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Evaluation Monitoring as an Alternative to Conventional Water Quality Monitoring for Water Quality Characterization/Management

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Abstract

Conventional "water quality" monitoring frequently involves measuring a suite of chemical constituents at various locations at a fixed, somewhat arbitrary sampling frequency over a period of one year. The data is then compared to US EPA water quality criteria and/or state standards based on these criteria. Exceedance of the criterion values is judged to represent an "impaired" waterbody which requires corrective action to eliminate the exceedance. The US EPA has been using this approach to inform the public about the current state of water pollution control within the US through its biennial reports to Congress in which urban area and highway stormwater runoff associated chemical constituents is reported to be one of the primary causes of water pollution in the US. A critical review of the traditional water quality monitoring programs shows that it is not possible to reliably assess true water quality use impairments to aquatic life resources based on chemical concentration measurements. Further, exceedance of a water quality criterion in an ambient water is rarely a reliable indicator of real water quality use impairments of concern to the public. This paper presents an alternative approach to conventional water quality monitoring (Evaluation Monitoring) which focuses monitoring resources on defining the real water quality use impairments that are occurring in a waterbody associated with urban area and highway stormwater runoff. Emphasis is given to assessing chemical impacts rather than chemical concentrations or loads. An Evaluation Monitoring program is being applied to the Upper Newport Bay, Orange County, California and the Sacramento River watersheds.

Introduction

With increased attention being given to fully implementing the requirements of the Clean Water Act (CWA), especially for the control of "toxics," it is appropriate to examine the adequacy of today's conventional ambient water quality monitoring. The typical "water quality" monitoring program involves measuring a suite of chemical constituents and some biological indicator parameters on a fixed monitoring grid where samples are taken at a somewhat arbitrarily established frequency, usually based on funding available for a period of a year or so. At the end of this period, the collected data is examined with respect to exceedances of US EPA water quality criteria and state standards based on these criteria. If there are exceedances of the standards by any magnitude with a frequency of more than once in three years, the waterbody is considered to be "impaired" and it is supposed to be listed on the state's 303(d) list of impaired waterbodies. This listing sets off a regulatory process that ultimately leads to the establishment of total maximum daily loads (TMDLs) for the sources of the constituents responsible for the exceedance of the water quality standard.

While, for a number of years, the initiation of the TMDL process for the control of toxics was not implemented in accord with regulatory requirements, through litigation initiated by environmental groups, the US EPA is entering into consent decrees which require that TMDLs be established in the next few years to control the violations of water quality standards that are occurring in ambient waters. In California, the State and Regional Water Boards must develop over 1,400 TMDLs in the next 13 years, based on the recently adopted 303(d) list of impaired waterbodies. This situation is causing regulatory agencies, the regulated community and others to critically examine the adequacy and reliability of the water quality monitoring database that was used to establish the 303(d) listing. Frequently this database is based on a typical routine water quality monitoring program. Such programs, however, typically fall far short of providing the information needed to:

- define the real significant water quality use impairments that are occurring in the waterbody of interest,
- define the specific constituents responsible for the use impairment and the sources of these constituents, and
- serve as a valid basis for developing a TMDL based water pollution control program.

Basically, most of today's water quality monitoring programs are patterned after 1960s/70s programs designed to address BOD/TSS-type problems. This type of program is deficient in providing the information needed to define the water quality significance of potentially toxic regulated constituents such as heavy metals and organics, nutrients and sediment associated constituents, etc.

A common, highly significant error that is made by many of those who work in the water quality evaluation and management field is to assume that a table of chemical constituent concentrations represents an assessment of a waterbody's water quality. As discussed below, there is no way to reliably translate chemical concentration data to water quality-use impairment impacts. The typical water quality monitoring program conducted today, while often said to be generating "chemistry" information, generates some chemical characteristic information and largely ignores the information that has been developed in the aquatic chemistry field over the last 30 years on how chemical constituents impact water quality-beneficial uses that are essential to developing technically valid, cost-effective water pollution control programs. The net result is that TMDL programs are being developed today, at great cost to the public, that do not adequately or reliably cost effectively control real water quality use impairments of concern to the public, who must ultimately pay for the water quality management programs.

Deficiencies in Current Stormwater Runoff Water Quality Monitoring

In order to determine whether a chemical constituent at a certain concentration in stormwater runoff causes a water quality problem in the receiving waters for the runoff, it is necessary to understand how chemical constituents impact the designated beneficial uses of the receiving waters for the stormwater runoff. The factors that need to be considered in making this type of evaluation are listed in Table 1.

