

Development of Sediment Quality Objectives for California¹

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Many potential pollutants tend to accumulate in sediments. Of particular concern are the heavy metals (copper, lead, cadmium, zinc, mercury) and the organics, such as organochlorine pesticides (DDT, chlordane, toxaphene), PCBs, dioxins, PAHs and pyrethroid-based pesticides. Also, nutrients (nitrogen and phosphorus compounds) tend to exist at higher concentrations in sediments. This arises from the fact that the particulate forms of these elements accumulate in sediments, where the organic fractions are, at least in part, mineralized, releasing the soluble orthophosphate, ammonia and, eventually, through nitrification, nitrate. At this time, the concentrations of potential pollutants in aquatic sediments in many areas are essentially unregulated. While it is well known that most of the potential pollutants in sediments are in nontoxic/nonavailable forms, there are situations where sufficient concentrations of potential pollutants are available to be adverse to benthic and epibenthic organisms, as well as to be released to the overlying water column, where they could have an adverse impact on water quality-beneficial uses of a waterbody. Further, aquatic sediments can be a source of bioaccumulatable chemicals that are a threat to human health and to higher trophic level organisms, as a result of their consuming the aquatic organisms as food.

One of the key issues that needs to be understood in terms of evaluating whether a constituent in sediments represents a significant threat to public health and the environment is the binding capacity of the sediments. Potential pollutants exist in a variety of chemical forms, only some of which are toxic/available. It has been known since the late 1960s/early 1970s that there is no relationship between the total concentration of a constituent in sediments and its impact on water quality. This is a significant situation that is often ignored by those who are developing regulatory programs for constituents in sediments.

One of the issues that needs to be understood about evaluating the water quality significance of contaminants in sediments is that sediment concentrations of a potential pollutant are not analogous to constituent concentrations in the water column. The concentrations of constituents in the water column, including particulate materials (suspended solids), are assessed based on a mass per volume – typically a liter of water. A liter of water is 55 moles (gram molecular weights) of water. It is of constant composition. However, in sediments, the concentration units are mass of potential pollutant per kilogram (mass) of sediments. The sediment matrix that makes up the bulk of the sediments is of variable composition, depending on the erosion from the watershed, the precipitation that occurs in the waterbody, as well as any accumulation of aquatic plants and other vegetative material in the sediments. This situation is extremely important, since each of the major types of sediment matrices, such as clays, calcium carbonate precipitates, sulfide precipitates, organics, iron oxides, quartzite sand, detrital

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carbonates, etc., have different binding capacities for various types of pollutants. For example, large hydrophobic organic molecules, like DDT, PCBs, some PAHs, etc., tend to bind strongly to the total organic carbon content of the sediments. They also bind to any iron oxides that are present, and to clays.

Whether a constituent in sediments is a pollutant (impairs beneficial uses of the waterbody) depends on its availability, either to the interstitial water, the overlying water or through the intestinal tract to benthic organisms. This availability is determined by the binding strength of the potential pollutant to components of the sediment matrix. For example, the total organic carbon content of sediments tends to bind large, hydrophobic organic molecules and some metals, through complexation on the particulate organic surface. Sulfides tend to bind many of the heavy metals, in the form of heavy metal sulfide precipitates. Clays bind both metals and organics. Iron oxides, such as ferric hydroxide, tend to bind metals and organics.

The strength of binding of a particular potential pollutant to a particular sediment matrix depends on a variety of factors, such as the actual composition, characterization and age of the matrix material, and the chemical forms of the constituent. Further, the release of the constituent from the sediments to the water column is dependent on physical processes of mixing of the interstitial water and the particulates into the water column. This rate of transfer is dependent on physical stirring/mixing of the sediments and the water column, as well as organism-induced mixing, such as fish foraging for food, bioturbation, anaerobic fermentation that releases methane and carbon dioxide in sediments, etc. Lee (1970) described the importance of physical and biological processes in influencing the exchange of pollutants between bedded sediments and the overlying waters. Thibodeaux (2003) has presented updated information on this issue.

In order to evaluate whether a particular chemical present in sediments is available for bioaccumulation, a site-specific evaluation should be made using a sediment bioaccumulation test such as the US EPA (2000a,b), in which standard test organisms are exposed to the sediments, and the amount of the potential pollutant that accumulates in the organism tissue is measured. Similarly, in order to evaluate whether a particular chemical in sediments is toxic to benthic organisms, it is necessary to conduct toxicity investigation evaluations (TIEs).

