ASSESSING THE DEGREE OF APPROPRIATE TREATMENT OF SHIPYARD AND DRYDOCK WASTEWATER DISCHARGES AND STORMWATER RUNOFF[1]

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June 1999

Abstract

Shipyards' and drydocks' (SYDD) wastewater discharges and stormwater runoff are currently being regulated to control the concentrations of chemical constituents in the discharges/runoff. The regulatory approach typically being used is based on worst-case assessments of the potential impacts of chemical constituents in the discharge/runoff as it may impact aquatic life in the receiving water column and sediments. This worst-case-based regulatory approach can readily lead to significant over-regulation, where SYDD are required to spend more funds in treating wastewater discharges and stormwater runoff than are necessary to protect the designated beneficial uses of the receiving waters for the discharges.

This paper presents an Evaluation Monitoring approach that will enable SYDD managers to work with regulatory agencies in assessing the appropriate degree of wastewater and stormwater treatment/management to protect designated beneficial uses of receiving waters without unnecessary expenditures. The focus of Evaluation Monitoring is on assessing the impacts of chemicals on aquatic life, and controlling these impacts in a technically valid, cost effective manner. This approach is significantly different from current regulatory approaches, which focus on chemical concentration control without regard to the aquatic chemistry/toxicology of the constituents of concern in wastewater discharges and stormwater runoff. Rather than measuring the concentrations of copper and then trying to extrapolate to aquatic life toxicity in the water column and sediments, Evaluation Monitoring focuses on using aquatic life toxicity tests to determine if the receiving waters for the wastewater discharge/stormwater runoff are toxic. If toxicity is found, the constituents responsible are identified and, through forensic studies, their source is determined.

An area of increasing concern to boatyard and drydock managers is the use of co-occurrence-based sediment quality guidelines to "assess" the water quality significance of chemical constituents in sediments in the vicinity of their facilities' discharges. Based on co-occurrence-based "sediment quality guidelines," boatyard and drydock owners are being named as responsible parties for toxic hot spot contaminated sediment cleanup in "Superfund"-like actions. The co-occurrence-based sediment quality guidelines imply that there is a relationship between total concentrations of chemical constituents in sediments and some biological effect. However, it has been well-established for over 30 years that there is no relationship of this type, and that the total concentration of a constituent in aquatic sediments is an unreliable predictor of biological impacts.

The Evaluation Monitoring approach for assessing the water quality significance of chemical constituents in sediments focuses on determining whether there is toxicity in the sediments, and, if toxic, its cause and the source of the constituents responsible. This approach provides a far more reliable assessment of past and current wastewater discharges/stormwater runoff-associated constituent impacts on water quality than currently-used approaches.

Introduction

The development of a wastewater treatment system and stormwater runoff water quality management program from SYDD should involve a detailed evaluation of the characteristics of the receiving waters for the discharges/runoff. The current approach for regulating wastewater discharges and the evolving approach for regulating stormwater runoff from SYDD is to require that the wastewaters/stormwater not cause or significantly contribute to exceedance of a water quality standard in the receiving waters for the discharge/runoff. Such an approach can result in large expenditures to construct and operate treatment works to achieve this level of constituent

1 To be published in Oceans '99 MTS/IEEE Conference proceeding session, "Treatment of Regulated Discharges from Shipyards and Drydocks," to be held Seattle, WA, September 13-16, 1999.

control, especially if it is applied to stormwater runoff associated constituents due to the large volumes that would have to be treated during major rainfall runoff events.

Definitions - Terminology

One of the major problems within the water quality management field is a lack of common understanding of water quality related terminology relative to regulatory requirements and appropriate evaluation of water quality. This lack of understanding, especially as it relates to developing technically valid, cost effective water pollution control programs, leads to over-regulation of wastewater discharges and stormwater runoff associated constituents for which there are water quality criteria/standards. It also leads to under-regulation of real significant water quality use impairments for the unregulated constituents for which there are no water quality criteria/ standards. It is important to use such terms as pollutant, pollution, water quality, water chemistry, etc in accord with legal and technically correct usage to eliminate the inappropriate characterization of a water quality evaluation situation. The adoption of the following terminology would significantly improve the technical quality and cost effectiveness of managing water pollution.

