressing Conflicting Technical Information

As discussed above, the BPJ weight of evidence approach should be conducted by a panel of experts knowledgeable in the topic areas. If disagreements arise among panel members or between the panel and others, then a full, public interactive peer review should be conducted of the issues in disagreement. Lee (1999) has presented a recommended approach for addressing conflicts on interpretation of information on water quality issues. Adoption of the public, interactive peer review process recommended by Lee (1999) would be a major advance over the typical adversarial approach in incorporating technically reliable science into public policy development.

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