DEVELOPMENT OF TMDL GOALS AND WET WEATHER STANDARDS FOR THE CONTROL OF HEAVY METALS IN URBAN STORMWATER RUNOFF[1]

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ABSTRACT

Studies on NPDES-permitted urban area and highway stormwater runoff have shown that the total and dissolved concentrations of several heavy metals – copper, lead, zinc, and frequently cadmium – are present in the runoff waters above US EPA worst case-based national water quality criteria. This situation can lead to violations of water quality standards at the point where the stormwater runoff enters a receiving water. Further, urban stormwater runoff-associated heavy metals can contribute to causing a waterbody to be listed as a Clean Water Act 303(d) "impaired" waterbody for which TMDLs will have to be developed to control the urban stormwater runoff discharge of heavy metals to the waterbody. The control of heavy metals in urban area and highway stormwater runoff so that their concentrations do not cause or contribute to violations of water quality standards in the receiving waters or TMDL discharge limitations will be expensive. This control will require the use of advanced wastewater treatment technology since conventional urban stormwater runoff BMPs such as detention basins are not effective in reducing the concentrations of heavy metals below worst case-based water quality standards. This paper discusses an approach to develop appropriate urban stormwater runoff heavy metal TMDL management goals and wet weather standards to protect the designated beneficial uses of waterbodies without unnecessary expenditures for heavy metal control.

KEYWORDS

Heavy metals, toxicity, water quality criteria, TMDL.

INTRODUCTION

The first step in developing an appropriate heavy metal TMDL control program as well as the development of site-specific wet weather standards is reliable monitoring of the stormwater runoff to insure that the analytical results reliably assess the total and dissolved heavy metal content of the runoff waters. "Clean" sampling and analytical procedures must be used for this purpose. Much of the data that has been generated on the concentrations of heavy metals in stormwater runoff and ambient waters overestimates the real concentrations present due to sample contamination during sampling and handling. The US EPA (1997a) has provided guidance on the analysis of heavy metals

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and other constituents with sufficient sensitivity and reliability to potentially develop reliable heavy metal data in stormwater runoff and ambient waters for the runoff.

If reliable sampling and analytical procedures show that the total and/or dissolved heavy metals are present in the runoff waters in excess of the US EPA worst case-based water quality criteria or state standards based on these criteria, then an assessment should be made of whether the exceedance of a criterion/standard represents an "administrative" exceedance in which the concentrations measured are above the standard, but this exceedance does not represent an actual impairment of the designated beneficial uses of the receiving waters for the stormwater runoff. Since copper, zinc, cadmium, lead, and nickel are of concern in stormwater runoff because of their potential to cause aquatic life toxicity, studies need to be done to determine if the stormwater runoff is toxic to a suite of sensitive toxicity test organisms. If toxicity is found then toxicity investigation evaluations (TIEs) should be conducted to determine the cause of the toxicity.

Studies of this type have been conducted at several locations in California in the San Francisco Bay region, Sacramento, Stockton and in Orange County. These studies have shown that the heavy metals in urban stormwater runoff from residential areas exceed US EPA worst case-based water quality criteria/state standards. These studies have also shown that urban stormwater runoff is toxic to fresh and marine water zooplankton *Ceriodaphnia* and *Mysidopsis*. TIEs conducted on this toxicity have shown that it is not due to the potentially toxic heavy metals in the stormwater runoff, but is due to the organophosphate pesticides diazinon and chlorpyrifos. Therefore, with respect to potential water column impacts, the exceedance of the heavy metal water quality criteria/standards in urban area street and highway runoff is an administrative exceedance that is not likely impairing the beneficial uses of the receiving waters for the stormwater runoff. Under these conditions it is appropriate to first modify the water quality standards for the heavy metals using US EPA (1994) guidance to develop a wet weather standard that will reflect the fact that the heavy metals in the urban stormwater runoff are in nontoxic forms. Further, even if the heavy metals in the runoff were toxic it is unlikely that aquatic organisms in the receiving waters would receive a critical exposure because of the short-term nature of the runoff event and/or the rapid dilution that occurs of the runoff water in the receiving waters.

Since the US EPA guidance for site-specific water quality criteria/standards does not adequately address the discharge of some forms of heavy metals which do not equilibrate during the time that the Water Effects Ratio (WER) toxicity tests are conducted, it can occur that US EPA guidance does not adequately adjust for receiving water characteristics and source forms of heavy metals that influence their toxicity. This situation has been found in San Francisco Bay where stormwater runoff from urban streets and highways causes the Bay waters to have concentrations of copper above WER adjusted criteria/standards yet the waters are nontoxic to aquatic life that are highly sensitive to copper. Under these conditions, as discussed by Lee and Jones-Lee (1995a), it may be necessary to work with elected officials to cause the US EPA to abandon its Independent Application Policy which requires that chemically based water quality standards must be achieved even though heavy metals, etc., are found through appropriate toxicity testing to be in nontoxic forms. This paper reviews these issues including evaluating potential sediment quality impacts from the discharge of particulate forms of heavy metals in urban stormwater runoff. The guidance provided in this paper is derived/updated from the Lee and Jones-Lee (1999a) expanded discussion of these issues.

