Urban Stormwater Runoff Water Quality and Associated Sediment Quality Issues: An Overview

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Introduction

The reliable evaluation of the water quality significance of contaminants in urban stormwater runoff is paramount to developing technically valid, cost-effective approaches that will control the real water quality problems that result in a use impairment of the receiving waters for urban stormwater drainage. Presented below is a discussion of the authors' over 30 years of experience relative to a number of aspects of evaluation and management of contaminants in urban stormwater runoff. Included is a discussion of the appropriate use of water quality criteria and standards to evaluate and manage stormwater runoff-associated contaminants. Also discussed is the approach that should be followed in developing best management practices for a particular stormwater discharge, stormwater quality monitoring, watershed management approaches, pollutant trading, permitting of contaminant sources and sediment quality evaluation and management. The discussion focuses on the importance of proper use of the current state of knowledge in aquatic chemistry and aquatic toxicology in evaluating and managing stormwater-associated contaminants.

US EPA Water Quality Criteria/State Standards

With the implementation of the US EPA's urban stormwater quality management program, controversy has developed on the appropriate goals for urban stormwater runoff-associated contaminant management. While there are some who advocate that the goal should be achieving the state water quality standards (objectives in California) at the point of discharge in the receiving waters, it is recognized (see Lee and Jones, 1991 and Lee and Jones-Lee, 1993a) that the use of the US EPA water quality criteria and state standards based on these criteria to regulate stormwater runoff-associated contaminants of urban and rural sources will lead to massive waste of public and private funds in developing control programs for such contaminants. Many chemical contaminants exist in aquatic systems in a variety of chemical forms, only some of which are toxic/available to aquatic life. Further, an aquatic organism's duration of exposure to toxic/available forms of pollutants is a significant factor that influences the toxicity of these contaminants (Lee, *et al.*, 1982). The basic problem in using US EPA water quality criteria and state standards based on these criteria is that many stormwater runoff- associated contaminants are in non-toxic, non-available forms. Further, while the US EPA water quality criteria are based on chronic continuous exposure conditions, stormwater runoff events are typically episodic and short-term, with the result that for those contaminants in stormwater runoff that are toxic/available much higher concentrations can be present in the ambient waters near the point of stormwater discharge without adversely impacting the designated beneficial uses of the waterbody. The foundation of PL 92-500 (the original Clean Water Act) was the protection of designated beneficial uses of the nation's surface waters. Water quality criteria and standards are

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tools that assist in achieving that goal. It is highly inappropriate to establish as the goal achieving the standards because of the highly over-protective approach used in standards development and implementation.

Urban stormwater runoff contains a wide variety of contaminants that will cause receiving waters for this runoff to exceed the current water quality criteria and standards. These exceedances, however, are largely "administrative," related to the inability of the federal and state regulatory agencies thus far to develop appropriate criteria and standards for stormwater runoff- associated conditions. These exceedances typically do not represent an impairment of the designated beneficial uses of the receiving waters such as adversely altering the numbers, types and characteristics of aquatic life in these waters. Because of the high cost and limited funds available for stormwater contaminant control, it is important that those responsible for developing and implementing stormwater contaminant control programs not mechanically accept a regulatory agency's overly-protective approach and the concomitant waste of public and private funds in contaminant control because of the administrative exceedances of state water quality standards. **The goal for the US EPA's stormwater runoff water quality management program should be the protection of the designated beneficial uses of waterbodies without significant unnecessary expenditures for contaminant control.** Since current US EPA water quality criteria and state standards based on these criteria will, in general, significantly over-regulate contaminants in stormwater runoff from urban and rural areas, at least a 10 year moratorium should be declared for the application of water quality criteria/standards to regulate stormwater runoff-associated contaminants. Since the current criteria and standards are not appropriate for stormwater runoff conditions, this 10 year period would be used to develop "wet weather" criteria and standards.

There is widespread agreement that since appropriate traditional regulatory tools (water quality standards) are not now available that the goal for urban stormwater contaminant control should be a performance standard based on achieving best management practices (BMP) for the stormwater associated contaminants. While it is appropriate to focus BMP's on controlling those contaminants derived from identified particular sources that contribute to real water quality problems in the receiving waters to the degree necessary to prevent impairment of beneficial uses of these waters, the control of all forms of a particular contaminant independent of whether a particular source contributes a contaminant in a form that is or that converts to forms that are adverse to receiving water quality is technically invalid and wasteful of public and private funds.