Without an adequate understanding of these issues, it is not possible to reliably estimate whether a potentially toxic heavy metal or other constituent present in runoff waters or in ambient waters is adverse to the aquatic life-related beneficial uses of a waterbody.

Aquatic life and most other designated beneficial uses are impacted by the concentration of toxic/available forms of chemical constituents in the immediate vicinity of the aquatic organisms and by the duration of organism exposure to the toxic/available form. This relationship has been described by Lee *et al.* (1982), Lee and Jones (1991) and Lee and Jones-Lee (1995a,b) and is presented in Figure 1. The stippled area on the figure is an area of adverse impact. If the concentration/duration of exposure relationship is outside of the stippled area, then there is no adverse impact on the aquatic organisms.

Duration of Exposure Issues. Of importance to assessing the water quality impacts of stormwater runoff is that, in most situations, the duration of exposure that aquatic organisms can receive associated with a stormwater runoff event is short-term and episodic. This means that elevated concentrations relative to worst case water quality criteria/standards of toxic/available forms of chemical constituents can be present in receiving waters for stormwater runoff without adversely affecting aquatic life. The US EPA water quality criteria, including the one-hour acute criterion, are not reliable for estimating critical concentrations of constituents in stormwater runoff that may be adverse to receiving water water quality. As discussed by Lee and Jones-Lee (1991, 1995a,b, 1998a), with few exceptions, the US EPA water quality criteria tend to significantly overestimate adverse impacts and therefore can lead to the unnecessary construction of structural BMPs for managing constituents in urban area and highway stormwater runoff.

Aquatic Chemistry Issues. Another component of basic information that must be available to relate chemical concentration data in stormwater runoff to water quality impacts in the receiving water is the concentration of toxic/available forms at the point of measurement in the runoff waters, as well as at the point of concern, i.e. in the sphere of influence surrounding an aquatic organism that could be impacted by the constituent. Figure 2 shows the general aquatic chemistry system that must be considered in translating the measured concentration of a constituent in runoff waters to a concentration of a constituent that adversely impacts aquatic life-related beneficial uses in the receiving waters. Many chemical constituents exist in several oxidation states which, in turn, determine their basic aquatic chemistry, i.e. the reactions which the chemical constituent enters into in the runoff waters and in the receiving waters determine the actual chemical species present. There are eight basic types of chemical reactions that a chemical in a particular oxidation state may enter into. Aquatic chemistry focuses on determining the kinetics (rates) and thermodynamics (energetics-positions of equilibrium) of the reactions that determine the chemical species that will be present in a particular waterbody, including the waterbody's sediments. It is the actual chemical species present that determines whether a potentially toxic chemical is toxic to aquatic life under a particular exposure scenario.

Stormwater Runoff Water Quality Impact Management

The current typical water quality monitoring program is an outgrowth of compliance monitoring for domestic and industrial wastewater discharges where there is interest in determining if these discharges contain chemical constituents at concentrations that violate NPDES permit conditions. However, as discussed by Lee and Jones (1991), and Lee and Jones-Lee (1995a, 1996b), the typical wastewater discharge compliance monitoring is not a reliable approach for monitoring the stormwater runoff from urban and rural areas with respect to defining what, if any, real water quality use impairments are occurring in the receiving waters for the runoff. In August 1994, the Engineering Foundation held a stormwater NPDES-related monitoring needs conference which focused on the current state of knowledge of the monitoring of urban area street and highway stormwater runoff for water quality impacts on the receiving waters for the runoff. Urbanos and Torno (1994), in an overview summary of the conference, discussed that little is known about the water quality impact of urban stormwater runoff-associated chemical constituents. They stated,

> *"If we are to acquire this understanding, we must stop wasting monitoring resources on the 'laundry list' type of monitoring encouraged or required by our current regulations. We must instead move towards well-designed and adequately funded national and regional scientific study programs and research efforts."*

The situation is not simply one of shifting urban area and highway stormwater runoff monitoring from edge-of-the-pavement, end-of-the-pipe monitoring to traditional receiving water monitoring. The traditional approach for such monitoring involves collecting a number of samples of receiving waters to determine their physical, chemical and biological characteristics. This is usually done on a more or less mechanical basis in which fixed-period sampling, such as once a month at a number of sampling stations, is conducted. At the end of the study period, the data that have been collected are examined for the purpose of attempting to discern water quality impacts caused by stormwater runoff-associated chemical constituents. Such programs frequently fail to provide reliable information on the water quality use impairments associated with chemical constituents in urban area and rural stormwater runoff.