REGULATORY ISSUES

The 1987 amendments to the Clean Water Act require that the US EPA develop a stormwater runoff water quality management program for urban areas, highways, industrial areas, construction sites and other areas. This led to the US EPA (1990) developing an NPDES permit system for urban area and highway stormwater runoff. Initially, the permit system applied to what are called "Phase I MS-4s," i.e., municipalities with populations greater than 100,000. The US EPA has expanded the scope of this program to include the Phase II municipalities and urban areas which can require stormwater management programs for populations on the order of 10,000 or greater. The US EPA's (1990) stormwater management program required that NPDES-permitted urban area and highway stormwater management areas control **pollution** to the maximum extent practicable (MEP) using best management practices (BMPs). The Agency did not define and has still not defined MEP and BMPs.

The US EPA has, however, determined that, ultimately, NPDES-permitted urban area and highway stormwater management areas must control the concentrations of constituents in the stormwater runoff so that they do not cause or contribute to violations of a water quality standard by any amount more than once every three years. While the time frame for compliance with this requirement has not been specified, recent US EPA actions in California, in connection with promulgation of the California Toxics Rule (CTR) (US EPA, 2000a), indicate compliance with the CTR water quality criteria in NPDES-permitted stormwater runoff at the point of discharge could be required within five years. As discussed by Lee and Jones-Lee (2000a) urban area street and highway stormwater runoff contains a variety of chemical constituents, such as heavy metals, certain organics, nutrients and pathogen-indicator organisms (coliforms) at concentrations in the discharge to receiving waters in excess of receiving water water quality standards. This, in turn, could require that the stormwater management agency control/treat NPDES-permitted urban area and highway stormwater runoff so that the concentrations of regulated constituents do not cause violations of water quality standards at the point of discharge to the receiving waters. In California and many other areas, urban area and highway stormwater runoff is not allowed a mixing zone, and, therefore, the application of water quality standards compliance to the discharge is in the discharge waters to the receiving waters.

Coincidentally with the implementation of the US EPA stormwater runoff water quality management program is the implementation of a total maximum daily load (TMDL) control of constituents in NPDES-permitted as well as non-permitted discharges that cause water quality standards violations that have resulted in the waterbody with the violation being placed on the US EPA Clean Water Act 303(d) list of "impaired" waterbodies. While urban area and highway stormwater runoff is typically considered a "nonpoint source" discharge, for the purpose of regulating stormwater runoff impacts, the US EPA determined that it is to be regulated as a point source discharge. It is, therefore, subject to TMDL requirements applied to domestic and industrial wastewater discharges. This means that, as being implemented now in California, if the receiving waters for an NPDES-permitted urban area and highway stormwater runoff are listed on the 303(d) list of impaired waterbodies for constituents that are in urban area and highway stormwater runoff above water quality standards at the point of discharge, the stormwater runoff managers can be required to manage stormwater runoff of the constituents in the runoff that cause or contribute to water quality standards violations. As a result, they can receive a TMDL "wasteload" allocation as part of the implementation of the TMDL program. Under these conditions, the BMP ratcheting-down process is waived in favor of the TMDL regulatory process, where compliance with regulatory standards can be required in accord with TMDL program implementation requirements. In California and in several other areas, heavy metals in NPDES-permitted urban area and highway stormwater runoff that are at concentrations above water quality standards in the runoff waters are subject to TMDL requirements for the control of the concentrations of these constituents.

Jones-Lee and Lee (1998a) and Taylor (1999) have discussed the fact that conventional BMPs will not treat urban stormwater heavy metals to achieve water quality standards. Presented herein is a discussion of how urban area and highway stormwater runoff water quality management agencies should proceed to comply with TMDL requirements for the control of heavy metals in urban area and highway stormwater runoff. This discussion is applicable to urban area and highway stormwater runoff water quality management agencies that, while not having to comply with TMDL requirements for the control of heavy metals, face, within possibly five years or so, having to meet essentially the same requirements in urban area and highway stormwater runoff in order to avoid causing or contributing to violations of water quality standards at the point of discharge to ambient waters.

