Development and Implementation of Evaluation Monitoring for Stormwater Runoff Water Quality Impact Assessment and Management

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Executive Summary

This report covers the development and application of Evaluation Monitoring (EM) to highway and urban area street stormwater runoff water quality impact assessment and management. A discussion is presented on the need for an alternative approach to the conventional approach of evaluating the water quality impacts of highway and urban area stormwater runoff associated constituents on receiving water quality. Information is presented on the background to the development and application of site-specific studies (EM) that can be conducted on the receiving waters for stormwater runoff that identify real water quality use impairments in these waters that are caused by chemical constituents and/or pathogenic organism indicators in the stormwater runoff.

It is widely recognized that conventional stormwater runoff water quality monitoring provides little in the way of useful information that can be used to evaluate the impact of stormwater runoff on the beneficial uses of the receiving waters for the runoff. The Evaluation Monitoring program is designed to replace the conventional "water quality" monitoring programs that are used for measuring the chemical constituent concentrations in highway and urban area street stormwater runoff. The results of the EM program provides a technically valid, cost effective basis for water quality best management practice (BMP) development that replaces the conventional approach that is used to develop stormwater runoff water quality BMPs. The conventional BMP development approach assumes that detention basins, grassy swales, various types of filters, etc. are effective BMPs for controlling real water quality use impairments due to heavy metals, organics and other constituents in highway and urban area stormwater runoff. However, it is now well known that particulate forms of heavy metals and other constituents that are removed in conventional stormwater runoff BMPs do not adversely impact the beneficial uses of the receiving waters for the runoff. The paniculate forms of heavy metals and other constituents are in non-toxic, non-available forms. Therefore, their removal in a detention basin or filter will not be of benefit to the beneficial uses of the receiving waters for the stormwater runoff.

Basically, the EM program shifts the funds that are used for end-of-the-pipe runoff monitoring to site-specific, highly directed studies designed to find real water quality use impairments of the receiving waters for the stormwater runoff. When such use impairments are found that are due to highway and/or urban area street runoff, then site-specific BMPs are developed that control the input of the pollutants, i.e. those constituents that cause impairment of the beneficial uses of the receiving waters for the stormwater runoff, to the maximum extent practicable. The focus of BMP development is on source control which limits the amount of pollutants entering the highway and urban area street stormwater runoff at their source, rather than trying to treat the stormwater runoff. The EM approach is in accord with current regulatory requirements for highway and urban area street stormwater runoff water quality management.

The EM program is designed to be a cooperative program in which technical representatives of the stormwater dischargers, regulatory agencies and those concerned about the water quality use impairment of the receiving waters for the stormwater runoff work together to formulate a watershed based water quality management program to implement the EM program in the most technically valid, cost effective manner for utilization of the financial and other resources available.

This report focuses on providing general guidance to those wishing to implement the Evaluation Monitoring approach on how to determine whether a particular waterbody is experiencing water quality use impairments due to:

- 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.

It also provides information on many of the issues that need to be considered in evaluating whether a waterbody is experiencing water quality deterioration due to any of these use impairments. Additional information is provided in literature references. Guidance is also provided on determining the significance of aquatic life toxicity in impairing the beneficial uses of the waterbody and its cause through the use of toxicity investigation evaluation (TIEs).

Guidance on the use of forensic studies to determine the source of the constituents responsible for the water quality use impairment is provided. Further, information is provided on the development of site-specific BMPs that will control the water quality use impairment to the maximum extent practicable.

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Highway and Urban Area Stormwater Runoff Water Quality Monitoring

Overview of Problems with Current Stormwater Runoff Water Quality Monitoring

The approach that is typically used to assess the "water quality impacts" from urban area streets and highway stormwater runoff is to monitor stormwater runoff by collecting a few samples of runoff at the edge of the highway or from a storm sewer discharge from two to three storms per year and analyzing these samples for a suite of conventional potential pollutants, such as the heavy metals, petroleum hydrocarbons, polycyclic aromatic hydrocarbons (PAHs), nutrients--N and P, total solids, suspended solids, and enteric pathogenic organism indicators. The results from these analyses are compared to US EPA (1987) water quality criteria/standards that have been established by regulatory agencies for the runoff-receiving waters. If exceedance of a water quality standard is found in the receiving waters, then the waterbody is said to be "impaired," and efforts are made to control the chemical constituents and pathogenic organism indicators (such as fecal coliforms) in the highway and urban area street stormwater runoff through the use of BMPs to the maximum extent practicable.