The technically valid and cost-effective approach for managing real water quality use impairments (pollution) caused by urban area and highway, as well as rural area, stormwater runoff is to find real water quality problems in the receiving waters for the runoff, determine the specific cause of this problem(s), and develop site-specific source control methods to control the problem to the maximum extent practicable. The Evaluation Monitoring (EM) program discussed in this paper is specifically designed to develop this type of information. The EM program was developed to determine, on a site-specific basis, whether chemical constituents and pathogenic organisms in urban area street and highway stormwater runoff are significantly adverse to the beneficial uses of the receiving waters for the runoff. The EM approach shifts the emphasis in the monitoring of the receiving waters from chemical constituent monitoring to highly focused event based water quality problem indicator monitoring, that specifically addresses stormwater runoff events as sources of potential pollutants.

The importance of reliably defining the real water quality use impacts of urban area and highway stormwater runoff as part of developing water quality management programs can be understood from the high cost associated with applying current water quality management programs for domestic and industrial wastewater discharges to urban area and highway stormwater runoff. Herricks (1995), editor of the Engineering Foundation Stormwater Impact conference proceedings, stated,

> *"...best management practices need to be holistic, and that any control strategy needs to be a reasoned application based on scientific understanding, not rule of thumb practice."*

Davies (1995) reviewed many of the issues that need to be addressed in evaluating and controlling nonpoint-source stormwater runoff impacts. He stated,

> *"It is generally agreed that NPS* [nonpoint source] *problems are unique and complex, and they will not be resolved as easily as the relatively simple treatment and standard compliance approaches used in the PS* [point source] *program. NPS programs will require development and application of innovative and imaginative control strategies, and the program will cost much more than the PS program."*

The general conclusion from the conference was that there has been far too much use of rule-of-thumb/standard-practice approaches in stormwater quality evaluation and management. Rather, there is need to focus on finding real water quality problems and solving them in a technically valid, cost effective manner.

Roesner (1994), a session chair for the Engineering Foundation stormwater NPDES-related monitoring needs conference stated, as part of the closing session for this conference,

> *"Throughout the course of this conference, it has become increasingly apparent to me that the course we are taking with the NPDES stormwater permitting program is going to cost municipalities a lot of money, but is not going to result in any significant improvement in the quality of our urban receiving water systems."*

Jones-Lee and Lee (1994, 1998) have reviewed the ability of conventional stormwater runoff best management practices, such as detention basins, filters, etc., to treat urban area and highway stormwater runoff to ultimately meet current regulatory requirements of not more than one exceedance of any magnitude in the stormwater runoff every three years. They conclude that conventional BMPs will not treat urban and highway stormwater runoff adequately to meet these requirements. As Jones-Lee and Lee discuss, advanced wastewater treatment practices, such as reverse osmosis, ion exchange, activated carbon, etc., will need to be used to achieve the required degree of treatment to prevent causing violations of water quality standards by stormwater runoff associated constituents. The cost of retrofitting the Los Angeles urban area and highway stormwater runoff conveyance structures with this treatment is estimated to be on the order of $60 billion. Obviously, with these kinds of costs, it is essential that real, significant water quality use impairments be found through appropriately conducted water quality monitoring/evaluation programs.

The US EPA (1990) defined the goal of its urban stormwater runoff water quality management program as the control of **pollution** of waters through the use of best management practices (BMPs) to the maximum extent practicable. It is important, when considering the potential impact of chemical constituents in urban area and highway stormwater runoff, to not label chemical constituents "pollutants" unless there is reasonable evidence to indicate that a particular chemical constituent in stormwater runoff is, in fact, or has a significant potential to be, significantly adverse to the beneficial uses of the receiving waters for the runoff, i.e. causing pollution. With few exceptions, most of what are called "pollutants" in urban area and highway stormwater runoff are more properly labeled "chemical constituents." Typically, individuals working in the water quality field label chemical constituents "pollutants." However, legally, under the Clean Water Act, pollution is defined in terms of use impairments, and not chemical concentrations. "Pollution" should only be used under conditions where well-defined impairment of uses has been documented or can reasonably be expected. "Pollutants" are those chemical constituents that are responsible for pollution. It is technically wrong, and highly misleading, to call all chemical constituents "pollutants." This is especially true when developing management programs for urban area and highway stormwater runoff.