MANAGING URBAN AREA STORMWATER RUNOFF WATER QUALITY IMPACTS

The key to developing a technically valid TMDL goal and site-specific wet weather standards for heavy metals in urban stormwater runoff is a reliable assessment of the impact of the heavy metals on the beneficial uses of the receiving waters. The current US EPA regulatory a approach of focusing on heavy metal concentrations relative to worst case-based water quality criteria/state standards based on these criteria tends to significantly over-regulate heavy metals in urban area and highway stormwater runoff. The US EPA provides some opportunity to adjust the worst case water quality standard for site-specific conditions. The development of an appropriate TMDL goal requires that the testing/evaluation be done to adjust the worst case-based criteria/standards to the characteristics of the source and the receiving waters. Presented below is a summary of the issues that should be considered in developing an appropriate water quality management program for heavy metals in urban area stormwater runoff.

Assessing Potential Water Quality Problems

Urban stormwater runoff contains elevated concentrations of a variety of constituents that, under certain conditions, may be adverse to the beneficial uses of the receiving water for the discharge/runoff. Of particular concern are heavy metals. Many of the constituents of concern in discharges/runoff are in particulate forms and, therefore, tend to accumulate in the receiving water sediments to cause these sediments to contain elevated concentrations of potentially toxic chemical constituents. As a result, there may be need to control both dissolved and particulate forms of chemical constituents in stormwater runoff in order to protect the designated beneficial uses of the receiving waters for the runoff.

The first step in developing an appropriate TMDL goal is to determine the impact of the existing runoff on the beneficial uses of the receiving waters. The mechanical comparison of the chemical concentration/characteristics of the stormwater to worst case-based water quality criteria/standards can lead to erroneous conclusions about adverse impacts of the constituents present in the stormwater runoff above water quality standards. The US EPA (1987) Gold Book criteria, as well as the 1999 (US EPA, 1999) updates of these criteria, are designed to be worst case, which would be protective of aquatic life and other beneficial uses under essentially all conditions. There are few waterbodies where the application of worst case-based water quality criteria as they are being implemented into discharge limits does not result in excessive treatment compared to that needed to protect beneficial uses.

Need to Incorporate Aquatic Chemistry. It is recognized that concentrations of constituents in the receiving waters above worst case-based water quality standards can readily occur in most waterbodies without significant adverse impacts on beneficial uses. There are situations, however, where an exceedance of a worst case-based criterion/standard represents a significant potential threat to the beneficial uses of a waterbody. A basic problem with using US EPA water quality criteria as discharge limits includes the failure to properly incorporate the aquatic chemistry of constituents into their implementation as state standards and NPDES discharge limits. It has been well known since the 1960s that many chemical constituents exist in a variety of chemical forms, only some of which are toxic/available. Further, ambient waters and their sediments contain a wide variety of constituents which detoxify/immobilize toxic/available forms of potential pollutants such as heavy metals, organics, etc. In general, it is not possible to reliably extrapolate from a concentration of a chemical constituent measured using standard chemical analytical procedures to the concentration of toxic/available forms in the receiving water. There are a wide variety of physical, chemical and biological factors that influence this extrapolation which are rarely quantified.

While the US EPA (1995) finally took the necessary action to focus the regulation of some heavy metals in ambient waters based on dissolved forms, even dissolved forms of some heavy metals in many waters tend to be over-regulated because the heavy metals interact with dissolved organic matter to form nontoxic/non-available complexes. Allen and Hansen (1996) have reviewed the importance of considering trace metal speciation in application of water quality criteria to state standards and discharge limits. The US EPA has not extended the regulations of heavy metals based on dissolved form to the many other constituents that occur in particulate or dissolved forms where the particulate forms are nontoxic and non-available. This leads to over-regulation of many organics that tend to sorb onto particulates in waterbodies.

Duration of Exposure. A key factor that is not properly incorporated into the application of US EPA water quality criteria and state standards based on these criteria is the duration of exposure that various types of organisms can experience without adverse impacts due to toxic/available forms of a constituent. The current regulatory approach involving no more than one exceedance by any amount every three years is well known to significantly over-regulate most chemical constituents in most waterbodies. It too is based on worst case assumptions that are rarely experienced.

The approach that has been adopted by the US EPA of basing the water quality criteria/state standards on a one-hour average or a four-day average concentration in the water of concern is more of the conservative nature built into these criteria/standards. The one-hour and four-day average criteria for acute and chronic criteria, respectively, are contrived for ease of implementation of a criteria/standard. They are not based on finding that an exceedance of a water quality criterion for acute and chronic toxicity above the criterion value necessarily represents toxic or available conditions.

Inappropriate Independent Application Policy. Yet another factor that makes the approach used for implementing US EPA water quality criteria into discharge limits is the US EPA's policy of independent application of the chemically-based criteria/standards, where these numeric values must be met even if properly conducted aquatic life toxicity tests show that the constituents of concern are in nontoxic/non-available forms. These issues were discussed by Lee and Jones-Lee (1995a). It is recognized that the appropriate approach for implementing US EPA water quality criteria involves the use of the criteria as a screen for potential adverse impacts, where the responsible parties for the discharge work with the regulatory agencies and the public in determining whether the exceedance of the criterion in a waterbody represents a real, significant use impairment of the waterbody. This approach has been discussed by Lee and Jones-Lee (1995b).