The current monitoring programs serve the function of mechanically satisfying regulatory requirements for having a monitoring program. However, no assessment is made of the value of the monitoring program in providing reliable and useful water quality information that can be used in a meaningful regulatory program. While some stormwater quality management agencies spend money trying to analyze the data obtained from such programs using statistical techniques and/or using the data in so-called stormwater quality modeling, this data manipulation is a waste of money in developing meaningful water quality information.

The basic problem in stormwater runoff water quality monitoring is with the stormwater quality regulations developed by federal and state agencies. These regulations stipulate that a monitoring program must be developed and usually establish the minimum data collection that must occur. The regulations, however, provide no information on the quality-reliability of the stormwater runoff water quality monitoring program. This lack of guidance has led to the development of the current stormwater runoff water quality monitoring programs that have little or no utility in helping stormwater managers develop technically valid, cost-effective, true water quality control management programs.

Al-Kazily *et al.* (1995) have prepared a report for Caltrans concerning a review of stormwater runoff monitoring from Caltrans highways. In a discussion of the conventional stormwater monitoring approach, Al-Kazily *et al.* state,

"The disadvantage of this approach to the storm water runoff management program is that, lacking good information about the potential problems in a specific receiving water, the problem is presumed to exist and money may be spent unnecessarily."

They further state,

"Careful planning is important to ensure that known problems are tackled first while efforts are made to determine whether actual problems exist at other locations. The discharger is encouraged to prioritize efforts in both of these areas."

In using stormwater monitoring to assess the impact of receiving waters, Al-Kazily *et al.* state,

"Identification of adverse impacts on receiving waters should be a cooperative effort between the dischargers in each watershed; however, coordination with municipal agency monitoring is needed."

The Al-Kazily *et al.* (1995) report to Caltrans supports the development of an EM approach of the type developed by Silverado Constructors in which real water quality use impairments are found, and then site-specific source control measures are developed as required to control the real use impairments associated with highway and urban area street stormwater runoff.

The failure of the monitoring programs to develop meaningful water quality data is manifested in the situation that is used today in developing stormwater runoff BMPs. The regulations stipulate that BMPs are to be used to control stormwater runoff impacts to the maximum extent practicable. They provide no guidance on how to determine what is a real BMP to control stormwater runoff water quality impacts. Those familiar with how the current BMPs for stormwater runoff that are listed in the various BMP manuals, such as the California BMP manuals (CDM *et al.,*1993; APWA, 1993; ASCE/WEF, 1992; WEF, 1993; WSDOT, 1995), the Federal Highway Administration (FHWA, 1996), the US EPA Coastal Zone (US EPA, 1993a), Washington Council of Governments (MWCOG, 1992) and the soon-to-be-released Water Environment Federation/American Society of Civil Engineers (WEF/ASCE, 1996), know that they are not based on a reliable evaluation of the impact of the so-called BMP on real water quality-use impairment issues associated with the receiving waters for the stormwater runoff.

Traditionally, detention basins, grassy swales and other vegetative areas, oil-water separators, and other structural BMPs are used to "treat" highway and urban area street stormwater runoff. However, there is growing recognition that the traditional approach for assessing water quality impacts of chemical constituents in highway and urban area street stormwater runoff is not technically valid and can lead to the attempt to control chemical constituents that have no impact on the designated beneficial uses of the receiving waters.

A number of early urban stormwater runoff NPDES permittees have collected several years of monitoring data on their stormwater runoff characteristics and have reconfirmed what was known in the 1960s--that highway, street, and urban area stormwater runoff contains elevated concentrations of a variety of constituents and enteric pathogenic organism indicators that exceed water quality standards at the point of discharge. However, it is also clear that such exceedances are not, in general, causing significant adverse impacts on the designated beneficial uses of the receiving waters for the highway and urban area street stormwater runoff. Many of these waters have desirable finfish and shellfish fisheries that do not appear to be significantly adversely affected by highway and urban area street stormwater runoff.

In 1991, the American Society of Civil Engineers Urban Water Resources Research Council sponsored the Engineering Foundation Stormwater Conference. This was part of a series of conferences devoted to urban stormwater runoff issues that have been held every couple of years. The 1991 conference was devoted to assessing stormwater runoff impacts on receiving waters (Herricks, 1995). A review of the conference proceedings shows that there are few documented cases in which the chemical constituents in stormwater runoff from highways and urban areas have been found to be significantly adverse to the designated beneficial uses of the receiving waters for this runoff.