Evaluation Monitoring as a Framework for Water Quality Problem Identification and Management

Evaluation Monitoring as developed by Lee and Jones-Lee (1996a) shifts the water quality monitoring resources from measuring source and/or ambient water chemical concentrations and loads to assessing chemical impacts in the receiving waters, focusing on finding real significant water quality use impairment problems. Where significant water quality problems are found, Evaluation Monitoring focuses on determining their cause, and defining the sources of the constituents responsible. This approach was developed about four years ago by Lee and Jones Lee (1996a) associated with water quality studies in the Upper Newport Bay watershed in Orange County, CA. As discussed by Lee and Jones-Lee (1996a, 1997a,b,c), Evaluation Monitoring is a watershed-based, technical stakeholder-driven water quality problem definition and control program. It serves as the basis for addressing the overly protective nature of US EPA water quality criteria and state standards based on these criteria. It also serves as the basis for regulating chemical constituents for which there are no water quality criteria/standards, as well as those situations where US EPA water quality criteria exists, such as chlorpyrifos, that are not adopted by the states as standards.

The mechanical application of US EPA criteria as state ambient water quality standards will, for many if not most waterbodies, be overly protective. If there were an infinite amount of money that could be spent to control chemical constituents within a waterbody's watershed, then working toward a goal of achieving these criterion values would be appropriate, provided that there were not other significant social problems which needed funding. However, today, with a large number of social problems that need funds, and limited funding for water quality management, it is important to focus water quality management programs on solving real, significant water quality use impairments that significantly adversely impact the beneficial uses of a waterbody. Table 2 lists the typical water quality use impairments of concern to the public. The impairment of beneficial uses of a waterbody for aquatic life-related uses should focus on finding significantly altered numbers, types and characteristics of desirable forms of aquatic life, or cause aquatic organisms that are used as food to have excessive concentrations of hazardous chemicals in their edible tissue through bioaccumulation.

Basically, the EM approach focuses the monitoring resources available on determining what, if any, real water quality use impairments are occurring in the receiving waters for the stormwater runoff. This problem definition phase of the EM program is conducted as a cooperative effort among the stormwater quality management agencies, industry/commercial stormwater dischargers, point source NPDES permitted dischargers, highway departments, regulatory agencies, agricultural interests, the public and others interested in water quality and appropriate use of public funds. When real, significant water quality use impairments are found, then efforts should be directed to determining the cause(s)/source(s) of constituents/ materials that are causing the use impairment(s). Once the cause and source of the impairments have been defined, then efforts are directed towards controlling the water quality use impairment, preferably at the source through source control.

Some of the basic questions that need to be addressed in evaluating whether stormwater runoff-associated constituents from a particular area are adversely impacting the beneficial uses of a waterbody include:

- Is there significant toxicity in the receiving waters that is associated with stormwater runoff events that could be adverse to aquatic life populations in the receiving waters?
- Are there closed shellfish beds, swimming areas, etc. that could be impacted by stormwater runoff-associated pathogenic indicator organisms?
- Is there excessive algal/aquatic weed growth that could be stimulated by aquatic plant nutrients (nitrogen and phosphorus) in the stormwater runoff waters?
- Is there litter and debris that is derived from stormwater runoff?
- Do the fish and/or shellfish contain excessive concentrations of hazardous chemicals that could be derived from stormwater runoff?
- Is the receiving water for the stormwater runoff excessively turbid during a runoff event?
- Is there shoaling, burial of spawning areas, shellfish beds, etc. occurring in the receiving waters due to the transport of suspended sediment in the stormwater runoff waters?
- Is there an accumulation of oil and grease in the receiving waters that is either aesthetically unpleasing and/or adverse to aquatic life?
- Are domestic or other water supplies experiencing treatment problems, excessive costs, etc. due to stormwater runoff-associated constituents?

The initial phase of the EM program involves determining how each of these use impairments could be detected in the receiving waters for the stormwater runoff where they are listed as a designated beneficial use of a waterbody of concern.

For many of the impacts, such as impairment of drinking water raw water quality, excessive bioaccumulation, excessive suspended and deposited sediments, excessive pathogenic organism indicators, low dissolved oxygen, and aesthetic impacts from litter, debris, oil and grease, etc., it is possible, through direct measurements of the receiving waters at the point of concern, to determine if there is a use impairment. For example, for excessive bioaccumulation, collecting edible organisms from the receiving waters and determining whether the tissue contains excessive concentrations of hazardous chemicals is straightforward and can be readily accomplished. Similarly, excessive concentrations of pathogenic organism indicators on a particular beach or within a shellfish population is also readily discernible. Therefore, for most of the use impairments, direct measurements of the impairment are readily possible by selected sampling of the receiving waters at the point of concern.

One of the more important, but difficult to assess, water quality problems is toxicity to larval forms of fish and other small aquatic life, such as zooplankton, which serve as important food for higher trophic level organisms. While it is relatively easy to detect large-scale acute impacts to adult, large forms of aquatic life, such as is associated with a fish kill, detecting adverse impacts on smaller forms is difficult.