Pollution. Pollution is defined in the Clean Water Act as an impairment of the beneficial use(s) of a waterbody. Finding chemical constituents in elevated concentrations in the water column or sediments is not pollution unless these constituents are impairing the beneficial uses of the waterbody.

Water Quality. Water Quality should be assessed based on the characteristics of the water relative to the beneficial uses of the water. Water Quality is not, as frequently used, a list of chemical constituent concentrations. In order to reliably assess whether the concentration of a constituent impairs the water quality - use impairment of a waterbody, it is necessary to evaluate on a site specific basis whether the constituent is present in toxic/available forms at a critical concentration for a sufficient duration to be significantly adverse to aquatic life that are important to the beneficial uses of the waterbody.

Water Quality Assessment. A water quality assessment is an evaluation of the beneficial use impairment that is occurring, or could potentially occur, due to the presence of a particular chemical(s) or other constituent. It is not an assessment of the frequency of exceedance of a water quality standard.

Water Quality Standard Compliance. Water Quality Standard Compliance is based on an assessment of the frequency of exceedance of a water quality standard in ambient waters receiving the discharge/runoff. Such compliance does not ensure that the beneficial use of the waterbody is being protected or that significant over-regulation is not occurring.

Administrative Exceedance. An Administrative Exceedance of a water quality standard occurs when concentrations of a constituent are present in waters above the standard without adverse impacts to aquatic life and other beneficial uses. For example, non-toxic forms of copper are present in a waterbody above a water quality standard that is based on copper toxicity.

Excessive Bioaccumulation. Excessive Bioaccumulation of chemicals occurs when the tissue residue-body burden within edible aquatic organisms exceeds US EPA or FDA regulatory guidelines. It is not an elevated concentration of a chemical constituent relative to background or so-called “NAS” guidelines. As whole organism tissue residue guidelines are developed to protect higher trophic level fish/shellfish-eating birds and animals such guidelines may be used to evaluate excessive bioaccumulation.

Aquatic Life Adverse Impact. In order for a chemical constituent to be adverse to the beneficial uses of a waterbody, and therefore be a pollutant, it is necessary that the chemical constituent cause an altered number and/or types/characteristics of desirable forms of aquatic life.

Cause of Aquatic Life Adverse Impacts. The association of elevated concentrations of a constituent in water and/or sediments with aquatic life toxicity or altered organism assemblages is not a valid basis for assessing the cause of adverse impacts. Site specific studies involving assessing cause and effect must be used to determine if chemical constituents in water or sediments are responsible for aquatic life related adverse impacts.

Aquatic Chemistry. Aquatic Chemistry is the physical, chemical factors/reactions that control the distribution of chemical species that impact how a chemical affects water quality-beneficial uses. It includes the transport (advection and mixing) and transformations-reactions (kinetics and thermodynamics) that control the concentrations of chemical species in a waterbody.

Aquatic Chemistry is not a list of the concentrations of chemical constituents found in a water or sediment sample. Such a list is a chemical characteristic, not chemistry.

Toxic Hot Spot. A toxic hot spot should be defined as an area in which there is aquatic life toxicity that is significant to the beneficial uses of a waterbody. Further, a toxic hot spot is an

area which serves as a significant source of a bioaccumulatable chemical that is present in edible organisms at hazardous levels. A toxic hot spot should not be defined based on exceedance of a water quality standard or sediment quality guideline.

One of the designation criteria that is used in the California Water Resources Control Board's BPTCP Policy is the finding that the concentrations of constituents in a water or sediments exceed a water quality criterion/standard. With few exceptions, the water quality criteria/standards are based on worst-case assumptions. Using exceedance of a water quality criterion/standard as the basis for designating a toxic hot spot is obviously technically invalid and can lead to over-regulation.

Managing Wastewater Discharges and Stormwater Runoff from Shipyards and Drydocks

Presented below is a summary of the issues that should be considered in developing an appropriate water quality management program for wastewater discharges and/or stormwater runoff from shipyards and drydocks.

Potential Water Quality Problems

Shipyards and drydock facilities wastewaters and stormwater runoff may contain 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, oil and grease, and potentially toxic organics. 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 SYDD wastewater discharges and stormwater runoff in order to protect the designated beneficial uses of the receiving waters for these discharges/runoff.

Increasing attention is being given to requiring additional treatment of wastewater discharges from industrial/commercial facilities such as SYDD beyond the normal treatment that is typically practiced. This additional treatment can represent a significant increase in cost for managing wastewater associated constituents compared to that normally being spent today to meet the traditional treatment/discharge requirements.