Pitt (1995), in the same conference proceedings, reviewed some of the literature on the biological effects of urban stormwater runoff. Most of the implied effects are based on chemical concentrations above water quality standards and are not real biological effects. These implied effects fail to consider toxic/available forms of chemical constituents in evaluating the true impact of the urban stormwater runoff-associated constituents.

Lee and Jones-Lee (1996a) conducted a survey of water quality problems associated with urban area and highway stormwater runoff. They found that there are few documented cases of urban area and highway stormwater runoff associated constituents causing significant impacts on the beneficial uses of the receiving waters for the 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 proceedings was that there has been far too much use of rule-of-thumb/standard-practice approach 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.

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 highway and urban area street stormwater runoff for water quality impacts. Roesner (1995), a session chair, 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."

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. 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 the edge-of-the-pavement, end-of-the-pipe monitoring to a 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 highway stormwater runoff.

The technically valid and cost-effective approach for managing real water quality use impairments (pollution) caused by highway and urban area stormwater runoff is to find a real water quality problem in the receiving waters for the runoff, determine the specific cause of this problem, and develop site-specific source control methods to control the problem to the maximum extent practicable. The EM program 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 highway and urban area street stormwater runoff are significantly adverse to the beneficial uses of the receiving waters for this runoff. The EM approach shifts the emphasis in the monitoring of the receiving waters from chemical constituent monitoring to highly focused water quality problem indicator monitoring that specifically addresses stormwater runoff events.

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 exception, 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 the duration of organism exposure to the toxic/available form. This relationship has been described by Lee *et al.* (1982a,b), Lee and Jones (1991a) and Lee and Jones-Lee (1994a) 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 stormwater runoff events in most situations is that the duration of exposure that aquatic organisms can receive associated with a stormwater runoff event is short-term and episodic. This means that high concentrations 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. With few exceptions, they tend to significantly over-estimate adverse impacts and therefore lead to the unnecessary construction of structural BMPs.

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 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 into which the chemical constituent enters into in the runoff waters and in the receiving waters that 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 sediments.

Table 1

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

Given the concentrations of a heavy metal or other constituent in stormwater runoff, what information is needed to determine whether the constituent represents an impaired use of the receiving waters?

Stormwater runoff

Need information:

- 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 - need information:

- Currents, tides - transport-advection
- Mixing-dispersion

Biological factors - need information:

- Duration of organism exposure to toxicant
- Organism movement - locomotion

Diel migration

- Sensitivity to toxicants
- Organism assemblages - resident populations relative to habitat characteristics

Chemical factors - need information:

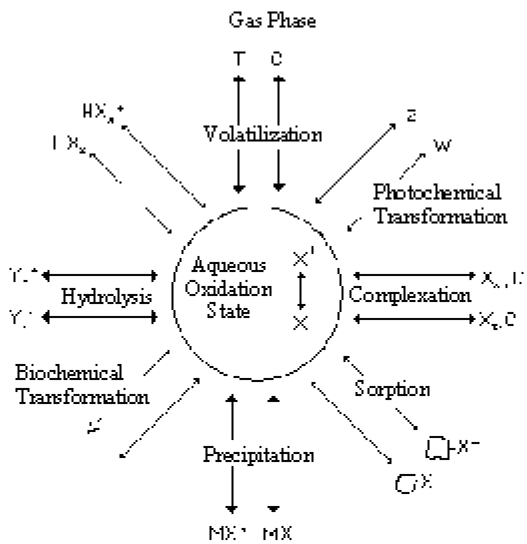
- Aquatic chemistry

Kinetics and thermodynamics of reactions

Additive, synergistic and antagonistic reactions and impacts

- Toxic and non-toxic, non-available forms
- Background concentrations of constituents of concern

Aquatic Chemistry of
Chemical Contaminants



- Distribution Depends on Kinetics & Thermodynanmics of Reactions in a Particular Aquatic System
- Each Chemical Species Has its Own toxicity Characteristics
- Many Forms Are Non-Toxic

Many times, a table of concentration data is characterized as the "chemistry" of the waters that were sampled, such characterization is unreliable. Concentration data provide information on the chemical characteristics of the water, not the chemistry of the water sampled. The concentration data are influenced by the chemistry, i.e. the reactions and the transport/mixing processes, that have occurred in the waterbody at the point where the sample was taken for chemical analysis. The kinds of reactions that are of importance in influencing toxicity/availability-true water quality impacts are discussed in aquatic chemistry texts such as Stumm and Morgan (1996). It is important to understand that many of the reactions occur in aquatic systems that control the actual distribution of chemical species for a particular element or compound and, therefore, the toxicity/availability, take place at relatively slow rates. Chemical kinetics is often an important factor in determining whether the thermodynamically stable species of an element or compound is present. While there are thermodynamic equilibrium models that can be used to estimate the thermodynamically stable species that should be present in a waterbody such as the US EPA's MINTEQ, it is important not to follow the approach recommended by Paulson and Amy (1993) of attempting to use such models to predict the chemical species that will be present in stormwater runoff. Such predictions can readily be in significant error.