In order to do this, it becomes necessary to assess whether toxicity under standard test conditions is found in the receiving waters that is of sufficient magnitude, areal extent and duration to be significantly toxic to larval forms of fish and/or smaller forms of aquatic life, such as zooplankton which are key components of larval fish food.

Traditionally, water quality monitoring programs have focused on measuring the concentrations of a constituent and, if flow data are available, the load of the constituent passing a particular point and then try to extrapolate as to whether the constituent of concern at a particular concentration is adverse to the beneficial uses of a waterbody. Toxicity to aquatic life is one of the primary areas of concern for many chemical constituents. Evaluation Monitoring, rather than trying to extrapolate from chemical concentrations to toxicity, focuses on measuring toxicity directly and then determining through Toxicity Investigation Evaluations (TIEs) the cause of the toxicity and, through forensic analysis, its source. Similarly, rather than trying to extrapolate from chemicals that are potentially bioaccumulatable to excessive tissue residues, Evaluation Monitoring measures directly whether excessive bioaccumulation has occurred in edible organisms in the receiving waters and then where such problems are found, through forensic studies, determine the source(s) of constituents responsible. This is the approach that is being used to a considerable extent in the Sacramento River watershed first year monitoring through the implementation of the Evaluation Monitoring approach.

Development and Implementation of a Water Quality Monitoring Program

Far too often water quality monitoring programs are implemented without proper planning of the program prior to initiation of the sampling. As discussed by NRC (1990) and Lee and Jones-Lee (1992), the key to development of a credible water quality monitoring program is the appropriate definition of the objectives of the program and the characteristics of the waterbody being investigated that need to be considered in achieving these objectives. Lee and Jones-Lee (1992) have provided guidance on the issues that should be considered in formulating the basic components of a water quality monitoring program, including defining the objectives of the monitoring program and how reliably the objectives of the monitoring program are to be assessed, selection of sampling stations and approaches, selection and evaluation of analytical methods, the use of clean "non-contaminating" sampling and sample handling procedures, QA/QC, data storage and retrieval and data interpretation, etc.

The Evaluation Monitoring approach is more difficult to implement than the traditional monitoring approach since it requires a high degree of expertise in understanding how chemical constituents in runoff waters, or within a waterbody, impact the beneficial uses of the water. Further, and most importantly, Evaluation Monitoring is based on an event based highly directed selective sampling of the runoff and receiving waters, focusing on runoff events and their near term and long er term impacts on receiving water beneficial uses. By focusing the sampling on these events it is possible to more reliably determine whether chemical constituents in the runoff are potentially adverse to the beneficial uses of the waterbody.

Implementation of an Evaluation Monitoring Program

Lee and Jones-Lee (1997c) have provided detailed discussion of the approach that should be used to implement an EM program. A summary of some of the key issues that need to be considered is presented in this section.

Review of Existing Water Quality Characteristic Data. The first phase of the Evaluation Monitoring program should be devoted to a critical review of the existing database on the water quality characteristics of waterbodies and their tributaries. Based on this review, information gaps on current water quality use impairments of the type listed in Table 2 should be defined, and the monitoring program then focused on filling these gaps. The initial purpose of the data review would be to critically evaluate the reliability of the existing data and compile a credible database. Once this database has been compiled, a critical review of the reliable data should be conducted to determine what water quality problems have been potentially identified as well as confirmed through the existing database. This should then be presented to the watershed stakeholders for their review and comment. Associated with this presentation should be a discussion of the areas that need further attention, with specific recommendations on the kind of monitoring/evaluation program that should be conducted to fill the information gaps.

Once a comprehensive set of data from past studies, as well as from any current monitoring programs, has been collected and a report prepared on this database, then a stakeholder-developed consensus should be formulated on what real water quality use impairments exist in the various parts of waterbodies within the watershed of concern. When the water quality use impairment problems have been defined, then, if the cause of these impairments has not been determined, site-specific studies should be undertaken to determine the cause, i.e. the specific chemical constituents responsible for the use impairments.

A use impairment should be a designated beneficial use impairment of the waterbody that is perceivable by the public. Not included in this definition is an exceedance of a water quality standard/objective. The water quality significance of exceedance of a water quality standard/objective should be addressed as a separate issue, where specific studies are conducted to determine the relationship between the exceedance of the objective and the impairment of the beneficial uses of the waterbody of concern for the public. Also, specific evaluations should be made of the improvement in the designated beneficial uses of the waterbody that would accrue through controlling the input of the constituent responsible for the water quality objective exceedance to a sufficient extent to eliminate the exceedance so that it occurs no more than once every three years, i.e. current CWA requirements. The emphasis in defining the cause of the water quality problem should not be on the total constituent, such as total copper, cadmium, lead, etc., but on the specific forms of the constituent responsible for the toxicity, excessive bioaccumulation or other use impairment, such as available forms of nutrients that impact excessive fertilization of a waterbody.