In the 1970s the authors were involved in a \$30-million, five-year US Army Corps of Engineers Dredged Material Research Program (DMRP) designed to evaluate the water quality significance of open-water disposal of contaminated dredged sediments. The Corps, as part of its congressionally mandated requirements, must maintain the navigation channels of the US. In many urban industrial areas, the sediments in these channels are highly contaminated by a variety of chemical constituents that are potential pollutants. In the late 1960s/early 1970s, there was concern raised about the Corps' practice of open-water disposal of contaminated dredged sediments, in which the sediments dredged from a waterway channel are piped or hauled to deeper waters to be disposed of.

Under contract with the Corps, the senior author, G. F. Lee, and his associates conducted over a million dollars in research devoted to evaluating the potential for release of potential pollutants from waterway sediments. These studies included taking sediments from about 100 sites across the US and measuring the total concentration of the constituents as well as those that

are released during suspension in the water column. It also included toxicity testing on the sediments and, in some locations, assessing the existing degree of bioaccumulation of hazardous chemicals (such as PCBs, DDT, etc.). Thirty chemical parameters were measured on each of the samples, including the suite of heavy metals, organochlorine pesticides, PCBs, nutrients, ammonia, etc. Over 30,000 data points were generated from this study. The results of this study have been summarized by Lee and Jones-Lee (2000). They confirmed what was known at the time the study was initiated in the early 1970s – that, with few exceptions, chemical constituents in sediments that are potential pollutants are not available, either to be toxic or bioavailable for bioaccumulation. Numerous studies have been conducted since the completion of the DMRP, all of which confirm the results. These results caused the US EPA and the Corps of Engineers to abandon any attempts to regulate dredged sediments' potential for pollution of receiving waters associated with open-water disposal of the sediments based on total concentrations of a constituent in the sediments. Instead, they adopted a biological effects-based approach, using aquatic life toxicity, bioaccumulation, etc. This approach has been reviewed several times since it was adopted in the late 1970s. It is still the approach that is used to regulate the open-water disposal of dredged sediments. It is implemented through US EPA/US ACOE (1991, 1998).

Approaches for Regulating Sediment Pollutants: Chemical Concentration versus Biological Impacts

There have been a number of attempts to regulate potential pollutants in sediments using chemical concentrations of the constituent of concern. A summary of these efforts is presented below. Except for heavy-metal binding by sulfides, all of these have failed to be reliable.

Equilibrium Partitioning. Beginning in the mid-1980s through the late 1990s, the US EPA (1993, 2002) attempted to develop equilibrium-partitioning-based approaches for developing sediment quality criteria. The focus of this effort was on organics, which tend to partition with particulate total organic carbon in sediments. As was suggested (Lee and Jones, 1992) when the US EPA first started this effort, equilibrium partitioning, in which a simple partitioning is made between particulate TOC on the surface of sediment particles and the interstitial water, has been found to be unreliable in predicting water quality impacts. In addition to variable-composition TOC (see Fredrickson, 2003), which affects binding capacity and strength, there are also other types of surfaces that tend to bind organics.

Acid Volatile Sulfides. With respect to heavy metals, it has been found that heavy metals in sediments tend to form highly insoluble precipitates with sulfides. Since many sediments are anoxic (i.e., do not contain oxygen), this leads to sulfate being reduced to sulfide resulting in metal sulfides being common in many sediments. A procedure has been developed (US EPA, 1994) called “acid volatile sulfide (AVS) extraction,” whereby it is possible to determine whether on a molar basis, there are excess sulfides in the sediments to precipitate the non-iron heavy metals that are simultaneously extracted in the AVS test. If the molar sum of sulfides is in excess of the non-iron heavy metals, the heavy metals have been found to be nontoxic. However, if the heavy metals exceed the sulfides, there is a potential for metal toxicity to benthic organisms. While the metals are not fully bound as metal sulfide precipitates, the metals can be bound (detoxified) by organics, carbonates, clays, etc. As Lee and Jones (1992) discussed, the use of AVS screening of sediments is a useful tool as part of toxicity identification evaluation (TIE). It is not, however, a reliable basis for developing sediment quality criteria.