Need for Site-Specific Evaluation. A site-specific evaluation should be conducted to determine whether a particular discharge of stormwater runoff is significantly impairing the beneficial uses of the receiving waters for the runoff. An Evaluation Monitoring approach (discussed below) of the type developed by the authors (Lee and Jones-Lee, 1996a; Lee and Jones-Lee, 1997; Jones-Lee and Lee, 1998a) provides a technically valid, cost-effective procedure for evaluating the degree of treatment of stormwater runoff needed to protect the beneficial uses of receiving waters.

The Evaluation Monitoring approach shifts the emphasis in water quality evaluation and management from a chemical concentration-based approach to a chemical impact-based approach. For example, rather than focusing on the concentration of a potentially toxic heavy metal or organic and then trying to extrapolate from the concentrations measured in stormwater runoff or ambient water, Evaluation Monitoring screens for potential toxicity in the runoff and receiving waters using a suite of toxicity tests that utilize sensitive test organisms. If a discharge/runoff and the associated receiving waters are nontoxic, then it may be possible to rule out a large number of the chemical constituents which are regulated based on exceedance of worst case-based water quality criteria and state standards as a significant threat to the beneficial uses of the receiving waters for the runoff.

Similarly, for constituents that tend to bioaccumulate to excessive levels such as mercury in edible aquatic organisms, causing these organisms to be a threat to human health through their consumption, Evaluation Monitoring focuses on screening edible fish/shellfish to determine if excessive bioaccumulation is a real water quality problem in a waterbody. If the fish in a waterbody do not contain excessive concentrations of potentially bioaccumulatable chemicals (e.g., Hg), then it is possible to assess that the discharge of such chemicals in stormwater runoff does not lead to excessive bioaccumulation. If, however, excessive tissue residues are found then it is necessary to determine whether the discharge of these constituents is in a bioavailable form and remains in this form or converts to this form within the receiving waters for the discharge/runoff.

Summary of Approach. A review of existing water quality characteristic data for the stormwater runoff and the receiving waters should be conducted to determine if there is an exceedance of a heavy metal receiving water water quality standard that is caused or contributed to by the stormwater runoff. If an exceedance is found then determine if a real water quality use impairment (pollution) of the receiving water is occurring in the receiving waters for the stormwater runoff that is due to constituents in the stormwater runoff. The purpose of this effort is to determine if the stormwater runoff is causing or significantly contributing to real pollution of the receiving waters for the stormwater runoff. This approach will assess whether the exceedance of the water quality standard is an "administrative" exceedance relative to the highly protective nature of worst case-based water quality criteria/standards when applied to many constituents in most waterbodies.

If an inadequate database exists to determine if a violation of a water quality standard or a receiving water use impairment is occurring, then initiate a water quality monitoring/evaluation program designed to evaluate whether a real significant water quality use impairment is occurring in the stormwater runoff's receiving waters. Use the Evaluation Monitoring approach in evaluating whether a real significant water quality problem exists in the receiving waters for the runoff.

Addressing Administrative Exceedances of Water Quality Standards. If a water quality standard violation occurs without a significant use impairment of the receiving waters, then petition the regulatory agencies for a "variance" from having to meet water quality standards in the runoff receiving waters based on there being no use impairment occurring in the receiving waters due to the stormwater runoff-associated constituents. This effort will enable stormwater runoff water quality managers to reveal and appropriately address the over-regulation that arises from the US EPA's Independent Applicability Policy and the use of worst case-based water quality criteria/standards.

This effort should include the opportunity to adjust the receiving water standards (wet weather standards)/stormwater discharge limits and/or the designated uses of the receiving waters to protect the designated beneficial uses of receiving waters for the stormwater runoff without significant unnecessary expenditures for chemical constituent control. These adjustments should be based on appropriately conducted receiving water studies that focus on assessing chemical impacts, rather than the traditional approach of measuring chemical concentrations and loads. The US EPA (1994), in their Water Quality Standards Handbook provides guidance on how the worst case-based water quality criteria can be adjusted for site-specific conditions. It is important to understand, however, that the Agency's approach for developing site-specific criteria/standards can still lead to over-regulation since it does not fully account for the aqueous environmental chemistry of constituents as they may impact the beneficial uses of a waterbody.

Determining the Cause of the Pollution and the Source of the Pollutant. If a water quality use impairment is found in the receiving waters for the stormwater runoff, determine the specific causes of the use impairment and, through forensic studies, whether the toxic/available form of the specific constituent(s) responsible for the use impairment is derived from the stormwater runoff of concern. Also determine the relative significance of the stormwater runoff versus other sources of the specific constituents responsible for the use impairment as a cause of the use impairment. The relative contribution information is needed to evaluate the potential improvement in the receiving water water quality as a result of implementation of the proposed BMPs.