When the specific constituents responsible for the use impairment have been identified, then through forensic studies, the specific sources of the constituents responsible for the use impairment should be determined. Again, the focus should not be on all sources of total copper or other constituents; it should be on those sources of copper, mercury, PAHs, etc. that are adverse to the beneficial uses of a particular part of the waterbodies in a watershed of concern.

Addressing Exceedances of Water Quality Criteria/Standards

An important component of a watershed-based water quality management program should be devoted to determination of what the exceedance of a water quality standard/objective means to the beneficial uses of a part of the watershed where the exceedance occurs and in downstream waters. The US EPA water quality criteria and state standards (objectives) based on these criteria assume worst-case or near worst-case conditions in developing the specific chemical numeric criterion values. The chemical constituents of potential concern are assumed to be in toxic/available forms and present in the vicinity of the organism for sufficient periods of time to cause chronic toxicity. The US EPA's regulatory approach, however, tends for many waterbodies, but not all, to over-regulate chemical constituents since many waterbodies contain constituents that detoxify or otherwise make unavailable, chemical constituents of concern. The US EPA water quality criteria were never intended to be implemented as mechanical, not-to-be-exceeded values. The US EPA site-specific criterion adjustment approach, such as the Water Effects Ratio approach, only partially adjusts for the aquatic chemistry of constituents in aquatic systems that impact their toxicity/availability. This approach does not allow adequate time for chemical equilibrium to be reached and fails completely to address the key issue of the impact of the form of the constituent of concern added to the waterbody on its toxicity/availability.

The current implementation approach of assuming that US EPA water quality criteria are appropriate state standards leads to significant over-regulation of most regulated constituents, i.e. those constituents for which there is a water quality criterion, for most waterbodies. This will certainly be the case for most watersheds. In some cases, much higher concentrations of constituents of concern than the water quality standard can be present without adversely impacting the designated beneficial uses of a waterbody. Today, any so-called "water quality" study of heavy metals and other potentially toxic chemical constituents that does not include aquatic life toxicity measurements as an integral component of the study is of little or no value in providing the kinds of information that is needed in a true water quality study. Aquatic life toxicity measurements must be the foundation of any credible water quality study where measurements of heavy metal or other potentially toxic constituents are being made. Similarly, a "water quality" study of mercury, without measuring edible fish tissue concentrations of mercury, is not a credible water quality study. This is the kind of study that is typically associated with compliance monitoring, which has been well known for many years to be of limited reliability in assessing water quality issues.

Detection of Subtle and New Water Quality Problems

A key component of the Evaluation Monitoring approach is a periodic review of the water quality characteristics of the waterbody of concern to determine whether the previous review failed to detect an incipient - unknown water quality problem as well as any new water quality problems that have developed since the last review due to the expanded use or new use of chemicals in the watershed that are adverse to the beneficial uses of a waterbody. It is suggested that a five year review cycle be used. This period of time is coincident with the duration of NPDES permits covering waste water and stormwater discharges. During this five year review, funds should be made available to examine the waterbody for more subtle water quality use impairments than were detected in the previous review.

Water Quality Significance of Aquatic Life Toxicity

Another issue that needs to be addressed as part of developing a water quality management program for a particular watershed or waterbody is the development of an approach for assessing the water quality significance of aquatic life toxicity of the type being found in many surface waters that receive some agriculture and urban stormwater runoff. Organophosphate pesticides such as diazinon and chlorpyrifos are being found to cause acute toxicity to *Ceriodaphnia* and some other forms of aquatic life. There is need to provide guidance on how to determine what represents excessive aquatic life toxicity within a particular waterbody that is adversely impacting the beneficial uses of the waterbody. As described by Lee and Jones-Lee (1998b) an expert panel should be appointed and provided with the necessary resources to formulate approaches that can be brought to the stakeholders that can be used to determine the water quality significance of toxicity to certain organisms at certain locations.

Once the overall guidance approach is defined, then site-specific application of this approach should be initiated for various parts of the watershed where toxicity has been identified and its magnitude, areal and volumetric extent, and duration is evaluated with respect to its potential significant to the beneficial uses of the waterbody. There will likely be need to conduct additional site-specific studies focusing on the relationship between the measured aquatic life toxicity in tributary waters and mainstem waters on aquatic organism assemblages within these waters. This type of information will ultimately become the key information needed to determine whether measured toxicity is a significant cause of a water quality use impairment at any location within a waterbody.

