"Co-Occurrence" in Sediment Quality Assessment[1]

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ABSTRACT

"Co-occurrence"-based sediment quality evaluation approaches, such as the Long and Morgan ER-M values, MacDonald PEL values, and AET values, involve determining the total concentration of a chemical constituent in a sediment database that co-occurs with some biological effect from the same database but not necessarily from the same sediment. The biological effect measured is typically an estimate of sediment toxicity or altered number of benthic organisms compared to a reference area. This approach is being used at the federal and state levels to determine the "excessive" concentrations of chemical constituents in sediments. However, since this approach is based on total concentrations of a chemical constituent and since the total concentration of a chemical constituent is not a reliable indication of the impact of that constituent in that sediment on aquatic life, co-occurrence-based approaches are fundamentally flawed and can and usually do provide highly unreliable estimates of excessive concentrations of chemical constituents in sediments. Also, this approach is unreliable for evaluating whether a sediment contains constituents that are impairing the beneficial uses of the waters associated with the sediments, since only a limited number of constituents are considered in the co-occurrence-based sediment quality evaluation. This paper discusses the inappropriateness of using co-occurrence-based sediment quality evaluation approaches and recommends approaches based on a non-numeric sediment quality "weight-of-evidence" approach to evaluate the water quality significance of chemical constituents in sediments.

Key words: sediment quality criteria, water quality, AET, co-occurrence, ER-L, PEL

INTRODUCTION

With increasing frequency, various regulatory agencies and others are using "co-occurrence"-based sediment "quality" assessments as part of an attempt to evaluate the potential water quality significance of chemical contaminants in aquatic sediments. A misconception is spreading in the sediment quality regulatory arena that sediment screening and evaluation approaches founded in "co-occurrence" represent "weight-of-evidence" approaches that account for "biological effects" of sediment-associated chemical contaminants. This is of serious concern because of the unreliability of co-occurrence approaches for developing technically valid, cost-effective sediment quality evaluation and remediation approaches and requirements.

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[1]Report of G. Fred Lee & Associates, El Macero, CA, February (1996).

CO-OCCURRENCE

The work of Long and Morgan (1990) and later of MacDonald (1992) has served as the basis for many of the co-occurrence evaluations made of sediment "quality." Those investigators reviewed literature on the concentrations of certain chemical constituents (primarily heavy metals and selected organics) in sediments and on assessments made of biological "impacts" that have been reported to be found associated with those sediments. For each of the selected chemicals that those investigators included in their evaluations, they developed a list of the concentration of that parameter in each of the sediments and an associated assessment of the "effect" of that sediment measured in any number of ways (e.g., benthic faunal analysis, toxicity tests), without consideration of what conditions or contaminants were causing or influencing the "effect." The sediments were listed in order based on concentration for that chemical, showing the co-occurrence of the concentration of the chemical and the reported "effect" of the chemical constituent in that sediment.

In regulatory applications, co-occurrence information has been used or proposed for use, albeit incorrectly, to establish various "effects threshold" values. That is, applying statistics to the ranked listing of co-occurrence information of a given chemical, it was determined for that data set the concentration of the chemical that has a given probability of co-occurring with an impact, or the lowest concentration with which "no effect" co-occurred for that set of sediments. Examples of these approaches are the "Apparent Effects Threshold" (AET), and numeric ER-L/ER-M values developed from Long and Morgan's (1990) data presentation, and "Probable Effects Levels" (PEL) values derived from MacDonald's (1992) co-occurrence compilations. If a sediment contains a chemical in concentrations above the AET, ER-L, ER-M, PEL, or similar value, the sediment is considered by some regulators or proposed regulations to be "polluted," and to require special consideration such as "remediation," alternate methods of dredged sediment disposal, or control of permitted discharges of a chemical to the waterbody that accumulates in the sediments.