Potential for Over-regulation

Traditionally, wastewater discharges from SYDD are regulated in accord with NPDES permits, which establish maximum concentrations of chemical constituents which are potential pollutants based on worst-case assumptions about the impact of the constituents on the receiving waters' beneficial uses. Application of this worst-case approach to wastewater discharges typically leads to increased cost of treatment compared to that needed to protect the designated beneficial uses of the receiving waters for the wastewater discharge. For stormwater runoff from SYDD, the increase in cost can be substantial, where large amounts of funds can be spent in developing and operating treatment works for which there would be little improvement in the beneficial uses of the receiving waters for the stormwater runoff.

This paper provides guidance on an Evaluation Monitoring approach that can be used to determine, on a site specific basis, the degree of treatment of SYDD stormwater runoff that is needed to protect the designated beneficial uses of the receiving waters for this runoff. While the focus of this paper is on stormwater runoff from SYDD, the issues and approaches discussed are, in general, applicable to managing wastewater discharges from these types of facilities, with particular reference to the need for additional treatment beyond the conventional treatment that is normally required.

Evaluation of Existing Water Quality Impacts

The first step in the development of treatment works for providing additional, beyond normal, SYDD wastewater discharges and for stormwater runoff is to determine the impact of the existing discharges/runoff on the beneficial uses of the receiving waters. The mechanical comparison of the chemical concentration/characteristics of the wastewater/stormwater to worst-case-based water quality criteria/standards can lead to erroneous conclusions about adverse impacts of the constituents present in the wastewaters/stormwater above water quality standards. The US EPA (1987) Gold Book criteria, as well as the 1995 (US EPA 1996) 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 over-regulate because the heavy metals interact with dissolved organic matter to form non-toxic/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 non-toxic and non-available. This leads to over-regulation to 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-based 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 non-toxic/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 or the residuals in a wastewater derived from SYDD are significantly impairing the beneficial uses of the receiving waters for the discharge/runoff. An Evaluation Monitoring approach (discussed below) of the type developed by the authors (Lee and Jones-Lee 1996a, 1997a, Jones-Lee and Lee 1998a) provides a technically valid, cost-effective procedure for evaluating the degree of treatment of wastewater discharges and 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 a wastewater discharge/stormwater runoff or ambient water, Evaluation Monitoring screens for potential toxicity in the discharge/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 non-toxic, then it is 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.

Similarly, for constituents that tend to bioaccumulate to excessive levels 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, then it is possible to assess that the discharge of such chemicals in stormwater runoff or wastewaters 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 from a SYDD is in a bioavailable form and remains in this form or converts to this form within the receiving waters for the discharge/runoff.

Similar kinds of screening approaches are used in the Evaluation Monitoring approach, where impacts of nutrients are screened based on excessive growths of algae or other aquatic plants in the receiving waters for nutrient discharges. Excessive fecal coliforms are screened through beach closures that are hydraulically connected to the discharge, etc. Lee and Jones-Lee (1997b) have provided a detailed discussion of the approaches that should be used in the implementation of the Evaluation Monitoring approach. Evaluation Monitoring is a far more technically valid, cost-effective approach for determining whether existing discharge/runoff associated constituents are significantly adversely impacting the beneficial uses of a waterbody.

Selecting Stormwater Runoff BMPs or Wastewater Treatment Approaches Based on Water Quality Considerations

While advanced wastewater treatment processes designed to remove specific constituents in order to achieve a desired concentration in the receiving waters are well established, the traditional hydraulic-based best management practices (stormwater runoff BMPs) design, which focuses on removal of some of the particulates in stormwater runoff, is not appropriate. As discussed by Jones-Lee and Lee (1998b), it is becoming increasingly recognized that particulate forms of heavy metals and other constituents in stormwater runoff are in non-toxic, non-available forms and therefore their removal in a conventional BMP will not necessarily improve receiving water quality-beneficial uses. The valid approach for selecting an appropriate BMP for controlling real significant water quality use impairment associated with stormwater runoff involves the following components. This same approach is applicable to determining the degree of additional treatment needed of wastewater discharges.

Review Existing Water Quality Characteristic Data for the Stormwater Runoff/Wastewater Discharges and the Receiving Waters

• Determine if there is an exceedance of a receiving water water quality standard that is caused or contributed to by the stormwater runoff or wastewater discharged by SYDD.