Co-occurrence Based Approaches. In the late 1980s, Long and Morgan (1990) developed co-occurrence-based sediment quality guidelines (SQGs). MacDonald (1992) subsequently developed his own version of sediment quality guidelines. These so-called “guideline” values are based on examination of the total concentration of a constituent in a variety of sediments, relative to what some investigator found with respect to toxicity or organism assemblages, or some other so-called “response parameter.” The same endpoint was used for a sediment for all parameters that were included in the guidelines development. The sediment chemical concentrations for each element considered were then ranked from low to high, and an effects level was determined. This approach is obviously technically invalid, since it is based on total concentrations of constituents in sediments. There is no attempt to relate the “effect,” through a cause-and-effect examination, to the concentration of a particular constituent. At best, as DiToro (2002) pointed out, it is a “coincidence” approach that has nothing to do with sediment chemistry, toxicology or other scientific issues. The co-occurrence-based approach ignores the substantial literature, which was available to Long and Morgan and MacDonald at the time they proposed their values, on the lack of relationship between the total concentration of a constituent and its impacts. O’Connor of NOAA (1999a,b) has found, based on a review of US EPA and NOAA databases, that flipping a coin is more reliable in predicting sediment toxicity than exceedance of the guideline values. Lee and Jones-Lee (2002a) have provided a detailed critique of the co-occurrence-based approach.

In an effort to improve the reliability of co-occurrence-based approaches, Long has developed a summed quotient approach, in which the concentration of a constituent in sediments is divided by the guideline value, and these values are then summed, and a new guideline value is developed for potential adverse impacts. Again, this is nothing other than a coincidence if there is a relationship between high summed quotient values and effects, such as toxicity. Basically, it shows that in areas where there are a variety of chemical constituents in the sediments at elevated concentrations (typically in urban or industrial areas), there tends to be toxicity in the sediments. This does not mean, however, that there is any relationship between the concentration of a single constituent, or the sum of the constituents that were included in the evaluation, and the toxicity found. The toxicity found could readily have been due to some unmeasured constituent, or several constituents, through additive toxicity, which are each below the individual guideline value. The summed quotient approach depends on the number of constituents, such as the number of PAHs, which are included in the evaluation.

There are some, including SETAC (see Wenning’s review of the SETAC sediment quality workshop proceedings [Wenning, 2003]), who are of the opinion that the Long and Morgan co-occurrence-based guideline values can be used as screening values for potential problems. This approach can lead to significant errors in evaluating sediment quality. It does not consider all of the chemicals that are common in sediments and known to cause sediment toxicity, such as ammonia, sulfide and low dissolved oxygen. The fundamental problem with the co-occurrence-based screening approach is that there are constituents in the sediments that are toxic to aquatic life, yet are not included in the evaluation. A sediment could “pass” a set of so-called co-occurrence-based screening values, and still be highly toxic to aquatic life. This approach will miss the unmeasured constituents and ignores the additive and synergistic effects of constituents. One of the fundamental flaws of the Long and Morgan original approach is that

they used a considerable part of the authors' 1970s Corps of Engineers data in developing the original guideline values, but they did not use ammonia, low dissolved oxygen or sulfide, for which data were available in the database.

It is well established that the most common cause of sediment toxicity and adverse impacts on organisms is low dissolved oxygen, the presence of sulfides and/or ammonia. Ammonia is present in many sediments at concentrations that are toxic to aquatic life. To ignore ammonia toxicity in making a sediment quality evaluation is technically invalid and shortsighted in terms of the purpose of sediment quality guidelines – namely, to make an evaluation of the potential significance of a particular contaminant in sediments. To a benthic organism it makes little difference whether it is killed by a heavy metal that is in a toxic/available form or by ammonia. It is still dead. Therefore, any sediment evaluation that ignores ammonia toxicity is inappropriate.

The origin of the low dissolved oxygen (DO), elevated sulfide and ammonia in sediments is related to the trophic status of the waterbody. Waterbodies with elevated algal content (higher degrees of eutrophication) tend to deposit more algae in sediments, which, when they decompose, use up the oxygen present in the sediments. This leads to sulfate reduction to sulfide and an accumulation of ammonia associated with the mineralization of organic nitrogen in the algal and other plant material that accumulates in the sediments. Therefore, the ammonia/sulfide/low-DO toxicity is typically related to the input of nitrogen and phosphorus to the waterbody that stimulates algal growth.