One of the most significant deficiencies of the various co-occurrence assessments such as Long and Morgan, AET, and PEL is that they require the acceptance of a number of technically invalid assumptions including the following. First, the approach presumes that there is a causal relationship between the concentration of each contaminant considered in a sediment and the water quality impact of that sediment. Second, it presumes that the "effect" reported for each sediment was caused independently by each of the measured chemical contaminants in that sediment. Third, it presumes that no other chemical or condition not included in the database has any influence on the manifestation of the "effect" that co-occurs with the particular chemical of focus; ignored are several sediment-associated contaminants and conditions that are well recognized to cause aquatic life toxicity including ammonia, hydrogen sulfide, and low dissolved oxygen. Fourth, it presumes that the assessments made of "effects" of the sediments relate in some meaningful way to adverse impacts on beneficial uses of the waterbody in which the sediments are located.

Lee and Jones (1991); Lee and Jones-Lee (1992a,b; 1993a); US ACE (1989, 1991); Wright (1992); Wright, *et al.* (1992); Chapman, *et al.* (1992); Giesy and Hoke (1990) and others have discussed technical deficiencies with the AET and similar co-occurrence approaches for the evaluation and regulation of sediment-associated contaminants. As discussed by Lee and Jones-Lee (1992a,b), none of the assumptions that underlie the development and application of co-occurrence approaches is technically valid.

It has been well established in the technical literature and in practical experience that there is no general relationship between the concentrations of chemical contaminants in sediments and the impact that sediment-associated contaminants could have on water quality. In their presentation of data, Long and Morgan (1990) made no claims that the "effects" reported for the sediments were "caused" by the chemicals with which they were associated, i.e., with which they co-occurred. In fact, for many of the chemical contaminants they considered in their evaluation, it is well understood that the forms associated with sediments are largely unavailable (nontoxic) to affect sediment/water quality.

The fact that two conditions exist together does not indicate that one condition (in this case, the total concentration of a particular chemical) is the cause of the other (in this case, the "effect" characteristic reported). The fundamentals of aqueous environmental chemistry of sediment-associated chemicals and aquatic toxicology show that, in fact, there is no relationship between the concentrations of chemicals in a sediment and the impact of those sediments on sediment/water quality. The fallacy of the approach can also be seen by recognizing that the same noted "effect" for a sediment co-occurs with each of the chemical parameters considered. The presumption of causality would mean that each of the selected chemical contaminants is considered to be independently and singularly responsible for the noted "effect" of the sediment. Thus, even if one of the contaminants considered were demonstrated to be the cause of the toxicity of the sediment, the other contaminants present would be considered equally responsible for causing the toxicity. Co-occurrence and statistical descriptions between co-occurring conditions do not demonstrate causality. Without causality demonstrated, the "relationship" developed has no predictive reliability. Furthermore, when a given sediment-associated chemical constituent is demonstrated to cause a particular impact, the significance of that chemical constituent's concentration in that sediment cannot be transferred to any other sediment. Thus, "remediation" of a sediment or reduction of a NPDES permitted discharge to achieve AET values for sediment-associated chemical constituents cannot be expected to address the real cause of adverse impacts.

It is well known that there are chemicals and conditions in a sediment that can cause toxicity to aquatic life, particularly ammonia, hydrogen sulfide, and low dissolved oxygen. Jones-Lee and Lee (1993) reviewed the significance of ammonia as a cause of toxicity in aquatic sediments. However, those chemical constituents and conditions are typically not considered in co-occurrence approaches. In fact, listings of co-occurrence such as those provided by Long and Morgan (1990) and MacDonald (1992) consider only a few of the tens of thousands of chemical constituents that can be present in sediments. Also not considered are the influence of habitat, grain size, and other conditions that can control populations of organisms found in a particular sediment. These conditions are ignored in the co-occurrence of an "effect" with concentrations of specific chemical constituents in a sediment.

Finally, many of the bases upon which "effects" have been determined are unreliable and/or have little or no direct relationship to impacts on beneficial uses of waterbodies. For example, the finding of "toxicity" under laboratory toxicity test conditions does not necessarily mean that such an effect would be manifested in an ambient water. Furthermore, the "toxicity" manifested in the laboratory test could be caused by ammonia or chemical constituents other than the one of focus in the co-occurrence evaluation. "Toxicity" information used in co-occurrence databases is often based on unreliable testing procedures such as Microtox procedures. *In situ* organism population data are often of limited or inadequate scope and do not consider physical, chemical-non-toxicant and biological factors that frequently affect the numbers and types of organisms present in a sediment. Lee and Jones-Lee (1992a) discussed significant technical deficiencies in some of the approaches used for determining "effects" of a sediment in the development of tables of co-occurrence.