BMP Performance Goals

While federal and state regulatory agencies are not now requiring attainment of water quality standards in the receiving waters for urban stormwater runoff, some agencies are continuing to use these criteria and standards as the goal for contaminant control in stormwater runoff from urban areas. As discussed by Jones-Lee and Lee (1994), regulatory agencies are proposing to judge satisfactory performance of BMP's based on how well they perform toward achieving current state water quality standards. A ratcheting down approach is proposed for use in which the management agency for a stormwater system or industry will be required to install certain agreed to BMP's for the control of contaminants in stormwater discharges. If the initial BMP's, such as control of illegal and illicit connections and discharges at the source, good housekeeping, etc., are not adequate to achieve state water quality standards (objectives), then additional typically more expensive BMP's will have to be implemented. Current US EPA water quality criteria and state water quality standards based on these criteria are no more reliable for judging the satisfactory performance of a BMP than they are for judging the impact of stormwater-associated contaminants discharged to a waterbody. The current ratcheting down approach on BMP's in which achieving current water quality standards are used as the basis for judging the satisfactory performance of the BMP is not technically valid and can be highly wasteful of public and private funds in implementing contaminant control programs.

As discussed by Jones-Lee and Lee (1994) and Lee and Jones-Lee (1993a), the first step in developing a BMP for a particular stormwater runoff/discharge should be the identification of a real water quality problem (use impairment) for the stormwater discharge. The identification of use impairment cannot now be done by chemical means. Specific studies of receiving water toxicity and altered numbers and types of desired organisms compared to the habitat-carrying capacity will have to be conducted to determine if a stormwater discharge is, in fact, adversely impacting the designated beneficial uses of a waterbody.

The satisfactory performance of BMP's should be based on eliminating or at least significantly reducing the magnitude of an identified use impairment in the receiving waters. Constructing structural BMP's of the type that are typically used today represents throwing money at a problem without properly evaluating the nature of the problem and the benefits that will result from the expenditure. The obvious appropriate approach is to identify a real water quality problem and then solve that problem in the most technically valid, cost-effective manner. This approach is significantly different from that which has been used for point source discharges, such as municipal and industrial wastewaters where these discharges were required to meet arbitrarily developed effluent treatment performance standards without regard to whether that level of treatment was necessary to achieve the protection of the designated beneficial uses of the receiving waters. The much higher costs associated with stormwater quality management from urban and rural sources and the shortage of funds available for such purposes necessitates that a more technically valid, cost-effective approach be used to manage stormwater-associated contaminants than has been used to manage contaminants associated with non-point sources. Further, point source dischargers are now beginning to critically evaluate the cost-effectiveness of achieving overly-protective state water quality standards in the receiving waters at the edge of the discharge mixing zone that are designed to control potentially toxic chemicals in the discharge.

Stormwater Quality Monitoring

With the development of the NPDES permitting of industrial and some municipal stormwater discharges, chemical contaminant monitoring of these discharges was initiated. Those responsible for these monitoring programs are now beginning to examine the data collected and are starting to ask what useful information can be developed from this data on the quality of the stormwater discharge and its impact on receiving waters. A critical review of the stormwater quality monitoring programs that have been established for industrial and municipal sources shows that the programs now being required by the regulatory agencies provide little in the way of useful data to evaluate the water quality significance of contaminants in the stormwater discharge (See Lee and Jones-Lee, 1992c). Basically, the monitoring data has been collected to meet a regulatory requirement with little regard to its utility in evaluating water quality impacts.

This data can best be described as "file cabinet fodder" where about all that can be meaningfully said about it is that it has satisfied a regulatory requirement and is being accumulated both in the generators' and the regulators' file cabinets.

Those who compare the stormwater chemical concentration data to water quality criteria and standards will find that almost without exception the concentration of many contaminants in stormwater runoff is above existing water quality criteria and standards. There was no need to collect any data to come to that conclusion, since that has been known for over 25 years. The primary conclusion of the US EPA's National Urban Runoff Program (NURP) conducted in the early 1980's was that urban stormwater runoff contains elevated concentrations of a variety of contaminants. Unfortunately, the administrators of NURP did not conduct this program in such a way as to evaluate at any location the water quality significance of these contaminants (Lee and Jones, 1981). The current water quality monitoring of stormwater discharges basically represents little more than a continuation of NURP and is largely a waste of public and private funds in addressing the real issues of concern in managing urban stormwater quality, namely are there contaminants in a particular stormwater discharge that adversely impact the designated beneficial uses of the receiving waters for the discharge. Further, a meaningful stormwater quality monitoring program should have as a key component the determination of the specific sources of contaminants that cause the impairment of the beneficial uses of the receiving waters for the discharge.