Stormwater runoff and receiving water systems are complex chemical systems that are often poorly characterized and understood for most chemicals of water quality concern. This situation has caused regulatory agencies and others to try to regulate stormwater runoff water quality based on total constituent concentrations or now, for many heavy metals, dissolved metal concentrations. It is the common-place, overly simplistic approach to aquatic chemistry which ignores real chemical issues that have to be considered in true water quality evaluation and management, that has led to inappropriate assessments of the water quality impacts of stormwater runoff-associated constituents, as well as inappropriate BMP selection and evaluation of the efficacy of stormwater runoff water quality BMPs.

Unreliable Reporting of Stormwater Runoff Impacts

The US EPA's (1990a) national, as well as many states' regional stormwater runoff water quality management programs are based on an inappropriate assessment of the real water quality problems caused by urban area and highway stormwater runoff. The US EPA's approach (US EPA 1992a, 1995a,b) toward assessing water quality problems due to stormwater runoff is based primarily on exceedance of US EPA water quality criteria. This approach tends to significantly over-estimate the real water quality use impairments that are occurring in the nation's waters due to urban area and highway stormwater runoff-associated constituents. Lee and Jones-Lee (1996b) have discussed the significant deficiencies with the US EPA's approach toward defining water quality use impairments associated with urban area and highway stormwater runoff. These deficiencies have resulted in the US EPA misinforming Congress and the public about the magnitude of the urban stormwater runoff water quality problems of the country. Many of these so-called problems will disappear when more appropriate regulatory approaches are adopted for regulating potentially toxic chemicals, such as heavy metals, in the nation's waters.

The US EPA's (US EPA 1995c) adoption of dissolved metals as the species to be regulated in ambient waters was a major step in the direction of adopting more appropriate regulatory approaches. Even dissolved metals, however, especially associated with stormwater runoff situations from highways and urban area streets, can occur in non-toxic, non-available forms. This is a result of the fact that heavy metals tend to form complexes with organics which render the metals non-toxic. Allen and Hansen (1996) have reviewed the importance of considering heavy metal speciation in regulating heavy metals in aquatic systems. Bergman and Dorward-King (1997) were editors of a SETAC workshop devoted to developing water quality criteria for heavy metals that are protective life. The papers from this workshop discuss approaches for assessing the effects of heavy metal exposure on aquatic organisms. While the Agency thus far has only addressed the dissolved constituent issue for some heavy metals, this same problem occurs for most other constituents of potential water quality concern where particulate forms are well known to be non-available and non-toxic.

The exceedance of a US EPA water quality criterion is, therefore, not a reliable basis to estimate water quality impacts for regulated chemicals. It is important that more appropriate approaches be used to assess whether potentially toxic constituents as well as those that tend to bioaccumulate to excessive levels in aquatic life tissue be used to assess water quality problems associated with stormwater runoff than are being used today.

Analytical Method Issues

In order to be able to translate chemical concentrations as typically reported in a stormwater runoff water quality monitoring program to adverse effects on the beneficial uses of the receiving waters for the runoff, it is necessary to have a good understanding of the analytical methods used with particular reference to what chemical species are measured by these methods. There is often little or no relationship between the concentrations of constituents measured in a typical stormwater runoff water quality monitoring program and the impact of a chemical on a receiving water's beneficial use. This is the result of the situation that the adverse impacts of a chemical are often restricted to a limited number of chemical species (forms) in which a particular chemical may occur. The analytical methods, on the other hand, rarely, if ever, only measure the toxic/available forms. This is another reason why it is, indeed, rare that chemical monitoring data provide reliable information to stormwater managers on adverse impacts of the constituents monitored on the beneficial uses of receiving waters.