Another of the common misconceptions about the co-occurrence evaluation of sediment characteristics is that it is "effects-based." Recognition of the lack of relationship between the concentrations of chemical constituents in sediments and water quality impact has caused regulators to begin to focus on the impacts that sediments may have on water quality. However, the fact that some estimate of "effect" was presented by those developing tables of co-occurrence does not indicate that the assessments are reliable or meaningful in terms of impacts on beneficial uses of ambient waters. These issues have been addressed by Lee and Jones-Lee (1992a).

The fact is that key assumptions made in using the AET and other co-occurrence approaches are technically unreliable for assessing the impacts of sediment-associated chemical constituents on the beneficial uses of the waterbody in which the sediments are located. It is well known from aqueous environmental chemistry and toxicology and practical experience that there is no relationship between the bulk concentration of a chemical constituent or a group of constituents in sediments and the impact that the constituent(s) has on the beneficial uses of the waterbody in which the sediments are located. While appropriate toxicity testing of sediments can be a reliable basis upon which to evaluate the potential impact of sediment-associated chemical constituents that are potentially toxic to aquatic life, incorporation of total chemical composition data with toxicity test results distorts, and can render unreliable, the useful information obtained from appropriate toxicity tests. Further, it is well known that the numbers and types of organisms present in a sediment depend on a variety of often ill-defined factors not related to the "toxic" chemical constituent characteristics of the sediment.

It is of great concern that the US EPA is using the total concentrations of chemical constituents in sediments as a basis for screening sediments for water quality impacts as part of the Agency's National Water Quality Inventory (US EPA, 1993a). As discussed in the literature and noted herein, it has been well known for more than two decades that that approach is unreliable. The underlying presumption for measured chemical constituents, that the presence of a constituent above a certain concentration, or an increase in the concentration of a constituent in a sediment represents a significant adverse impact on the beneficial uses of the waterbody, is invalid. That presumption ignores the aqueous environmental chemistry (kinetics and thermodynamics of the physical, chemical, and biological reactions) of chemical constituents as it affects the availability of the measured constituents to adversely affect aquatic life/beneficial uses of a water. It also ignores the large number of unmeasured constituents in sediments that could be adverse to beneficial use of the waterbodies through their potential to cause toxicity or other adverse impacts. Failure to properly consider the aqueous environmental chemistry results in significant over-estimation of the potential impact of measured sediment-associated constituents. The failure to consider all chemical constituents of potential water quality concern can result in the under-estimation of the water quality significance of sediment-associated chemical constituents.

Several years ago, as part of its attempting to develop justification for its sediment quality management program, the US EPA reported on the chemical characteristics of US sediments in terms of whether they exceeded so-called chemical constituent threshold values (Zarba, 1989). Examination of how those chemical constituent threshold values were developed as reported by Zarba, however, shows that they were not reliably developed and do not properly assess the potential water quality significance of chemical constituents in aquatic sediments.

MISUSE AND EVALUATION OF CO-OCCURRENCE INFORMATION

There are numerous examples of the inappropriate application of co-occurrence-based sediment quality evaluations. The Santa Monica Bay Restoration Project (SMBRP, 1994) proposed that $42 million be spent in controlling selected chemical constituents in urban stormwater runoff to Santa Monica Bay based on the finding that several chemical constituents were present in Santa Monica Bay sediments in total concentrations in excess of co-occurrence-based numeric values. Similarly, in its EMAP program, the US EPA (1993b) discussed the concentrations of sediment-associated chemical constituents found in the Virginian Province (Cape Cod to North Carolina) as being "excessive" as compared with co-occurrence-based values. State regulatory agency staffs in Florida and California, and Environment Canada (Smith *et al.*, 1993) have proposed to use co-occurrence-based values to screen and rank the water quality significance of chemical constituents in sediments. The California Water Resources Control Board staff has proposed to use co-occurrence-based approaches for developing the state's sediment quality criteria. As discussed further below, co-occurrence-based approaches have been used for a number of years in the Seattle-Puget Sound area to regulate waterway channel dredging projects. Further, they are being used to establish sediment clean up objectives at Superfund sites in the region.