Some state regulatory agencies, such as the states of Florida and Washington, attempt to use chemical-concentration-based approaches for regulating water quality impacts of aquatic sediments. This approach involves analyzing the sediment for the total concentration of a constituent, and then comparing the results of the analysis to some empirically developed co-occurrence sediment quality guideline. This approach disregards the substantial literature that shows that there is no relationship between water quality impacts and total concentrations of constituents in sediments. While those who advocate this approach say that there is literature that claims that there is a relationship, a critical review of this literature shows that it is a coincidence, and that it is not reliable, in many instances, for predicting sediment toxicity.

As Lee, et al. (1999, 2001) and Lee and Taylor (2003) reported, urban area stormwater runoff and some agricultural area stormwater runoff and discharges in California and many other areas contain elevated concentrations of the organophosphorus pesticides diazinon and chlorpyrifos. In urban areas, this is a result of the use of these pesticides by the public on their property to control ants, termites and other home and garden pests. The organophosphorus pesticides are highly toxic to certain zooplankton, such as *Ceriodaphnia*. They are not especially toxic to fish. The US EPA has determined that these pesticides represent a threat to the health of children, and chlorpyrifos has been banned from further sale in urban areas. Diazinon is being phased out, so that by December 2004 it will no longer be sold in urban areas for residential use.

The pyrethroid pesticides, however, are being sold in large amounts as replacements for the organophosphorus pesticides. Pyrethroid pesticides are as toxic, if not more toxic, to zooplankton and fish. One of the differences between the organophosphorus pesticides and the

pyrethroid-based pesticides is that pyrethroids tend to sorb strongly on sediments. Weston and Lydy (2003) have reported finding that sorbed pyrethroid-based pesticides are bioavailable to at least some benthic organisms (i.e., can be taken up from the benthic organism's intestinal tract). Further, they found that these same sediments are toxic to some benthic organisms. It is not clear from the work that has been done thus far whether the toxicity is due to the pyrethroid pesticides. There is no doubt that, in areas where pyrethroid pesticides are sold over the counter for residential use, which is many areas of the US, pyrethroid-based pesticides will be present in stormwater runoff from the areas where they are used, and they will accumulate in the receiving water sediments. Any attempt to screen these sediments for potential adverse impacts due to heavy metals or other constituents for which Long and Morgan or MacDonald have developed a guideline value, will miss the potential for the pyrethroid-based pesticides in the sediments to be adverse to sediment quality.

Pyrethroid pesticides are not the only chemicals of this type. There are many chemicals that can be present in sediments, which are not part of the co-occurrence-based sediment quality guideline evaluation, which can be adverse to sediment quality and not be properly "screened" by the use of co-occurrence-based approaches. It will be extremely important that water quality managers not assume that toxicity in stormwater runoff or sediments is due to heavy metals, since it is unlikely that this will be the case, even though the heavy metal concentrations found exceed the US EPA water quality criteria. It will be important to use toxicity identification evaluations (TIEs) to identify the cause of toxicity in stormwater runoff and in the receiving waters for this runoff and their sediments in order to properly identify the cause of toxicity.

In the past few years Long has frequently stated that his so-called "guideline" values should not be used for regulatory purposes, yet they are being used for projects in which tens of millions of dollars of public funds are being spent because of exceedance of a Long and Morgan value. Some of the "horror" stories that the authors are familiar with include the exceedance of a Long and Morgan lead concentration value in Santa Monica Bay sediments causing those in the stormwater runoff watershed for Santa Monica Bay to spend \$42 million controlling lead and other heavy metals in urban area and highway stormwater runoff. This \$42-million project (the Santa Monica Bay Restoration Project) was shepherded by a State Water Resources Control Board staff member, and had the approval of the Los Angeles Regional Water Quality Control Board, the State Water Resources Control Board and the US EPA Region 9. However, it was obviously technically invalid, since anyone who understands even the most elementary aspects of lead chemistry in marine environments knows that lead is not a pollutant in a marine environment. Its chemistry is such that it is rendered inert and does not impact the aquatic-life-related beneficial uses of marine waters and sediments. Lead can be present in marine sediments well above Long and Morgan guideline values without adverse impacts. Flegal (2003) has presented a review on this issue.