Lee and Jones (1991) have discussed these aspects of stormwater quality monitoring programs. They point out that the first step in developing a meaningful monitoring program is to carefully define the goals of the monitoring program. If the goal is simply to meet a regulatory requirement and thereby generate "file cabinet fodder" then this should be acknowledged up front and then no one after the fact would be questioning what to do with the data collected over the past year or so in monitoring stormwater runoff. If, however, the purpose of the stormwater quality monitoring program is to develop technically valid, cost-effective approaches for managing real water quality problems associated with the discharge of stormwater to a particular waterbody, then a markedly different approach must be adopted than those being used today that incorporates the latest information in aquatic chemistry and aquatic toxicology into a water quality hazard assessment. Lee and Jones-Lee (1992a) have provided guidance on the approach that should be followed in developing stormwater quality monitoring programs that if carried out will yield useful data. Some communities, such as the City and County of Sacramento, have been conducting more in-depth stormwater quality monitoring/evaluation programs and have found that what appears to be a water quality problem in the receiving waters based on total contaminant concentrations in the stormwater runoff were not adversely impacting receiving water quality.

Watershed Management Approach

There is considerable discussion today about implementing the watershed management approach for point and non-point sources of contaminants. Some point source dischargers who advocate this approach hope that they will receive relief from having to achieve stricter discharge limits associated with achieving the requirements of the US EPA's National Toxics Rule for potentially toxic chemicals than are being required today. They claim that since non-point source dischargers are not being required to meet water quality standards in the receiving waters, further restricting the discharges of point source dischargers should not be required until the non-point source dischargers come into compliance with achieving water quality standards. The argument would be valid if the impact of the contaminants in point and non-point source discharges were the same. However, as discussed below, this is rarely the case.

A watershed management approach should be adopted where both point and non-point source dischargers work with the regulatory agencies to evaluate the real water quality problems in a particular waterbody that drains a watershed. After these have been identified then require that the specific source(s) of the pollutants that is responsible for use impairment be required to control their input of the pollutants to the degree necessary to protect the designated beneficial uses of the waterbody independent of the nature of the source, i.e. point or non-point, ag or urban, etc.

It is important that those responsible for implementing the watershed management approach recognize that all sources of a particular type of contaminant such as copper do not contribute copper to the waterbody that impacts designated beneficial uses to the same degree. Copper from automobile brake linings/pads in urban stormwater runoff will certainly be significantly different in its potential impact on receiving water quality than copper from copper sulfate used to control algae in a water supply reservoir or the copper that is used to kill roots that have penetrated a sanitary sewer system. In one case (the brake linings/pads) the copper originates as a metallic element that is unavailable and non-toxic to aquatic life. In the other, the specific form of copper (copper sulfate) is added to the water which is designed to be highly toxic to plant life. Before it should be assumed that all sources of copper to a waterbody have equal adverse impacts on the beneficial uses of a waterbody, site-specific studies should be conducted to determine whether this unexpected situation is occurring. The assumption that all sources of copper or other contaminants are of equal adverse impact is strongly contrary to aquatic chemistry and aquatic toxicology. Based on the authors' experience it will be indeed rare, if ever, that all sources of copper, or for that matter other contaminants, will have equal adverse impact on the designated beneficial uses of a waterbody.

Pollutant Versus Contaminant

Significant problems exist today in the water quality management field because of a failure to recognize the difference between **pollutants** and **contaminants**. As discussed by Lee and Jones (1990), contaminants are any materials added to water, irrespective of the impact. Pollutants by tradition and national regulations are those contaminants that are present in a water in sufficient concentrations of available/toxic forms and for a sufficient duration to adversely impact the designated beneficial uses of the waterbody. The goal of PL 92-500 (CWA) is zero pollutant discharge, not zero contaminant discharge. The latter would require that distilled water be discharged. In many instances the discharge of large volumes of distilled water would be highly adverse to the designated beneficial uses of waterbodies.

To assume that pollutants and contaminants are the same, as is sometimes done, can and usually is highly wasteful of public and private funds in "water pollution" management programs. This will be especially true as attempts are made to control pollutants from non-point sources. In order to determine whether a contaminant is a pollutant it is necessary to have a good site-specific understanding of the aquatic chemistry and toxicology of the contaminant of concern.

Every chemical is toxic to aquatic life and man at some concentration and duration of exposure. The primary issue in water **pollution** control from stormwater runoff is the evaluation of the concentrations the contaminants that are, because of their chemical forms, in the runoff impacting the designated beneficial uses of the receiving waters for the discharge. Paulson and Amy (1993) have suggested that thermodynamic models, such as the US EPA's MINTEQ model, can be used to determine the toxic forms of contaminants in stormwater discharges. However, Lee and Jones-Lee (1993g,h) have pointed out that such an approach is not technically valid and will, in general, greatly over-estimate the toxic forms of contaminants, such as heavy metals, in stormwater runoff.