In its *"Guidelines for Preparation of the 1994 State Water Quality Assessment (305(b) Reports)"* the US EPA (1993a) indicated that the Long and Morgan co-occurrence values may be used to indicate whether contaminants in a sediment represent excessive concentrations and are, therefore, impairing the water quality of the waters associated with the sediments. This approach will contribute to an even greater unreliability of the US EPA's National Water Quality Inventory biannual Reports to the US Congress on the water quality conditions of the nation's waters. This issue has been reviewed by Lee and Jones-Lee (1996).

Recently, several advocates of co-occurrence-based approaches (Carr *et al.*, 1994 and MacDonald *et al.*, 1994) have claimed that co-occurrence-based approaches have reliably predicted sediment toxicity. Further, the May 1994 issue of the US EPA's *"Contaminated Sediments News"* (US EPA, 1994) carried a discussion entitled, *"Verification of Sediment Quality Guidelines with Sediment Toxicity Tests"* in which it was reported that the Long and Morgan and MacDonald values have been shown to have high degrees of reliability in predicting sediment toxicity. Such claims of predictive capability are not valid. Examination of the procedures used for collection and handling of sediments employed in those studies shows that the samples were handled inappropriately. The changes in sediment composition that would result from the sediment handling would make the use of those samples highly unreliable in any evaluation of *in situ* toxicity. Further, comparison of the predictions of sediment toxicity provided by the Long and Morgan and MacDonald co-occurrence-based approaches with actual toxicity to the types of organisms that were used in developing the original data base, shows that in fact those co-occurrence approaches have very poor predictive capability. Therefore, while claims were made in professional paper presentations at the American Chemical Society's "Scientific and Regulatory Issues Associated with Sediment Contamination" symposium in San Diego in March 1994 and, more recently in the US EPA's *"Contaminated Sediments News,"* that co-occurrence-based sediment quality assessment values have high degrees of predictive capability, the fact is that such claims are based on inappropriately conducted studies and inappropriate interpretation of the data.

Summers (1994) indicated that those who are associated with the US EPA's EMAP program have evaluated the reliability of the Long and Morgan ER-M values in predicting sediment quality impacts and concluded that the ER-M values are poor predictors of such impacts. Summers also indicated that low dissolved oxygen, and elevated hydrogen sulfide and ammonia, which are parameters which are not being considered by the US EPA in its National Sediment Inventory, are principle causes of sediment toxicity - impacts.

Daskalakis and O'Connor (1994) conducted a review of the US EPA EMAP data for the east and gulf coasts of the US. This data set is one of the most comprehensive data sets in existence on sediment chemical characteristics and toxicity. They found that sediments with concentrations of chemical constituents above ER-M values were not particularly strong predictors of sediment toxicity. This is what is to be expected, based on how the ER-M values were developed.

Advocates of the AET approach for the evaluation of sediment quality in the Puget Sound - Seattle, WA area often claim that the AET approach has been found to be highly successful. However, a critical examination of how AET has been used in regulating waterway dredging projects in that area shows that it is not a reliable basis upon which to determine the potential water quality significance of chemical constituents in sediments as they may impact dredged sediment disposal. Sediments that pass the AET screen used and are thus exempt from further testing, could readily be toxic or otherwise significantly adverse to aquatic life at a dredged sediment disposal site due to contaminants present in the sediment that are not considered in the AET evaluation. Those sediments that do not pass the AET screen are subject to the more technically reliable biological effects-based testing in accord with US EPA and US ACE (1991) procedures. It would be far more reliable and cost effective to skip the unreliable AET screen and proceed directly with appropriate biological effects-based testing to determine whether measured, as well as unmeasured, chemical constituents in sediments are potentially toxic to aquatic life. The fact that the AET approach has been used ("successfully applied") to make management decisions, does not mean that the approach is reliable or appropriate. Thus, while the AET approach has been used in the Puget Sound area for screening sediments for potential adverse impacts, the application of that technically unreliable approach cannot be considered a "success;" to the contrary, the use of the AET in that area is wasting public and private funds for unnecessary and inappropriate testing.