When the Santa Monica Bay Restoration Project approach was first proposed, the authors (Lee and Jones-Lee, 1994; Lee, 1995) suggested to the Santa Monica Bay Restoration Project management that, before they adopted a restoration program costing the public \$42 million, which was based on exceedance of a Long and Morgan lead concentration in Santa Monica Bay sediments which predicted that the lead could be toxic, they ought to measure sediment toxicity. The Regional Board, the State Board and the US EPA Region 9 did not follow this suggestion.

Instead, they simply assumed that exceedance of a Long and Morgan co-occurrence-based lead guideline demonstrated that there was such a significant adverse effect on Santa Monica Bay by lead in stormwater runoff, so as to cause the public to spend \$42 million trying to control it.

Another equally technically invalid approach occurred when the US EPA developed the TMDL to control the organochlorine “legacy” pesticides (such as DDT) and PCBs that enter Upper Newport Bay (Orange County, California) and become incorporated into Bay sediments. The organochlorine compounds that were bioaccumulating to excessive levels were derived from stormwater from both agricultural and urban sources. It should have been obvious, through the most elementary review of how the Long and Morgan guideline values are developed for the organochlorines, that the guideline value does not consider in any way the potential for the constituent to bioaccumulate to excessive levels in fish, which would render the fish hazardous to those who consume the fish as food. Bioaccumulation to excessive levels in edible organisms was not, and still is not, an endpoint that is used in evaluating the coincidence (co-occurrence) between a concentration of a constituent in sediments and its bioaccumulation in aquatic organisms. These issues are further discussed in Lee and Jones-Lee (2002a).

Another recent example of the gross unreliability of Long and Morgan co-occurrence-based values that contributes to another “horror” story on their use is with the California Department of Fish and Game (DFG). DFG staff are attempting to improve anadromous fish spawning habitat in California Sierra rivers through the addition of gravel to the rivers. The gravel source that is being used is the dredger tailings from the former gold recovery operations in the terrestrial areas near existing rivers. These areas, through former erosion, have transported appreciable gold concentrations into the surficial sediments. Miners dredged these sediments and extracted some of the gold from them, using mercury to bind the gold. This approach has left substantial amounts of mercury in the dredged tailings. DFG staff have been using the Long and Morgan guideline value for mercury as a criterion to determine whether the dredger tailings contain excessive mercury. Again, this is obviously a technically invalid approach when an elementary review is conducted of the basis by which Long and Morgan developed their mercury guideline value. Mercury is of concern because, in certain aquatic sediment environments, it is converted to methylmercury, which then can bioaccumulate through the food web to excessive levels in fish, so that the fish become hazardous for use as food by humans and some fish-eating birds. The Long and Morgan guideline value for mercury does not in any way consider this issue.

Even though it is well recognized that the Long and Morgan and MacDonald co-occurrence (coincidence) values are unreliable and should not be used for any purpose, including screening, regulatory agency staff and others still use them. It is the authors’ experience that there are some individuals, including some in the regulatory community, that just want a number so that they can regulate or be regulated. They do not want to be confused with such issues as the aquatic chemistry and toxicological reliability of the value that they are using. While there are some individuals, such as the authors (Lee and Jones, 1992), Dr. Robert Engler of the Corps of Engineers Waterways Experiment Station, and Dr. Tom Wright formerly of the Corps of Engineers Waterways Experiment Station, who have been discussing the unreliability of the Long and Morgan and MacDonald co-occurrence-based guideline values for over 10 years,

recently there has been increasing recognition of the inappropriateness of using these values for any purpose.

In the fall 2002, the Aquatic Ecosystems Health and Management Society held an international conference entitled “Aquatic Ecosystems and Public Health: Linking Chemical, Nutrient, Habitat and Pathogen Issues.” A number of the leading authorities on sediment quality evaluation, such as Dr. Alan Burton, Dr. Peter Chapman, Dr. Dominic DiToro, as well as others at other conferences (see US ACOE/US EPA, 2003), including Dr. Robert Engler, Dr. Todd Bridges and Richard Wenning, have all discussed in the last year or so the unreliability of Long and Morgan and MacDonald so-called “sediment quality guidelines.” These guidelines should not be used for any purpose. It is a serious mistake by Long and Morgan to have ever developed them. They have done and will continue to do significant harm to properly regulating contaminants in sediments.