Pollutant Trading

As part of developing the watershed management approach there is discussion of "pollutant" trading, where one source of pollutants could be controlled to a greater degree than required based on allowed total maximum daily loads (TMDL) thereby enabling another source of the same contaminant to control the contaminant to a lesser degree. As discussed by Lee and Jones-Lee (1992b) this approach should be implemented where it can be shown that each of the sources of contaminant which are to be traded contribute contaminants in the same specific chemical forms to the overall waterbody of concern so as to enable an improvement in the designated beneficial uses to develop to the same degree based on the control of the contaminant from either source to the same degree. This situation will almost never occur for potentially toxic contaminants such as heavy metals, organics and other contaminants from point and non-point sources. It is highly unlikely that it will ever be possible to reliably trade pollution loads between point and non-point sources because of the differences in the chemical forms/impacts of most contaminants from these two types of sources.

Another potentially significant problem with pollutant trading is that pollutants may adversely impact waterbodies in two overall ways; near the discharge and in the overall waterbody. Pollutant trading as it is being discussed today does not adequately consider localized adverse impacts near the discharge point on the beneficial uses of the waterbody. Local impacts on large waterbodies can be quite significant to the public that utilizes the beneficial uses of the waters near the point of discharge.

San Francisco Bay Copper Management

One of the prime examples of an inappropriate regulatory approach for point and non-point sources of a contaminant is occurring today for the regulation of copper inputs to San Francisco Bay. The San Francisco Regional Water Quality Control Board with the concurrence of the US EPA Region IX has locked the people of northern California into a massive waste of public and private funds in excess of $1 billion for the control of copper from point and non-point sources within the San Francisco Bay watershed. First, as discussed by Lee and Jones-Lee (1993b) the San Francisco Regional Water Quality Control Board or others have yet to find, after extensive investigation, a real water quality problem in San Francisco Bay that is associated with the current copper discharges to the Bay. However, there are administrative exceedances of the highly over-protective water quality objective that was adopted by the State Water Resources

Control Board in April, 1991 and the water effects ratio based site-specific water quality objective developed for San Francisco Bay by the San Francisco Regional Water Quality Control Board in 1993. The Board followed the US EPA water effects ratio guidance which does not account for the most important reason (source chemical forms) for the need to develop site-specific water quality criteria and standards. The approach used assumes that all forms of contaminants, such as copper, are present in each of the sources of copper for the waterbody in the most toxic available form, i.e. the form that was used in the water effects ratio toxicity testing. This assumption would never be valid for any waterbody with multiple sources of a contaminant or for any single source over a period of time. The US EPA's current and proposed water effects ratio approach falls far short of what is needed to develop reliable site-specific contaminant loads/concentrations for waterbodies such as San Francisco Bay. The use of this approach can waste large amounts of funds. For San Francisco Bay the amount will be in excess of $1 billion unless the current approach adopted by the Regional Board is amended to more properly reflect the information available on aquatic chemistry and aquatic toxicology for copper from each source and within the Bay waters and sediments.

Rather than addressing the fundamental problem of the use of inappropriate standards (objectives) for copper in San Francisco Bay, the San Francisco Bay Regional Water Quality Control Board chose to adopt *arbitrary* TMDL's for copper from all point and non-point sources, including the riverine source of the Sacramento River and its tributaries. The Regional Board acknowledges that it does not understand the relationship between copper load in San Francisco Bay from various sources and the administrative exceedances of the copper concentrations in the San Francisco Bay waters. It is the Board's position that if the initial TMDL's do not achieve the water quality objectives within a specified time period, more restrictive TMDL's will be adopted where all discharges will face a ratcheting down of their copper loads to the Bay. This Board, however, has chosen to ignore the fact that the sediments in San Francisco Bay contain sufficient copper so that during storms when the sediments are stirred into the watercolumn there will still be administrative exceedances of the water quality objective that has been adopted by the Board for the Bay waters. These exceedances will occur in perpetuity even if all external sources of copper for the Bay were eliminated. Stormwater dischargers to the Bay face spending over $1 billion in copper control programs which after spent will have no impact on the designated beneficial uses of San Francisco Bay waters.