Even though, as discussed herein, co-occurrence-based approaches are fundamentally technically invalid because they fail to properly consider the aquatic chemistry and aquatic toxicology of contaminants in sediments as they may impact the designated beneficial uses of the waterbodies in which the sediments are located, the use of co-occurrence-based approaches in the sediment regulatory arena is growing because of the ostensible "ease" of their application and use in "decision-making." This is of great concern because of the inherent unreliability of co-occurrence for such purposes. The growing use of co-occurrence-based approaches is providing the US Congress and state legislatures, regulatory agency governing boards, as well as the public, with highly unreliable information on the water quality significance of chemical constituents in sediments. This, in turn, is causing a significant misapplication of funds in addressing sediment quality issues.

WEIGHT-OF-EVIDENCE

The authors have found that staffs of several states' water pollution control agencies (California and Florida) have stated in documents and correspondence that their sediment screening/ranking methodology is based on a weight-of-evidence approach when in fact it is based on co-occurrence information or the combining of various types of information into a numeric index value. Weight-of-evidence is not, as is being presumed by the state agency personnel, simply the inclusion of multiple types of information, irrespective of its technical validity and reliability. Rather, weight-of-evidence evaluation is, in concept, an approach by which best professional judgment of qualified individuals is used for the gathering, reviewing, synthesizing, and interpreting of information pertinent to a particular problem to give greatest weight to the most important and reliable information. The amount and type of reliable information upon which to make an evaluation may vary from situation to situation. The information cannot be reliably reduced to a single-value index number or ranking. Lee and Jones-Lee (1992a, 1993a) discussed technical deficiencies in the process of reducing technical information on sediment characteristics into a single numeric value or index, and of incorporating unreliable or irrelevant information in the assessment process.

In promoting the use of the MacDonald "PEL" values for screening and ranking sediment-associated contamination, the staffs of the state regulatory agencies in California and Florida have attempted to claim some "credibility" for the approach by claiming it represents a "weight-of-evidence" approach. They have further stated that since the weight-of-evidence approach has been endorsed by US EPA Science Advisory Board (SAB), the co-occurrence approach is endorsed by the SAB. The fact is that PEL/co-occurrence-based values were not formulated through, and do not represent, weight-of-evidence evaluations.

Some state regulatory agency staff members have superficially acknowledged the technical difficulties with the AET and PEL values, but have asserted that use of those values is the only way they can use existing data on total concentrations of sediment-associated chemicals to begin to regulate contaminated sediments. Such an argument presumes that existing chemical data must be used even though they may have been generated for other purposes and/or are not reliable or appropriate for judging potential water quality significance of sediment-associated chemical constituents. The fact is that unreliable information in no way aids in the decision-making process; rather, it renders the decisions made unreliable. A key element of a weight-of-evidence evaluation is the proper screening of data to properly use only those that are reliable for the task at hand. While processing data to generate a single numeric, pass/fail index, or relying on readily measured bulk chemical parameters may be bureaucratically expedient, it is not reliable for assessing the potential impacts of sediment-associated chemical constituents. Use of unreliable approaches generates unreliable answers.

For assessing the significance of sediment-associated chemical constituents on the beneficial uses of ambient waters, a weight-of-evidence evaluation would be expected to consider the following components.

- Aquatic toxicology - appropriate toxicity tests using various types of appropriate, sensitive organisms.

- Aquatic chemistry - evaluation/studies of the sediment and interstitial waters. "Aquatic chemistry" is not simply chemical analysis, but rather an evaluation of the thermodynamic and kinetic aspects of the reactions, transformation, transport, and fate of the chemical constituents that can affect their availability to affect beneficial uses of the ambient water. Of particular concern in sediment quality evaluation is a determination of the chemical constituents in sediments that are responsible for toxicity, through toxicity investigation evaluation procedures (TIEs).