• Determine if a real water quality use impairment (pollution) of the receiving water is occurring in the receiving waters for the stormwater runoff/wastewater discharge that is due to constituents in the stormwater runoff/wastewater discharge. The purpose of this effort is to determine if the stormwater runoff/wastewater discharge is causing or significantly contributing to real pollution of the receiving waters for the stormwater runoff. This 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/wastewater 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/ wastewater discharge 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 variance should include the opportunity to adjust the receiving water 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/wastewater discharge, 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/wastewater discharge of concern. Also determine the relative significance of the stormwater runoff/wastewater discharge 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/advanced wastewater treatment.

Selection and Economic Evaluation of BMPs

• Select a BMP(s)/treatment processes 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 the non-toxic form.

Evaluate Cost Effectiveness of a BMP(s) in Controlling Significant Pollution

• If the development and operation of the proposed stormwater runoff BMP/wastewater treatment process 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/wastewater treatment chemical constituent control is the best use of the funds potentially available to meet societal needs.

Evaluate the Efficacy of the BMP/Treatment Processes

• Evaluate the efficacy of the stormwater runoff BMP/wastewater treatment processes in controlling existing use impairments as well as preventing new use impairments. The traditional approach of measuring the removal of a chemical constituent(s) across a structural BMP such as a filter, detention basin, etc. as well as wastewater treatment works 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 works 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 or wastewater discharges. 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 and wastewater treatment plant facilities upgrading should be

formulated/implemented on a watershed-based water quality management program in which the stakeholders for the management of the stormwater runoff/wastewater discharge water quality and the beneficial uses of the receiving waters and downstream waters for the stormwater runoff/wastewater discharge 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.

Managing Contaminated Sediment Quality Issues

The aquatic sediments near SYDD often contain elevated and sometimes greatly elevated concentrations of a variety of chemical constituents that are potential pollutants that have been derived, at least in part, from wastewater discharges/stormwater runoff from SYDD. 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 programs in which responsible parties 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 recently 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.

As discussed by Lee and Jones-Lee (1998a), there are situations where the discharge of hazardous chemicals in wastewaters and stormwater runoff to waterbodies causes significant water quality use impairments associated with elevated concentrations of chemical constituents in aquatic sediments. There are also many situations where elevated concentrations of chemical constituents in aquatic sediments that are potential pollutants such as heavy metals do not cause an impairment of a waterbody's beneficial uses. Because of the great cost of "superfund" aquatic sediment remediation programs, it is important to properly evaluate whether an elevated concentration of a chemical constituent in aquatic sediments represents a real significant use impairment that would justify the remediation of the sediments to remove the constituents that are causing the elevated concentrations.

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 concentrations.

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 non-toxic non-bioavailable forms. It is well established since the 1960's 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 (1992), Lee and Jones-Lee (1993a) and Lee and Jones-Lee (1996b) 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 non-toxic.

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, it is obvious that since this approach involves relating the total concentration of a chemical constituent in sediments to a water quality impact, that co-occurrence based guidelines are technically invalid. Lee and Jones-Lee (1993a,b,c, 1996b), 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 of sediment based 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.

Suggested Approach. The approach that can be followed in evaluating whether elevated concentrations of a chemical constituent represents a potential cause of water quality impairment include 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 over a year 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 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 (1997) 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 that 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, for that matter, 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, such as a boat yard or a drydock, 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 well 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 applied 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 NPDES permit or waste 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 (1996d), it should be based on a site specific evaluation of the aqueous environmental chemistry/toxicology of the constituents derived from each source.

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 the incorporation 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 bureaucratic simple to administer but obviously, then and today, technically invalid approach.

While the Agency management staff claim that this approach is highly successful, in fact, as discussed herein, 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.

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) would work with the regulatory agencies and the public to develop the additional information needed. When this information is available it would be critically reviewed by the triad expert panel and a decision would 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 would 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 will 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 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.

Summary

The stormwater runoff BMP/improved wastewater treatment process development approach recommended herein is designed to transform the development of stormwater runoff BMPs from the current obviously technically invalid, non-cost effective traditional approach to one that incorporates mid-1990s 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' web site, www.gfredlee.com. These publications contain references to the work of others that is pertinent to the topics discussed.

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