Formulation of Water Quality Management Programs

Once the true water quality problems have been defined and the source of the specific constituents responsible for the problem identified, then there is need to begin to formulate water quality use impairment management plans. As part of formulation of the potential water quality management plans, there is need to incorporate high-quality current science and engineering into determining the potential benefits of controlling the input of a constituent responsible for a water quality use impairment to a particular degree on the beneficial uses of a particular part of a waterbody. This determination should include consideration of impacts near the point of discharge/runoff (near field impacts) and on the overall beneficial uses of the waterbody (far field impacts). Typically today, water quality management programs for specific constituents in the current point source discharge management program, as well as for watershed based water quality management programs, are formulated without adequate incorporation of aquatic chemistry and aquatic toxicology information into the program. The mass load approach for managing water quality in a waterbody, which is based on total constituent loads, is an example of a technically invalid approach for formulating a watershed based water quality management program.

Not all sources of a constituent of concern contribute the constituent in toxic/available forms. Further, even the discharge of a toxic/available form in one part of a watershed does not lead to that constituent being toxic/available throughout the downstream waters. An example of this situation is copper in the Sacramento River system discharged by the Iron Mountain Mine in the upper part of the watershed. While there is toxicity due to copper near the point of discharge, this toxicity is rapidly lost in the Sacramento River system even though the total copper is still present at concentrations above water quality standards. It is inappropriate to assume that the copper present in the Sacramento River system which exceeds the copper water quality objective is adverse to the beneficial uses of all downstream waters associated with the exceedance of the objective. This issue has been reviewed by Lee and Jones-Lee (1997d).

While the Iron Mountain Mine contributes to the copper concentration that is part of the cause of the water quality objective exceedances that occur in San Francisco Bay, the San Francisco Estuary Institute (SFEI 1997) has published the results of the 1996 Regional Monitoring Program. This report indicates that after three years of monitoring which included toxicity testing using the same test organism as was used to develop the national as well as the San Francisco Bay site-specific water quality standard (objective), the exceedance of the copper water quality objective is not associated with aquatic life toxicity in San Francisco Bay waters or sediments.

Lee and Jones-Lee (1996c), discuss the importance of using current readily available science and engineering in identifying water quality problems in a watershed and for formulating technically valid, cost-effective control programs for these problems. As discussed, these control programs should focus on real, significant water quality use impairments and not divert the limited financial resources available to chasing ghosts of problems that arise out of overly protective approaches associated with the US EPA's ill-founded Independent Applicability Policy. This Policy requires that chemical specific numeric criteria/standards must be met for potentially toxic constituents, even though properly conducted toxicity tests show that the constituents are in non-toxic, non-available forms. For further discussion of the inappropriateness of this Policy, consult Lee and Jones-Lee (1995b, 1996d). As they discuss, from a watershed-based water quality management program approach, the US EPA water quality criteria should be used as a trigger to conduct further work to define the water quality significance of exceedance of a water quality objective.

Conclusion

The current water quality monitoring programs in which a suite of chemical constituents and selected biological indicators are measured periodically at selected stations in a waterbody is typically an unreliable approach for defining the water quality use impairments of a waterbody. This approach evolved out of waste water treatment plant discharge compliance monitoring, where the objective of the monitoring program is to determine whether there has been an exceedance of an NPDES permit condition. Such an approach relies on the use of exceedances of US EPA worst case based water quality criteria and state standards based on these criteria as a reliable measure of a water quality use impairment. However, with few exceptions, the exceedance of a US EPA water quality criterion is not a reliable basis for determining whether a real water quality use impairment of a waterbody of concern to the public. Also, this approach fails to address the water quality problems caused by those constituents for which there are no water quality criteria or for which states do not use the available water quality criteria as a basis for developing a water quality standard. The current US EPA approach for defining water quality use impairments based on exceedance of water quality standards is not a technically valid approach for developing the 303 (d) list of impaired waterbodies, and for formulating TMDLs. Through the use of this approach, the US EPA and state pollution control agencies are providing unreliable information to Congress and the public on the magnitude of the water quality use impairments of the nation's waters caused by urban area and highway stormwater runoff associated chemical constituents.

The Evaluation Monitoring approach shifts the monitoring emphasis from chemical concentrations and loads to chemical impacts - use impairments. This is a far more reliable approach for using the monitoring resources available for detection of real significant water quality use impairments than traditional water quality monitoring. With increasing emphasis being placed on managing the subtle impacts of potentially toxic constituents, it is essential, if the public funds are to be used wisely in controlling real significant water quality problems, that a significantly different approach be used to define water quality problems and to develop appropriate water quality management programs to control these problems in a technically valid cost effective manner.