- Populations/Bioaccumulation - *in situ* evaluation of the numbers, types, and characteristics (including morphology and body burdens of selected potentially hazardous chemicals) of the aquatic organisms present in the region of concern relative to the habitat characteristics of that region. The focus of body burden evaluation should be on those chemicals which are of concern for their bioaccumulation and potential impact on higher trophic-level organisms and humans (e.g., mercury, PCBs, dioxins). Body burden information should be evaluated relative to reliable public health criteria/standards such as the Food and Drug Administration

Action Levels and risk-based exposure (dose)--response (toxicity) evaluations. As reliable wildlife water quality criteria are developed, body burden information on excessive concentrations of chemicals in aquatic organism tissue that could affect higher trophic-level organisms can be developed.

The data collection efforts should be carefully planned for the particular site and the nature of the concern. The information should be evaluated in a hazard assessment framework. These aspects are described and discussed in greater detail by Lee and Jones (1992). If sufficient funds are not available to obtain reliable data in all three areas, highest priority should be given to obtaining reliable toxicological information since it provides the best, overall assessment of potential impacts of sediment-associated chemical constituents on aquatic life-related beneficial uses of the waterbody.

If the edible aquatic organisms of the region are found to contain excessive concentrations of chemical constituents that are a potential hazard to public health or to higher trophic-level organisms, consideration must be given to the role of sediments as a source of the chemicals of concern in a weight-of-evidence, hazard assessment.

The chemistry information that should be used in a true weight-of-evidence evaluation includes presentation of test results for specific forms of contaminants in sediments and interstitial waters, with particular emphasis on identifying the toxic available forms. Much of the data on the chemical characteristics of sediments and interstitial waters is unreliable as a result of those making the measurements failing to properly handle the sediments to preserve their *in situ* chemical integrity. It is very important to properly sample, handle, and analyze the sediments to preserve the chemical environment that was present in the ambient-water sediments (see Lee and Jones-Lee, 1992a). Bulk chemical composition has highly limited utility in a weight-of-evidence evaluation. While such information can indicate that the sediment has an elevated concentration of a chemical compared to that which is found at some other location, it provides no information on potential adverse impacts of that chemical on the beneficial uses of the waterbody in which the sediment is located. It is well known from many studies that high concentrations of some chemicals in a certain sediment can be non-toxic and unavailable, while lower concentrations of the same chemical in another sediment can be highly toxic and available to adversely affect aquatic life. The significance of concentrations of chemical constituents in sediments cannot be determined with chemical analytical techniques.

The primary factor governing the adverse impacts of sediment-associated chemical constituents on water quality is not the concentration of the chemical in the sediments but the concentration of the bulk matrix of the sediments which may detoxify - immobilize the chemical. It is for this reason that simplistic attempts to evaluate the significance of chemical constituents in sediments based on concentrations of the chemical are inherently unreliable.

While some regulatory agencies try to establish a numeric weight-of-evidence value by arbitrarily assigning weighting factors to various measured characteristics for the areas in which the sediments are located, such an approach is technically invalid. A weight-of-evidence evaluation should not be reduced to numeric scores by assigning arbitrary factors and "averaging." While developing numeric scores is bureaucratically simple and attractive, a weight-of-evidence evaluation is more reliably accomplished by a panel of qualified experts who critically review reliable data and group the evaluated sediments relative to the urgency of concern based on the panel members' cumulative "best professional judgment." The characterization of the sediments by the panel should be classified as high, moderate, or low priority for attention.