Hydrodynamic Issues

It is also necessary to understand the chemical transformations (aquatic chemistry) that can occur from the point of measurement to the point of concern for potential impact of the chemical. In addition to chemical transformations (kinetics and thermodynamics of the various reactions that the analytically measured species may undergo between the point of measurement in the stormwater runoff and the point of concern for stormwater runoff impacts), which are often poorly understood, it is also necessary to gain a good understanding of the hydrodynamics (advection and mixing) of the runoff waters with the receiving waters and within the receiving waterbody. Further, the receiving waters will often have background concentrations of chemical constituents with their own particular chemical species distribution that must be considered in evaluating the potential impacts of stormwater runoff-associated constituents on receiving water beneficial uses.

It is, therefore, readily understandable why without a substantial research effort it is not possible to reliably assess, with any degree of certainty, the water quality impacts of chemical constituents as measured in a typical stormwater runoff edge-of-the-pavement/end-of-the-pipe monitoring program on real water quality use impairment issues in the receiving waters for the runoff. It is simply not possible to translate concentrations measured in runoff waters to concentrations of toxic/available forms in the receiving waters in the vicinity of an organism or at some other point where there is concern about the potential impact. This is an complex issue that requires site-specific, detailed understanding of aquatic chemistry, toxicology and hydrodynamics.

It is for these reasons that there is growing recognition that the current stormwater runoff water quality monitoring programs that have evolved out of the US EPA's national stormwater management program are expensive and are not technically valid for assessing impacts on receiving waters since they provide essentially no useful information to stormwater managers and regulatory agencies on whether the concentration of a particular constituent or suite of constituents present in stormwater runoff from urban area street and highways needs to be controlled in order to protect the designated beneficial uses of the receiving waters for the runoff. The key issue in developing technically valid, cost-effective urban area and highway stormwater runoff water quality management programs is how to reliably, and in a cost-effective manner, determine where real water quality use impairments are occurring in the receiving waters for the stormwater runoff that require the implementation of source control and/or structural BMPs. The EM approach described below was specifically developed for this purpose.

Event Mean Concentration as a Water Quality Parameter

Widespread use of Event Mean Concentration (EMC) of constituents in stormwater runoff is being made by stormwater quality managers and their consultants. EMCs evolved out of the US EPA's National Urban Runoff Program (NURP) (US EPA, 1983a; Pitt and Field, 1990) as an edge-of-the-pavement/end-of-the-pipe parameter that enabled chemical concentration time data associated with runoff events to be reduced to a single numeric value. However, the average concentration of a chemical constituent from a runoff event is a poor predictor of the adverse impact of a runoff-associated constituent on receiving water aquatic life. First, as discussed above, aquatic organisms respond to concentrations of available chemical forms-duration of exposure relationships where, as shown in Figure 1, there is a critical duration of exposure for any given concentration of toxic/available forms that can be adverse to aquatic life associated with short-term, episodic events such as occurs with stormwater runoff near the point of discharge. It is entirely possible that high concentrations of toxic forms which would occur for only a short time could cause aquatic life toxicity where the average concentration during a runoff event (the EMC) would predict no adverse impacts. Brent and Herricks (1996) and Herricks *et al.* (1996) have recently presented data which report on toxicity measurements for short periods of time associated with stormwater runoff situations where aquatic life could be affected for short-term exposures that would not be predicted based on average concentrations of constituents in the runoff waters.

Some stormwater runoff water quality monitoring programs focus substantial resources on stormwater runoff "water quality" monitoring data reduction where various statistical techniques are used to examine the characteristics of EMCs for stormwater runoff over a period of time or to a particular waterbody. This EMC data manipulation is characterized as having relevance to water quality. In fact, since EMCs have no relevance to real water quality issues, manipulations of the data through various statistical treatments will not improve the relevance. Fundamentally, EMCs are an unreliable stormwater runoff water quality parameter. They do not incorporate the fundamental characteristics of how chemical constituents impact aquatic life and other beneficial uses. The use of EMCs in stormwater runoff water quality data reduction should be discontinued since they provide unreliable information to stormwater runoff water quality managers.

Environmental Indicators of Water Quality

The US EPA has initiated a program designed to develop "environmental indicators of water quality." The US EPA (1996a,b) has released reports which present information on the potential for using various types of measurements of water quality characteristics to assess current water quality and water quality trends. A review of the Claytor and Brown (1996) report, "Environmental Indicators to Assess Stormwater Control Programs and Practices," shows that many of the "indicators" discussed are not necessarily reliable for assessing real water quality use impairments of concern to the public. Further, some of the discussion provided on some environmental indicators is superficial and, in some cases, inaccurate. Basically, the Claytor and Brown (1996) report provides limited reliable information on appropriate measurements for assessing real water quality problems due to stormwater runoff. Further, this report does not adequately, or necessarily reliably, discuss the "disadvantages" of the proposed indicators. Many of these deficiencies were pointed out by Lee and Jones-Lee (1995a) in a discussion of the draft report.