Control of Stormwater Contaminants at Source

One of the major areas of concern in regulating urban stormwater drainage is the presence of a number of heavy metals in the stormwater runoff. Copper is one of the elements of greatest concern. Copper and many other heavy metals are present in urban stormwater runoff at concentrations considerably above US EPA water quality criteria. It has been found that one of the principal sources of copper is its use in brake linings/pads for automobiles. This has led some to call for copper source control by requiring that the manufacturers of brake linings/pads stop using copper where some other material will be substituted for the copper that is used today. Numerous studies have shown, however, that the heavy metals, including copper, in urban stormwater runoff are not a source of toxicity to aquatic life (see Mangarella, 1992). There are significant questions, therefore, about whether a voluntary or national ban on the use of copper in brake linings/pads is an appropriate BMP for stormwater discharges. While adoption of this approach would likely reduce some of the administrative exceedances of copper at some locations, such as for San Francisco Bay, it would not likely address any real water quality problems (use impairment) associated with the presence of copper in stormwater runoff. Further, since some other material will have to be substituted for copper, concern should be raised on the potential public health and environmental impact of the substitute material.

In formulating a non-point source contaminant control program, it is important to reliably evaluate the aquatic chemistry and toxicology of the contaminants that are to be controlled through BMP's. It is also important to understand that the current suite of structural BMP's, such as detention basins, grassy swales, etc., were not based on a technically valid assessment that their implementation would solve real water quality problems. A prime example of this situation is the use of detention basins where low flow stormwaters are retained in a basin for a period of time where large particulate forms of contaminants settle out. However, particulate forms of contaminants are generally non-toxic and non-available to aquatic life. Detention basins typically do not remove the soluble/toxic forms of contaminants.

If a receiving water has a problem due to siltation, i.e., accumulation of silt, that is adversely affecting its beneficial uses, then if the silt cannot be controlled at the source, a detention basin is an appropriate BMP for a stormwater runoff that contains large amounts of silt that adversely affects the receiving waters. The use of detention basins, however, to control chemical contaminants in stormwater that may be toxic is frequently technically invalid and is likely wasteful of public and private funds. It is totally inappropriate to include detention basins as a BMP where their performance is judged on how well they remove contaminants that only cause administrative exceedances of contaminants in receiving waters.

In October, 1993 the US EPA (1993a) changed its policy for regulating heavy metals in the nation's waters to "dissolved" metals. Since the 1980's the Agency had been recommending that its water quality criteria be implemented based on total recoverable metals. The total recoverable metals are the metals measured after strong acid addition in the analytical procedure. The Agency has repeatedly acknowledged that the previous approach is highly over-protective since it requires that non-toxic, non-available forms of metals, such as the particulate forms, be controlled to the same degree as toxic/available forms. Lee and Jones-Lee (1993c) have reviewed the development of water quality criteria for heavy metals and their implementation since the late 1960's. They point out that it has been since the late 1960's that total recoverable metals was not a valid basis for regulating heavy metals. The National Academies of Science and Engineering in their 1972 Blue Book of water quality criteria recommended against this approach and suggested that direct assessment of aquatic life toxicity using toxicity tests was the only reliable method available then, and for that matter still today, to determine if a heavy metal in an effluent or water is toxic.

The US EPA in their 1976 Red Book of water quality criteria adopted the National Academies' recommended approach. However, in the 1980's the US EPA changed from what was a technically valid approach for regulating heavy metals to the use of total recoverable metals based on the fact that total recoverable metals was easier to administer. Basically, those in the Agency responsible for this policy chose to use a bureaucratically simpler approach for administration over a technically valid approach. This has led to the widespread administrative exceedances of US EPA water quality criteria and state standards which are the basis for the US

EPA's 1992 Report to Congress that claimed that urban stormwater discharges needed to be regulated because they were "impairing" the designated beneficial uses of the nation's waters. Lee and Jones-Lee (1993a) have discussed the unreliable information that the US EPA provided to Congress which serves as a basis for developing the current national urban and industrial stormwater quality management program.

While the use of "dissolved" metals as now recommended by the US EPA for implementing its water quality criteria into state standards and NPDES discharge permits is a major step in the right direction since dissolved metals is much closer to toxic/available metals than total recoverable metals, dissolved metals will for most point source discharges of domestic wastewaters and non-point source discharges of urban stormwaters lead to over-regulation of heavy metals from these sources (see Allen, 1993, 1994 and Lee, 1994). Dissolved metals consist of a number of aquo, complexed and colloidal chemical species and forms, only a small part of which are toxic/available to aquatic life. This is especially true for copper in urban stormwater runoff.