It is important that the "expert" panel evaluation address not only chemical and toxicological characteristics of the sediments of concern, but also the water quality significance (impacts on beneficial uses) of the sediment-associated chemical constituents in the waterbody of concern. Consideration must be given to actual toxicity in sediments which impacts the numbers, types, characteristics; and wholesomeness of the fish and other aquatic life. It should never be assumed that "toxicity" or "bioaccumulation" measured in laboratory tests translates directly to significant adverse impacts on the beneficial uses of a waterbody to require remediation and reductions in NPDES permit limitations. It is well known that many aquatic sediments are toxic to some aquatic life, while very good to excellent fisheries are supported in the overlying waters (Lee and Jones, 1987).

The cost of sediment clean-up and costs of reductions of contaminant load from NPDES-permitted point and non-point source discharges, as well as non-permitted discharges such as atmospheric sources, are normally of such magnitude that sufficient funds should be spent to develop reliable data/information that can be used in a true weight-of-evidence evaluation for a particular sediment before control or remediation is required. The economic situation in many states and in the nation behooves the regulatory community to develop reliable information on the real cause-and-effect relationships between sediment characteristics and real beneficial use impairment, and on the improvement in beneficial uses that would accrue from regulatory action, before contaminated sediment clean-up projects or other actions are undertaken. Societal needs today are such that any funds spent on contaminated sediment evaluation and management should be based on the best possible technical information and not on what are obviously technically invalid, co-occurrence evaluations.

REGULATORY PROCESS

Some may recognize technical limitations of the co-occurrence or other approaches for sediment character assessment, but presume that such approaches should be adequate for "screening" sediment. As discussed by Lee and Jones-Lee (1993a,b), however, that position inappropriately presumes that values used for "screening" can justifiably be less reliable than those used in subsequent evaluation. While values that are used to "screen" sediments or situations for inclusion in a group in need of further evaluation may be more inclusive, i.e., more conservative, than those which would serve as determiners of further action, they can be no less *reliable* technically. It is incorrect, indeed highly misleading, to assume that an *unreliable* value or approach is "conservative." To the contrary, an unreliable value or approach may well be under-protective.

Long and Morgan (1990) made it clear that the values that evolved out of their selected data review should not be used for regulatory purposes. Nevertheless, staffs of state regulatory agencies (e.g., in California and Florida) and others have proposed to use and are using Long and Morgan values or modification of those values, such as the MacDonald (1992) PEL values, for screening and ranking sediments based on the chemical concentration data for selected chemicals in sediments as part of the states' regulatory programs for sediments. Some regulators assert that use of numeric values or assessments for initial "screening" is not tantamount to their use for "regulation." While such may be true in theory, in reality, that is not the case. The screening and ranking that takes place is the initial phase of the regulatory process; it sets the agenda and priorities for sediment evaluation and clean-up and changes in NPDES limitations for point and non-point sources of chemical constituents that accumulate in the sediments. The "remediation" and alterations in NPDES chemical constituent discharge limitations that may be required in response to classification or ranking of sediments or to water quality assessments based on "sediment quality" can involve expenditure of many millions of dollars. Initiating the regulatory process based on the technically unreliable designation, categorization, or ranking of sediments can readily lead to massive waste of public and private funds in remediating non-problems and in failing to address real water quality problems caused by pollutants in sediments.

Once a regulatory process on a water or sediment is set in motion at the state or local level, it is very difficult to correct even when it is found through subsequent study that the original screening, ranking, or assessment was done incorrectly. Attempts of a regulatory agency to make corrections of overly restrictive requirements subsequently found inappropriate can readily, albeit improperly, be considered by environmental groups and members of the public to be a relaxing of requirements or bending to political or other pressure by industrial, commercial, or other interests. Some environmental groups threaten litigation against regulatory agencies when they try to use the new, more reliable information to lessen previously developed positions on the degree of pollution of a sediment.

An example of such a situation was observed in the establishment of clean-up objectives for copper in a portion of San Diego Bay, California, that had received copper ore concentrate from spillage associated with shore-to-ship loading of the material. As discussed by Jones-Lee and Lee (1994) and Lee and Jones-Lee (1994), the copper concentrations in the sediments where the spill occurred exceeded 50,000 ppm; however, toxicity tests on some of the more highly copper ore concentrate-contaminated sediments (the most contaminated sediments tested) with nine different test organisms, several of which are highly sensitive to copper, showed no toxicity. Further, the body burdens of copper in organisms from the highly contaminated area were no greater than those in low-copper areas of the Bay. It was clear that the copper from the copper ore concentrate, as well as copper from urban stormwater runoff, copper derived from the use of copper-containing anti-foulants on ship hulls, and copper from other sources contributing to the copper in the "contaminated" area was inert in the sediment environment and was not having an adverse impact on the designated beneficial uses of San Diego Bay waters.