Managing Contaminated Sediment Quality Issues

The aquatic sediments near points of urban area and highway stormwater runoff can contain elevated concentrations of a variety of chemical constituents that are potential pollutants that have been derived, at least in part, from stormwater runoff. Increasing regulatory attention is being given at the federal and state level to managing the water quality impacts of chemical constituents in aquatic sediments. This is leading to the development of an aquatic "Superfund" - aquafund-like program in which principal responsible parties (PRPs) are being designated to pay for contaminated sediment remediation. Further, the NPDES wastewater and/or stormwater discharge permits for suspected sources of the constituents that are present in the sediments at elevated concentrations are being modified to reduce the input of the associated constituents. The California Water Resources Control Board (WRCB, 1998) has adopted the Bay Protection and Toxic Hot Spot Cleanup Program Policy that implements a California aquatic sediment aquafund. Lee and Jones-Lee (1998b) have discussed the significant technical problems with the BPTCP toxic hot spot cleanup Policy. This Policy, as adopted, will lead to inappropriate designation of toxic hot spots and the naming of PRPs for their remediation.

Reliable Evaluation of the Water Quality Significance of Chemical Constituents in Aquatic Sediments. There is considerable misinformation on how to reliably evaluate whether a chemical constituent or group of constituents present in an aquatic sediment are significantly impairing the beneficial uses of the waterbody in which the sediments are located. There are basically two approaches being advocated. One of these is a chemical concentration approach in which an elevated concentration of a chemical constituent that at some locations and under certain conditions is in a form that is adverse to the organism assemblages present within or on the sediments. The other is a biological effects-based approach which focuses on measuring chemical impacts rather than chemical concentration.

There are situations where constituents in sediments that are of concern because of their potential to bioaccumulate to excessive levels in higher trophic level edible organisms (fish and shellfish) serve as important sources of hazardous chemicals in fish that are used as food. There are also situations where the elevated concentrations of potentially toxic or bioaccumulatable chemicals in sediments are in nontoxic non-bioavailable forms. It is well established since the 1960s that there is no relationship between the concentrations of chemical constituents in sediments and their toxicity/availability for bioaccumulation. As discussed by Lee and Jones-Lee (1993a, 1994, 1996b, 2000b), the toxicity/availability of chemical constituents in aquatic sediments is determined by the concentration of many of the bulk parameters of the sediments such as TOC, sulfides, carbonates, clays, iron and aluminum oxides, etc., that interact with the potential pollutants to cause them to be nontoxic. The US EPA has recently released guidance for bioaccumulation testing and interpretation for the purpose of sediment quality assessment (US EPA, 2000b).

Some regulatory agencies at the federal and state level such as the US EPA (Keating, 1998), have adopted or are in the process of adopting sediment quality guidelines based on co-occurrence based approaches. Since this approach involves relating the total concentration of a chemical constituent in sediments to a water quality impact, co-occurrence based guidelines are technically invalid. Lee and Jones-Lee (1993a,b; 1996b,c), as well as many others such as O'Connor (1999a,b) have discussed the unreliability of co-occurrence based guidelines. O'Connor (1999a) based on a critical review of the NOAA and US EPA data concluded, "*All these criteria are better than random selections in identifying toxic sediment but they are not reliable. They are all more often wrong than right and should not be used, by themselves, to imply anything about biological significance of chemical data.*" Co-occurrence based sediment guidelines are unreliable and should not be used even as screening values to infer that a concentration of a chemical constituent in aquatic sediments is responsible for any water quality impacts that may be associated with those sediments. Such an association can readily lead to erroneous conclusions on the chemicals responsible for aquatic life toxicity and the sources of those constituents.

Specific Components of Suggested Approach. The approach that can be followed in evaluating whether elevated concentrations of a heavy metal in stormwater runoff that accumulate in sediments represent a potential cause of water quality impairment in the receiving waters and, therefore, should be subject to TMDL limitations, includes the following.

Aquatic Life Toxicity

- Determine if the sediments are toxic using several sensitive test organisms and several appropriate toxicity test reference sites. Conduct toxicity tests at at least three sites in the area of concern quarterly for a year.
- If the sediments are toxic, determine if the aquatic life assemblages associated with the toxic sediments are significantly different from those present in the reference areas as well as nearby apparently less impacted sediments than those of primary concern.
- Determine if there is an aquatic organism assemblage gradient that is apparently related to toxicity in the sediments of concern.
- If there is a significant aquatic organism assemblage gradient that persists for an extended period of time that is apparently related to toxicity of the sediments of concern, evaluate the water quality significance of this toxicity. Also evaluate the potential improvement in the designated beneficial uses of the waterbody if the toxic sediments were remediated.