The approach that should be used to regulate heavy metals and, for that matter, many other contaminants in urban stormwater runoff is to use dissolved forms of the contaminant (metals and others) as a trigger of potential water quality problems. If the concentrations of the dissolved forms exceed the US EPA water quality criterion, then the discharger should be provided the opportunity to conduct site-specific studies in the receiving waters for the discharge to determine whether the discharge is potentially contributing to an impairment of the designated beneficial uses of the waterbody. For example, if the concern is the potential for aquatic life toxicity in the receiving waters, then use aquatic toxicity tests with sensitive organisms to test the receiving waters to determine if the potential toxicity based on dissolved forms of metals and other constituents is, in fact, manifested in the receiving waters. Lee and Jones (1991) have provided guidance on how this evaluation should be made considering the relative durations of exposure that occur in standard toxicity tests compared to those that aquatic organisms could receive in the receiving waters for a stormwater runoff event. As they point out, finding toxicity in a stormwater discharge does not mean that there will be toxicity in the receiving waters for that discharge that adversely affects aquatic life. The toxicity tests that are typically used expose aquatic organisms for a much longer period of time than aquatic organisms can typically experience in a waterbody receiving urban stormwater discharges. Since the standard toxicity tests greatly overestimate the real toxicity in ambient waters, there is need to adjust the duration of exposure in the toxicity test to match the duration of exposure and chemical concentration profile that the organisms can actually receive in the receiving waters for a stormwater discharge.

Impact of Stormwater Discharges on Sediment Quality

The US EPA in their October 1, 1993 guidance governing the use of dissolved metals to implement US EPA water quality criteria indicated that if there was interest in protecting aquatic life associated with sediments from toxicity, that the heavy metal criteria should continue to be implemented based on total recoverable metals. Lee and Schwer (1993) have discussed the inappropriateness of continuing to use total recoverable metals as a basis for implementing US EPA criteria into state ambient water quality standards and NPDES discharge permit limits for effluents. There is widespread agreement among those familiar with this topic area that there is no technical justification today for continuing to use total recoverable metals for implementing

US EPA criteria to regulate municipal wastewater discharges or urban stormwater drainage. There is also general agreement within the US EPA and among others that sediment quality should be regulated based on site-specific evaluations of particular sediments using appropriate approaches. There is no way to reliably translate total recoverable metals in an effluent or in a watercolumn to potential water quality problems associated with sediment-associated contaminants.

The control of total heavy metals in an urban stormwater discharge through the use of detention basins will reduce the total heavy metal load to a waterbody and, therefore, the amount of heavy metals that accumulate in sediments. However, since there is no relationship between the total heavy metal load to a waterbody and the water quality impacts of the heavy metals, it is inappropriate to assume that the use of detention basins to remove heavy metals is justified based on protection of sediment quality. Small loads of dissolved forms of metals can ultimately cause greater sediment quality problems than large loads of particulate heavy metals.

Sediment Quality Criteria

At this time the US EPA and a number of states are developing sediment quality criteria that will be used to determine whether the sediments at a specific location contain contaminants in a toxic/available form that are adverse to the beneficial uses of the waterbody in which the sediments are located. There is, however, considerable controversy about the technical appropriateness of both the US EPA and the states' efforts in developing sediment quality criteria. A review of the approaches being used to develop sediment quality criteria is discussed below.

Equilibrium Partitioning

Several years ago the US EPA proposed to use what they call equilibrium partitioning as a basis for developing sediment quality criteria. As being implemented by the Agency, equilibrium partitioning assumes that there is a well-defined relationship between the concentration of contaminants in sediments as normalized by some factor which accounts for part of the sediment detoxification capacity and the concentration of the contaminant in the sediments interstitial (pore) waters. It is also assumed by the Agency that if the predicted "dissolved" concentration of contaminants in the pore waters exceeds the US EPA water quality criterion for the overlying waters, then the sediments will be adverse to aquatic life. For non-polar organics, such as some of the chlorinated pesticides and PAH's, the sediment concentration normalizing factor is the total organic carbon in the sediments. It is the Agency's position in their recently proposed sediment quality criteria (US EPA, 1993b,c) that a simple two compartment model can be used to predict the toxic effects of non-polar organics associated with sediments in which there is a partitioning between the dissolved organic and the organic carbon present in the sediments. Lee and Jones (1992) have reported on the inappropriateness of this assumption if it is to be used in the regulatory arena to determine which sediments are potentially toxic to aquatic life to a sufficient extent to adversely impact designated beneficial uses of a waterbody. Recently, the Division of Environmental Chemistry of the American Chemical Society held a 1.5 day symposium devoted to "Scientific and Regulatory Issues Associated with Sediment Contamination" that was held in San Diego in mid-March, 1994. There were over half a dozen papers presented in this symposium that discuss the inappropriateness of the US EPA's overly-simplistic approach in trying to develop sediment quality criteria based on equilibrium partitioning.