Additional information on the implementation of the Evaluation Monitoring approach is available in the comprehensive guidance provided by Lee and Jones-Lee (1997c). This guidance, as well as the other papers and reports developed by the authors listed in the Literature Cited section, are available from the authors' web site, http://members.aol.com/gfredlee/gfl.htm.

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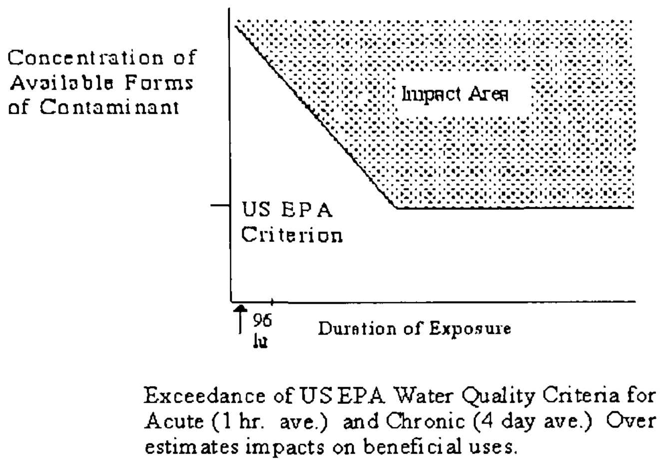

Figure 1. Aquatic toxicology.

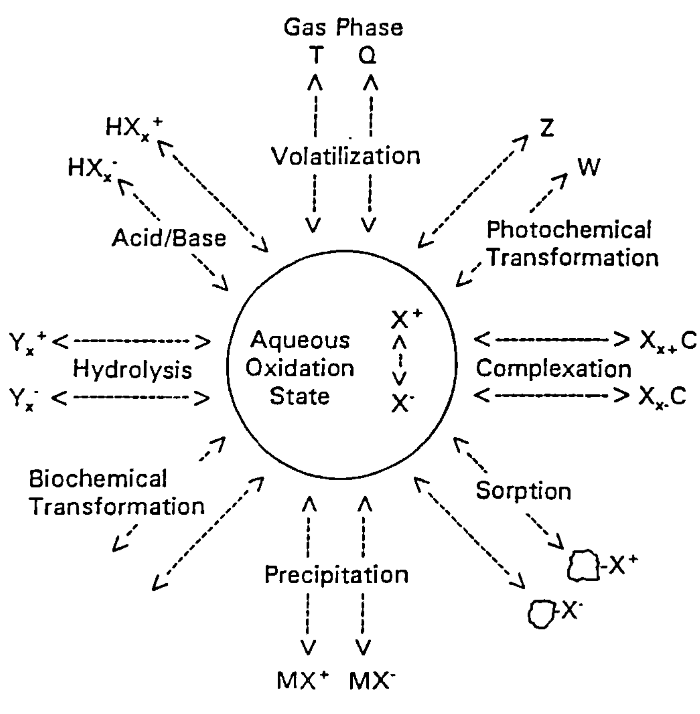

Figure 2. Aquatic chemistry of chemical contaminants.

Table 1. Factors that Must Be Considered in Translating Runoff Measured Concentrations of a Constituent to Potential Aquatic Life Water Quality Impacts

The information needed to determine whether a potentially toxic constituent causes an impairment of the beneficial uses of receiving waters for stormwater runoff includes the following.

Stormwater runoff

- measured concentration of constituent during runoff event - concentration time profile
- discharge of the runoff waters during runoff event - hydrograph
- analytical chemistry of the method used for analyses - what chemical species are measured

Receiving waters

- Physical factors:
  - Currents, tides - transport-advection
  - Mixing-dispersion
- Biological factors:
  - Duration of organism exposure to toxicant
  - Organism movement - locomotion
    - Diel migration
  - Sensitivity to toxicants
  - Organism assemblages - resident populations relative to habitat characteristics
- Chemical factors:
  - Aquatic chemistry
    - Kinetics and thermodynamics of reactions
    - Additive, synergistic and antagonistic reactions and impacts
  - Toxic/available and non-toxic, non-available forms
  - Background concentrations of constituents of concern

Table 2. Water Quality Use Impairments

- Aquatic life toxicity - water column,
- Sediment toxicity that impairs water quality - beneficial uses,
- Excessive bioaccumulation of hazardous chemicals,
- Dissolved oxygen depletion,
- Domestic water supply water quality,
- Groundwater recharge,
- Eutrophication - excessive fertilization,
- Sanitary quality impairment - contact recreation and/or shellfish harvesting,
- Suspended sediment impacts and accumulation,
- Oil and grease accumulation, and
- Litter accumulation.