  It is important to note that this evaluation program has not thus far included any attempt to determine the cause of the sediment toxicity.

- Reliably evaluate the potential cost of sediment remediation.

- If sediment toxicity appears to be a significant cause of a water quality use impairment and it appears to be economically feasible to remediate the contaminated sediments to eliminate the sediment toxicity, then proceed with evaluation of the cause of sediment toxicity.
- Conduct sediment chemistry/toxicity investigations (sediment TIE's) to determine the constituents that are in the sediments that are responsible for the toxicity.
- Do not use co-occurrence based sediment quality guidelines to "associate" the presence of chemical constituents in aquatic sediments with constituents that are toxic to aquatic life that cause significantly altered organism assemblages.

Excessive Bioaccumulation

- Determine if edible fish/shellfish from the waterbody preferably in the area of concern contain excessive concentrations of potentially hazardous chemicals that would cause the use of these fish as food to be a threat to human health. US EPA (1997b) provides guidance on conducting bioaccumulation investigations. Use a human health based guideline consumption rate of one meal of local fish per week. Evaluate if this consumption rate is appropriate for local populations that are consuming the fish from the waterbody of concern.
- Determine the chemical characteristics of the sediments twice per year (late spring and fall).
- Determine the concentrations of the suite of heavy metals, PAH's, chlorinated hydrocarbon pesticides, PCB's and dioxins. Analyze the sediments for those chemical constituents that have been found to be present in excessive concentrations in edible fish taken from the waterbody.
- If the sediments of concern contain elevated concentrations of constituents that have accumulated in edible aquatic life tissue to cause the use of the aquatic life as food to be considered a threat to human health, utilize the US EPA/COE (1991, 1998) procedures to assess the bioavailability of the constituents of concern in the sediments. Also, measure the tissue concentrations of benthic invertebrates taken from the sediments of concern to determine if they have elevated concentrations of mercury for those situations where mercury has bioaccumulated to excessive levels in fish within the waterbody.

This information should be used to determine whether the elevated concentrations of chemical constituents that are potentially bioaccumulatable in a sediment are contributing to the excessive bioaccumulation problem within organisms taken from the waterbody in which the sediments are located.

Forensic Source Studies

In order to control the development of future contaminated sediments and water column toxicity/ bioaccumulation problems, it is necessary to reliably define the source(s) of the constituents that have been and/or could be causing water quality problems. In some situations this is relatively obvious, in that there is a single discharger, that is isolated from all other sources of the same types of constituents of concern responsible for the sediment or water column toxicity or excessive bioaccumulation. However, in many situations, such as in bays or in major urban industrial areas, there will be multiple discharges/sources of the same general types of constituents that are causing the water quality problem. Under these conditions it is necessary to conduct a reliable forensic study to determine the specific source(s) of the specific constituent(s) responsible for the adverse impact on water quality.

This type of study should not follow the approach recommended by the California Water Resources Control Board (WRCB, 1998) in their Bay Protection and Toxic Cleanup Program (BPTCP) Toxic Hot Spot Policy of using elevated concentrations of constituents in the sediments to define the constituent(s) responsible for the toxic hot spot (toxicity source or source of the bioaccumulatable chemicals) in which a source of the elevated concentrations of the constituents is any discharger that has the same constituents in the discharge as were "associated" with the toxic hot spot. Such an approach is obviously technically invalid in that it ignores the aqueous environmental chemistry of chemical constituents that controls the toxic/available forms of potential pollutants.

It is understood by those with an elementary knowledge of aquatic chemistry/toxicology that all copper from all sources in all waterbodies is not equally toxic. The same situation applies to many other constituents. While tentative sources of potential pollutants can be identified through association based on elevated concentrations, detailed site-specific investigations must be conducted to confirm that a potential source is in fact a real source of pollutants whose stormwater NPDES permit or discharge limits should be modified to control the input of pollutants.

These forensic studies must include detailed consideration of the aqueous environmental chemistry of the constituents of concern within the waterbodies of concern to determine whether a particular discharge of a potential pollutant of concern is toxic/bioavailable at the discharge and/or converts to toxic/bioavailable forms within the receiving waters for the discharge that accumulate/are present at sufficient concentrations to cause a water quality use impairment at the point of concern.

When there are multiple sources of potentially significant constituents, then an attempt to quantify the relative contributions of each source should be made. Again, this should not be done based on a total concentration mass load approach. As discussed by Lee and Jones-Lee (1996d), it should be based on a site-specific evaluation of the aqueous environmental chemistry/toxicology of the constituents derived from each source.