California Approach for Developing Sediment Quality Objectives

In 1989 the California legislature developed the Bay Protection and Toxic Cleanup Program (BPTCP). This program required that the California State Water Resources Control Board (SWRCB) develop sediment quality objectives. The BPTCP was misdirected and poorly implemented by SWRCB staff, who tried to develop chemical concentration-based sediment quality objectives. After spending very large amounts of money, the SWRCB BPTCP effort failed to develop sediment quality objectives.

In 1989 a lawsuit filed by an environmental group caused the SWRCB to have to try again to develop sediment quality objectives. The settlement of the lawsuit resulted in a compliance schedule, which specified that,

- by June 30, 2003, the SWRCB must adopt a scoping document (workplan) for developing sediment quality objectives
- by August 5, 2005, the SWRCB must circulate draft objectives
- by February 28, 2007, the SWRCB must adopt objectives and a policy for their implementation, and submit them to the Office of Administrative Law.

The SWRCB staff developed a workplan in accordance with the schedule; however, this workplan was found by a number of individuals to be significantly deficient.

The California approach for developing sediment quality objectives is based on the California Water Code (Porter-Cologne) section 13391.5(d):

“‘Sediment Quality Objective’ means that level of a constituent in sediment which is established with an adequate margin of safety for the reasonable protection of the beneficial uses of water or the prevention of nuisances.”

Section 13393(b) of the California Water Code states,

“The state board shall adopt the sediment quality objectives pursuant to the procedures established by this division for adopting or amending water quality control plans. The sediment quality objectives shall be based on scientific information, including, but not

limited to, chemical monitoring, bioassays, or established modeling procedures, and shall provide adequate protection for the most sensitive aquatic organisms. The state board shall base the sediment quality objectives on a health risk assessment if there is a potential for exposure of humans to pollutants through the food chain to edible fish, shellfish, or wildlife.”

The California sediment quality objectives are to be used to identify sediments that need to be remediated in an aquatic Superfund (“Aquafund”) program. They are also to be used to modify NPDES wastewater discharge permits for discharges that could be a source of the chemicals that violate the sediment quality objectives. Unfortunately, serious errors can occur if the current SWRCB staff makes the same mistake as the past Board staff, of claiming that the source of a constituent can be determined based on total concentrations of constituents in sediments. Any attempt to identify the source of the constituent that causes a sediment quality objective violation must be based on appropriate TIEs.

Based on recent meetings, the SWRCB staff is again trying to develop sediment quality objectives using chemical concentrations, Long and Morgan sediment quality “guidelines,” and the California BPTCP database that was generated in the previous BPTCP effort. The authors are familiar with this database and have found that, for many situations, the database is not adequate to develop sediment quality objectives. Basically, the managers of the BPTCP and those who implemented the program failed to collect the required information for evaluating the causes of sediment toxicity. Again, this was related to an inappropriately planned and implemented/conducted program. The data simply do not exist now to develop sediment quality objectives. Another significant problem with the current approach is that \$2.5 million was made available for development of sediment quality objectives. This is too little money and too little time to properly develop sediment quality objectives. One of the most significant deficiencies of the current approach is that those responsible have explicitly stated that they do not plan to do any TIE work to determine whether toxicity in a sediment is due to a particular constituent. They will rely, instead, on the total concentrations of the constituent, which will obviously fail to provide reliable results.

Another significant deficiency with the SWRCB approach for developing sediment quality objectives is that they are giving a lower priority to develop guidance for regulating chemicals that lead to excessive bioaccumulation, such as mercury, PCBs, dioxins and “legacy” organochlorine pesticides (such as DDT, chlordane, dieldrin, toxaphene, etc.). To the public, the most significant issue with respect to sediment quality is whether the sediments are contributing to excessive concentrations of these chemicals in fish that are used for food. This is far more important to the public than a limited-scope alteration of the numbers and types of benthic organisms (worms) that might be associated with a limited toxicity.

It is predicted that the California State Water Resources Control Board’s approach for developing sediment quality objectives will again fail to develop reliable sediment quality objectives for a sediment regulatory program. For further information on the problems with this approach, see Lee (2003a,b,c), as well as the SWRCB website, in the BPTCP section for comments made by others.

How Should Sediment-Associated Contaminants be Regulated?