Despite this technically highly convincing evidence that there was no need to "remediate" those copper-contaminated sediments, the Port of San Diego and others had to spend several million dollars in sediment remediation based in part on an inappropriately developed sediment quality clean-up objective that had been established by the Regional Water Quality Control Board. Further, an environmental group in the region petitioned the State Board to review the Regional Board's actions in developing the sediment clean-up objective as insufficiently stringent because the copper concentrations in the sediments exceeded the copper AET value developed for Puget Sound in the state of Washington.

It is clear from the San Diego Bay experience with copper that the regulatory arena today cannot properly deal with inappropriately or unreliably developed sediment quality evaluations. Once a clean-up objective has been established, however unreliable or inappropriate, it will be used by those who wish to further a particular mission. It is, therefore, essential that all sediment quality screening and ranking criteria and approaches have a high degree of reliability. That stipulation precludes the use of co-occurrence-based approaches for sediment quality screening and ranking.

SUMMARY

In his *"Comments on the US EPA's Proposed Strategy for Management of Contaminated Sediments,"* Lee (1992) concluded that the US EPA had failed to properly evaluate the magnitude of the water quality/beneficial use problems caused by contaminated sediments in the US. While it is well known that some sediments serve as sources of chemical constituents that bioaccumulate in organisms to adversely impact the designated beneficial uses of waters (e.g., DDT, PCBs), there are significant questions about whether sediment-associated chemical constituents that are potentially toxic to aquatic life are significantly impairing the designated beneficial uses of US waters. It is well recognized that aquatic sediments contain a number of naturally occurring toxic chemicals/conditions, such as low dissolved oxygen, hydrogen sulfide, and ammonia. It is also recognized that despite the presence of many sediment-associated contaminants, natural and/or anthropogenic, overlying waters support good "fisheries." It is certainly inappropriate for this country to enter into another Superfund-type program for sediments ("Aquafund") focusing on anthropogenic toxicants before a reliable assessment is made of the nature and extent of true water quality/beneficial use impairment problems caused by natural and anthropogenic toxicants. In addition, an in-depth understanding must be developed of the relationship between the results of laboratory toxicity tests or other testing/screening approaches and the water quality significance (assessed in terms of impairment of designated beneficial uses of waterbodies of sufficient magnitude to justify expenditure of public and/or private funds for remediation) caused by sediment-associated chemical constituents. A corollary requirement is that the nature and degree of improvement in designated beneficial uses that would be realized from any remediation approach be clearly demonstrated.

Co-occurrence-based evaluations of sediment-associated chemical constituents, such as those developed from Long and Morgan (1990) and MacDonald (1992), are not technically reliable foundations for assessing or regulating sediment-associated chemical constituents. They are not weight-of-evidence approaches for evaluation of potential water quality impacts of sediment-associated chemical constituents. Co-occurrence evaluations provide no reliable information that can be used for any aspect of evaluation or regulation of sediment-associated chemical constituents. A non-indexed weight-of-evidence approach in which aquatic chemistry, toxicology, and organism population characteristics are considered should be used to evaluate the water quality significance of sediment-associated chemical constituents. The evaluation of sediment chemical and toxicological characteristics should be reviewed in an ecological risk assessment framework in order to use funds available for evaluation of sediments cost-effectively. The sources of the chemical constituents of concern (dischargers) will need to fund the required studies. Such funding will be highly cost-effective in developing reliable information upon which to formulate sediment quality evaluations and management. Continued use of bureaucratically simple but unreliable sediment quality evaluation approaches will waste massive amounts of public and private funds in unnecessary or inappropriate treatment, and delay addressing real water quality problems.

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