Selection and Economic Evaluation of BMPs

Select a BMP(s)/treatment process(es) to control the specific constituents responsible for the use impairment. The BMP/treatment process selection should be based on the specific chemical species that cause a water quality use impairment in the receiving waters rather than the total concentrations of the constituent. For example, focus the BMP on removing those forms of dissolved copper that are significantly adverse to beneficial uses in the receiving waters for the runoff rather than on total copper, much of which is in a nontoxic form.

Evaluation of Cost Effectiveness of a BMP(s) in Controlling Significant Pollution. If the development and operation of the proposed stormwater runoff BMP appears to be economically feasible, then estimate the potential improvement in the designated beneficial uses that will occur relative to the unregulated or under-regulated sources of the same pollutant(s) responsible for the use impairment. If the potential improvements in the receiving water's designated beneficial uses is limited compared to projected costs to eliminate the use impairment, then the community leaders, regulatory agencies, environmental groups and public groups that are interested in appropriate use of funds should be consulted to evaluate if the expenditures for stormwater runoff chemical constituent control is the best use of the funds potentially available to meet societal needs.

Evaluation of the Efficacy of the BMP(s). Evaluate the efficacy of the stormwater runoff BMP in controlling existing use impairments as well as preventing new use impairments. The traditional approach of measuring the removal of a chemical constituent(s) such a heavy metals across a structural BMP such as a filter, detention basin, etc., does not evaluate whether the BMP/treatment process causes an improvement in the receiving water's impaired uses. BMP/treatment process efficacy evaluations must be based on evaluating the improvements that the BMP/treatment process causes or, for new developments, is expected to cause in the receiving water beneficial uses. This will require site-specific studies of the impact of the development and operation of the BMP/treatment process on the receiving waters' beneficial uses for the treated discharge.

Detection of Future Stormwater Runoff Water Quality Problems

Develop an ongoing monitoring/evaluation program to search for subtle and new water quality use impairments. An important component of a properly developed and implemented stormwater runoff water quality management program is the funding of a stakeholder consensus-based monitoring/evaluation program to detect subtle water quality problems that were not detected in the initial search for real significant water quality use impairments. This program should be designed to detect new water quality use impairments that arise from the use of new or expanded-use chemicals that become part of stormwater runoff. The search for undetected and new problems should be repeated every five years to coincide with the NPDES permit cycle.

Watershed-Based Approach

The stormwater runoff BMP selection should be formulated/implemented on a watershed-based water quality management program in which the stakeholders for the management of the stormwater runoff water quality and the beneficial uses of the receiving waters and downstream waters for the stormwater runoff that could be impacted by the runoff, work together in a consensus-based approach to formulate, implement and evaluate the stormwater runoff water quality management program.

Funding of Site-Specific Evaluation

While some potential dischargers of chemical constituents that could be adverse to the beneficial uses of a waterbody assert that it is the responsibility of the regulatory agency to prove that their discharge has or is, in fact, causing pollution-impairment of the beneficial uses of a waterbody, the burden of proof for water pollution control is on the discharger rather than the impacted public/regulatory agencies. However, in adopting this approach it is incumbent on the regulatory agencies to carefully specify the conditions under which potential polluters are designated. Approaches such as those adopted by the California Water Resources Control Board in its BPTCP Policy (WRCB, 1998), in which "association" of elevated concentration of chemical constituents is used to designate a toxic hot spot, should be considered technically invalid since they can lead to frivolous designation of pollutants and/or responsible parties for contaminated sediment cleanup and NPDES permit modification.

It is important to understand that the adversarial regulatory system that exists today cannot tolerate frivolous designation of toxic hot spots. There are a number of examples where inappropriate designation of pollutants in sediments have been made using co-occurrence based approaches that cause the public to have to spend large amounts of funds cleaning up contaminated sediments under conditions where this expenditure will not result in an improvement of the beneficial uses of a waterbody. This type of situation has been discussed by Lee and Jones-Lee (1993b).

The implementation of higher quality science and engineering into water quality management will require a substantial increase in site-specific evaluations compared to the approach that is being used today to develop regulatory requirements for a particular discharge/runoff. In order to ensure that the funds needed to properly implement this more enlightened, technically valid approach are made available by the discharger, the discharger should be given the option of either complying with worst case-based chemical constituent control or complying with an appropriate assessment of the real impacts that chemical constituents in discharges/runoff have on the beneficial uses of a waterbody. Adoption of this approach would encourage dischargers, both public and private, to invest in appropriately conducted, watershed-based, stakeholder consensus developed receiving water evaluations in order to improve the cost-effectiveness of expenditures for water pollution control.

A Technically Valid Water Quality Management Approach - A Water Quality Triad

There is growing recognition that the current water quality regulatory approach, in which a single exceedance by any amount of a constituent for which there is a water quality standard more than once every three years, is a technically invalid approach for cost-effective water pollution control. The US EPA, as part of adopting this chemical concentration based approach in the early 1980s, opted for a bureaucratically simple to administer but obviously, then and today, technically invalid approach. While some of the Agency staff claim that this approach is highly successful, in fact, it is strongly contrary to the public's interests. In order to avoid massive waste of public and private funds chasing ghosts of problems associated with exceedance of a worst case-based water quality criterion/standard, there is need to elevate the quality of science and engineering to the current level of understanding of how chemical constituents impact aquatic life and other beneficial uses of waterbodies.