With respect to the PAH's, the partitioning that is found depends on the origin of the PAH, whether from petroleum or combustion processes. Further, it is now widely recognized that sediment interstitial waters contain large amounts of colloidal organics which interact (partition) with organic contaminants in much the same way as particulate organic carbon. The contaminants associated with the colloidal organics, however, are not toxic. The use of the octanol water partition coefficient to predict the partitioning of non-polar organics between sediment particulate organic carbon and the interstitial waters in which the colloidal organics present in these waters is ignored, results in a highly inaccurate estimate of the potential toxicity of the contaminants in the sediments. The US EPA's proposed approach for estimating the potential toxicity of non-polar organics in sediments based on equilibrium partitioning is unreliable and cannot be used as a regulatory tool without significant errors occurring.

Acid Volatile Sulfides

Another equilibrium partitioning based approach that is proposed for use for developing sediment quality criteria for heavy metals involves the measurement of the acid volatile sulfides and the simultaneously extracted metals in the sediments. It is assumed that if the molar sum of the non-iron heavy metals in the sediments exceeds the molar sum of the acid volatile sulfides in the sediments that the heavy metals in the sediments are free and therefore potentially toxic. If the sulfides exceed the heavy metals, then the metals would be precipitated as sulfides and would not be toxic. While that statement is true, the reverse is not necessarily true. As discussed by Lee and Jones (1992), there are a wide variety of mechanisms for detoxification of heavy metals in sediments besides precipitation of sulfides. The acid volatile sulfide normalization of heavy metal concentrations in sediments is not a reliable tool for evaluating whether heavy metals present in the sediment are potentially toxic to aquatic life and for developing sediment quality criteria.

Co-Occurrence Based Approaches

It has been known for 30 years that the total concentration of a contaminant in the sediment is not a reliable basis to judge potential impact on aquatic life or other beneficial uses of a waterbody. While there is no question about this conclusion, there are individuals who are still trying to develop sediment quality criteria based on the use of total concentrations of contaminants within the sediments. They attempt to justify this approach through the use of co-occurrence based reasoning, where the data for the concentrations of a contaminant are ranked in increasing concentration and some assessment of potential impacts of all of the contaminants present in the sediments on some biological parameter are used to determine the total concentration of the contaminant that is associated with an adverse impact. This has led to the Long and Morgan ERL and ERM values and the MacDonald PEL values as well as apparent effects threshold (AET) values. As discussed by Lee and Jones-Lee (1993d), all sediment quality criteria that are based on co-occurrence, such as the Long and Morgan values, the MacDonald values and state of Florida sediment screening values, are fundamentally flawed and unreliable for evaluating the potential for contaminants in aquatic sediments to be adverse to aquatic life since they are based on the total chemical concentrations of contaminants. The attempt to use total contaminant concentrations with co-occurrence with some kind of a biological response does not remove the fundamental flaw with this approach.

A number of the originators of the co-occurrence approaches (Long, MacDonald, and others at the recent ACS meeting in San Diego) are now attempting to justify the continued use of this approach by releasing papers that claim that the approach has high degrees of predictive capability. However, examination of the data upon which this predictive capability is allegedly based, leads to just the opposite conclusion. Where attempts have been made to utilize this approach for a new data set, it is generally found that it is a poor predictor of sediment impacts for the types of organism impacts that were used to develop the database. Co-occurrence based approaches are unreliable and should not be used for sediment screening or as sediment quality criteria.

Biological Effects-Based Approaches

Lee and Jones-Lee (1993e, 1994) have recently reviewed the relative merits of chemically versus biologically effects-based approaches for developing sediment quality criteria. They conclude that rather than trying to estimate using chemical methods whether sediments are toxic to aquatic life based on equilibrium partitioning or co-occurrence, it is far more reliable to measure the toxicity directly using several sensitive organisms in standard US EPA and Corps of Engineers sediment toxicity tests. Lee and Jones-Lee (1994) have recently summarized their experience and the literature on the approaches that should be used to evaluate whether contaminants in the sediment are adverse to aquatic life. They point out that there is no need to use unreliable chemically based approaches for developing sediment quality criteria, since reliable sediment toxicity testing approaches are available. There is an urgent need for studies that will relate the results of a sediment toxicity test to the water quality significance of sediment toxicity as it impacts the designated beneficial uses of a waterbody. There are many sediments that are naturally highly toxic to aquatic life that have high quality fisheries associated with them. Statistically significant sediment toxicity compared to a reference station should never be equated to mean that this toxicity is ecologically important or that it is of significance to the beneficial uses of a waterbody.