It is clear, as was found by the authors' and other studies in the 1970s, that chemically based approaches are unreliable and should not be used for regulating sediment-associated constituents. Instead, biological-effects-based approaches should be used. There is growing recognition that the approach for regulating constituents in sediments that are potential pollutants – i.e., under some conditions, the constituent can be adverse to the beneficial uses of a waterbody – should be based on a non-numeric, best professional judgment (BPJ) triad weight-of-evidence approach. This approach integrates reliable information on sediment toxicity to a suite of sensitive organisms, organism assemblage information in the area where the constituents of concern are located relative to similar unimpacted habitats, and non-pollutant chemical information. In addition, information on the potential for chemicals present in the sediments to be incorporated into the aquatic food web through bioaccumulation in aquatic life to levels that are hazardous to their use by higher trophic level organisms (including humans) as food needs to be included in the sediment quality evaluation. The US EPA (2000a,b) procedures should be used to assess the bioaccumulability of potentially hazardous chemicals, such as the organochlorine legacy pesticides, PCBs and dioxins. The aquatic organism assemblage assessment should include appropriate reference site information and gradient analysis from a hot spot or source of pollutants, to see if the organisms are potentially responding to the constituents of concern. Burton, et al. (2002a,b), and Chapman, et al. (2002, 1992), have provided comprehensive reviews of the approach that should be used in implementing the weight-of-evidence approach for sediment quality evaluation.

There is an aspect of the weight-of-evidence approach that is not well understood with respect to how to reliably incorporate chemical information into the triad. A number of investigators attempt to use total concentrations of constituents in sediments as the weight-of-evidence chemical information. This approach is obviously technically invalid. High concentrations of inert forms of contaminants, such as routinely occur in many sediments, can skew the weight-of-evidence evaluation so that it becomes unreliable. Lee and Jones-Lee (2002b) discuss this issue, and point out that the chemical component of a triad weight-of-evidence approach must be based on toxic/available forms, evaluated through a TIE, and not based on total concentrations. While many individuals, especially those with limited chemistry backgrounds, attempt to shortcut or circumvent the complexity of the aquatic chemistry of constituents in aquatic sediments, there is no reliable shortcut. Properly developed and implemented chemical tools should be used.

As discussed by Lee and Jones-Lee (2002b), the weight-of-evidence approach should be implemented as a non-numeric best professional judgment by an expert panel in a public interactive peer-review process. This approach would eliminate many of the biases that become involved in scientific evaluation by individuals who either do not understand the issues or want to support their client's or agency's position on issues, irrespective of the technical information available.

In California, rather than wasting the funds in trying to develop numeric chemically based sediment quality objectives, as the SWRCB staff is now doing, the \$2.5 million available and the two years allowed for developing sediment quality objectives should be devoted to developing guidance on the weight-of-evidence approach for evaluating sediment quality. This

guidance then should be evaluated at several locations to determine its implementability and reliability.

Evaluation of the Water Quality Significance of Sediment Toxicity

There are some issues that need to be evaluated in the regulation of sediment quality impacts caused by chemicals. These include the fact that many aquatic sediments are toxic due to sulfides, ammonia and low dissolved oxygen, yet, as discussed by Lee and Jones-Lee (1996) these waterbodies, which have highly toxic sediments, also have high-quality fisheries. There is a very poor understanding of the relationship between sediment toxicity and its impairment of the beneficial uses of waterbodies.

Another important factor is that much of the sediment toxicity that is found is due to sulfides, ammonia and low dissolved oxygen, – i.e., materials that arise from the decay of algae that accumulate in sediments. There are regulatory agency personnel and some agencies that have adopted the policy that the toxicity of sediments that is due to ammonia, sulfide or low DO can be allowed, yet toxicity to the same organisms in the same magnitude due to a heavy metal must be controlled. This is an obviously inappropriate policy to the organisms. Whether they are killed by ammonia or a heavy metal makes no difference. There is an urgent need to better understand what sediment toxicity means to the beneficial uses of waterbodies.

Conclusions

There is need for a regulatory approach for controlling the water quality impacts of chemicals in sediments that are real, significant pollutants – i.e., they impair the beneficial uses of waterbodies. Chemical-concentration-based sediment quality objectives cannot be used to reliably regulate sediment quality. A non-numeric best professional judgment triad weight-of-evidence approach should be used to regulate sediment quality. Those concerned with properly regulating sediment quality should become involved in the California sediment quality objective development areas, to work toward stopping the technically invalid approaches that the State Board staff have apparently adopted, and redirect this program to meaningfully use the remaining funds so that at least something useful will come out of the program.

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