The water quality triad approach is evolving as a regulatory approach in which the current science and engineering can be incorporated into defining a real significant water quality use impairment and the approach that should be used for its control/remediation. A water quality triad evaluation of potential beneficial use impairments of a waterbody is based on a non-numeric, best professional judgement, integrated assessment of information on aquatic organism assemblages, toxicity, bioaccumulation and chemical information. It involves determination of the numbers, types and characteristics of aquatic life present in a waterbody relative to the habitat characteristics. It also involves an assessment of aquatic life toxicity to a suite of sensitive test organisms relative to appropriate reference controls, as well as the use of chemical techniques (toxicity investigation evaluations) to determine, through toxicity assessments on the fractionated sample, the chemical constituents responsible for aquatic life toxicity.

As discussed by Lee and Jones-Lee(1999b), the water quality triad should be implemented through a panel of experts in the topic area of concern, where this panel critically evaluates the adequacy of the current data/information base in defining a real significant water quality use impairment and the cause/source of the constituents responsible for the use impairment. If an inadequate database is available for a reliable evaluation, then the discharger(s) should work with the regulatory agencies and the public to develop the additional information needed. When this information is available it should be critically reviewed by the triad expert panel and a decision should be rendered by the panel on the magnitude of the water quality problem that exists, its significance to the public's interests and approaches with associated costs for its control/ remediation. This information should then be used by the regulatory agency to implement a technically valid, cost-effective water quality management program.

Addressing Disagreements Among Experts

The current regulatory approach is largely based on an adversarial approach, where proponents (dischargers, regulatory agencies, environmental groups, etc.) of a particular position support their position without discussing the technical weakness of the position. If those in opposition to the position have adequate funding, they hire consultants who will support their position. The regulatory board, which is typically composed primarily of lay members of the public, as well as the courts, are faced with trying to evaluate the technical merits of complex topics where there are what appears to them equal and opposite views/conclusions on issues. This situation frequently results in regulatory decisions being made which largely ignore current science and engineering that should be used to formulate public policy on a water quality management issue.

It is recommended (Lee, 1999) that a public interactive peer review of technical issues be conducted in order to resolve disagreements among experts, including the water quality triad panel members, on complex technical issues. By adopting a public interactive peer review process anyone who peer reviews a topic must be prepared to defend these reviews in a public arena where those who find that the reviews are inadequate have the opportunity to point out the inadequacies of these reviews under a situation where the review board has the opportunity to hear an exchange of discussion of issues and receive written documentation with appropriate references in support of positions by the parties involved.

The peer review should not be conducted by a single individual but should involve the development of a peer review panel consisting of at least three knowledgeable individuals. The selection of the peer reviewers for the peer review panel should be a public process where the peer reviewers are knowledgeable and will take the time to fully review the pertinent information on the topic. They should review not only the regulatory board staff's discussion on issues, but also the comments made by others on the lack of validity of the staff's approach as well as those of the project proponents and others who commented on the issues.

The peer review panel should present the preliminary results of their reviews in a public meeting where the public has the opportunity to question and comment on the adequacy of the review. The reviewers then should be given the opportunity to make revisions in their review based on any new information obtained and develop a final review which is then submitted to the Board where again the public would have the opportunity to comment on its adequacy. The peer reviewers should be adequately compensated for their time and expenses associated with the peer review process.

CONCLUSIONS

The development of TMDL goals to control heavy metals in stormwater runoff that exceed a water quality standard requires a detailed investigation of the water quality beneficial use impairment that is caused by the heavy metals for which a TMDL must be developed. This effort should lead to site-specific TMDL goals that will protect the beneficial uses without unnecessary expenditures for heavy metal control. The stormwater runoff BMP development approach recommended herein is designed to transform the development of stormwater runoff BMPs from the current technically invalid, non-cost effective traditional approach to one that incorporates current science and engineering information into water quality management. Adoption of this approach will enable stormwater runoff water quality managers to select, implement and properly evaluate the efficacy of stormwater runoff water quality BMPs that will cost-effectively address real water quality use impairments in the receiving waters for the runoff in a technically valid manner. It will also enable those responsible for managing public funds to do so in a technically valid, cost-effective manner.

ADDITIONAL INFORMATION

Additional information on these issues is available in the references listed below as well as in papers and reports developed by the authors that are available as downloadable files at the authors' website, www.gfredlee.com. These publications contain references to the work of others that is pertinent to the topics discussed.

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