Permitting the Source of Stormwater Associated Contaminants

One of the stated purposes of developing sediment quality criteria is to regulate the sources of contaminants that are accumulating in sediments that are adverse to aquatic life to a sufficient extent to impair the designated beneficial uses of a waterbody. Except under extremely limited situations where a single discharger discharges to a limited body of water in which sediment toxicity is adversely affecting the beneficial uses of the waterbody, it will not be possible without a major research effort to determine the sources of contaminants for a sediment that are causing the toxicity within the sediment. As discussed above, not all sources of contaminants have the chemicals in the same form to adversely affect water quality in the watercolumn. Exactly the same situation occurs for particulate contaminants. The various forms of particulate contaminants that are discharged to a waterbody as well as those that are formed therein will have significantly different behavior within the sediments that affects the contaminants availability/toxicity. The copper derived from brake linings/pads will certainly have a different potential toxicity in sediments from the copper derived from its use as an anti-foulant on boat hulls. Both sources of copper may be non-distinguishable by the chemical analytical procedures used in sediment quality evaluation. There is little likelihood that regulatory agencies will be able to reliably determine whether a contaminant in a sediment derived from urban stormwater discharges, agricultural runoff and point source municipal or industrial wastewater discharges is the part of the copper that is responsible for the adverse impact without a major research effort. Such an effort will be necessary in most instances if technically valid, cost-effective approaches are to be used to control the source of contaminants that are accumulating in sediments and, as a result, are impairing the designated beneficial uses of a waterbody.

CA WRCB Sediment Quality Objectives

The State of California Water Resources Control Board has had a major effort under way for several years designed to try to develop sediment quality criteria. A staff report (WRCB, 1993) has recently been released on the current "Status of the Bay Protection and Toxic Cleanup Program." A number of groups, including the authors (see review by Lee and Jones-Lee, 1994), have commented on the inappropriate approaches being used by the WRCB staff for designating and ranking toxic hot spots within the state's waters and in the development of sediment quality criteria. The WRCB staff are using a number of co-occurrence and other unreliable bases for designating and ranking toxic hot spots. Further, they are attempting to use the geometric mean of equilibrium partitioning based, co-occurrence based AET and spiked bioassay results as a sediment quality criteria. Since all three of these components of the sediment quality criterion are unreliable, the geometric mean of them will also be unreliable. While the problems with this approach were brought to the attention of the Board when the Board staff first announced this approach two years ago, the Board chose to let the staff proceed even though several groups testified at the hearing that the approach that the staff had proposed was technically invalid. It is likely now too late to head off the WRCB ultimately adopting what are invalid approaches for developing sediment quality criteria in the state. This means that since urban stormwater discharges contain significant amounts of particulate chemical contaminants that will accumulate in sediments, the managers of the stormwater quality management program for municipalities and industry will almost certainly face significant over-regulation of the particulates in their stormwater discharges because of their accumulation in sediments. Further, in some instances stormwater management entities may face "Superfund"-like liabilities because the WRCB did not develop technically valid approaches for designation and ranking of toxic hot spots and sediment quality criteria.

Waterborne Pathogens

Urban stormwaters normally have high concentrations of sanitary quality indicator organisms such as fecal coliforms that at times have caused the closing of beaches for contact recreation. This approach is justified based on controlling various enteric diseases such as typhoid, giardiasis and cryptosporidiosis as well as a number of diseases caused by enteroviruses. Lee and Jones-Lee (1993f) have reviewed the public health significance of waterborne pathogens in domestic water supplies, reclaimed wastewaters and to a lesser extent, urban stormwater runoff. With respect to the latter, they point out that while there are known cases of typhoid fever having been acquired from contact recreation (swimming) in highly polluted waters that have received municipal wastewater discharges, typically there are few deaths and limited illnesses that can be attributed to waterborne pathogens associated with contact recreation in waters that contain somewhat elevated concentrations of sanitary quality indicator organisms, such as the coliform group.

It is now widely recognized that the coliform group is not a reliable indicator for the hazards associated with contact recreation in fecal (man and animal) polluted waters such as those associated with stormwater runoff. Lee and Jones-Lee (1993f) report on a major study conducted by the New Jersey Department of Health in an attempt to examine the relationship between the exceedance of indicator organism concentrations in the nearshore beach water and illness of the bathers who recreate in these waters. The waters that were being examined at several locations along the New Jersey coast were not highly polluted with domestic wastewaters during the time of the study. It may be concluded that exceedance of the sanitary quality indicator organism standards does not necessarily indicate that those who recreate in such waters will have a high probability of becoming ill. There is need to develop better contact recreation indicator organisms and standards for sanitary quality of beach waters that are impacted by urban stormwater runoff that do not receive combined sewer overflows where there is direct input of large amounts of inadequately treated domestic wastewaters to the nearshore waters of a waterbody.

Further Information

The authors have developed a short-course on stormwater quality issues that they make available at any location where a local sponsor will make arrangements for it. An outline for this course is attached. Further information on any of these topics, including back-up references, is available from the authors upon request.

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