The US EPA's (1996a,b) environmental indicators are designed to cover all aspects of water quality impairment irrespective of the source of the constituents responsible. They can also be unreliable in providing information on real water quality conditions and trends in the nation's waters. Basically, the Agency is attempting to over-simplify assessing true water quality by use of the environmental indicator approach. Lee and Jones-Lee (1996c) have provided a detailed discussion of the deficiencies in the US EPA's environmental indicator approach. They point out the need to use, as environmental indicators, direct measurement of water quality use impairments of concern to the public. "Indicators" that do not directly assess use impairments will likely provide unreliable information upon which to judge the true water quality of a waterbody and how this water quality changes with increased urbanization and other land use changes as well as the result of pollution control programs.

Alternative Monitoring/Assessment Approaches

Urbanos and Torno (1994) and Lee and Jones-Lee (1994a,b; 1996d) reviewed the deficiencies in current stormwater runoff water quality monitoring programs. As they point out, there is growing recognition that there is need to stop the end-of-the-pipe/edge-of-the-pavement monitoring and focus the funds available for such monitoring on finding what, if any, real water quality use impairments are occurring in the receiving waters for the stormwater runoff.

Several years ago, the authors faced this issue in connection with developing BMPs for stormwater runoff for a new highway (the Eastern Transportation Corridor-ETC) being constructed in Orange County, California. Prior to that time, the authors had become aware of the unreliable approaches that were being used by the Federal Highway Administration (FHWA) and others in assessing the need for structural BMPs to "treat" stormwater runoff from highways because of the excessive concentrations of chemical constituents present in edge-of-the-pavement samples of stormwater runoff. The FHWA and its contractors (FHWA, 1996 and Driscoll *et al.*, 1990) have been mislabeling chemical constituents in stormwater runoff from highways as "pollutants," implying that the elevated concentrations of heavy metals and other constituents in the stormwater runoff were adversely impacting water quality. However, examination of the results of the large number of studies of highway stormwater runoff that have been conducted by the FHWA and others showed that, as of yet, no real water quality use impairments have been reliably documented due to the elevated concentrations of constituents in highway runoff. Lee and Jones-Lee (1996a) have recently reviewed the information on the characteristics of highway runoff relative to potential water quality impacts on the receiving waters for the runoff. They point out that to their knowledge, as of yet, there are no documented cases where highway stormwater runoff-associated constituents have been the cause of water quality problems in the receiving waters for the runoff. While, as discussed below, such adverse impacts are possible, they will be rare.

In an effort to use the limited water quality monitoring funds in a more technically valid, cost-effective manner, the authors (Lee and Jones-Lee, 1996e,f, 1997a) have developed the EM approach for stormwater runoff impact evaluation and

BMP development and efficacy evaluation. Basically, the EM approach focuses the 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 permit dischargers, highway departments, regulatory agencies, agricultural interests, the public and others interested in water quality.

- 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.

The authors, in formulating EM, took the approach of evaluating for each of the types of waterbodies (marine/estuarine bay, a moderate-sized river, small streams and several reservoirs) the potential problems that could occur due to stormwater runoff from highways and urban area streets based on the characteristics of the receiving waters and of the runoff waters. The chemical characteristics of highway stormwater runoff, as well as urban area street stormwater runoff, are fairly well-defined based on the large amount of edge-of-the-pavement monitoring that has been done beginning in the 1960s. There is little need for additional monitoring of this type since, as discussed above, all that can be shown from it is that there are elevated concentrations of a variety of constituents that under certain receiving water conditions could be adverse to the beneficial uses of these waters. However, the site-specific investigations that are needed to determine whether the elevated concentrations would result in an adverse concentration for a sufficient duration to impact the numbers, types and characteristics of aquatic life in the receiving waters have not been done. From the information available, it appears that it would be indeed rare that the elevated concentrations in the runoff waters would result in significant adverse impacts to beneficial uses of the receiving waters.

The water quality use impairments of normal concern include:

- Drinking water use impairment - surface and groundwater;
- Aquatic life toxicity in water column and/or sediments;
- Excessive bioaccumulation - human health and/or wildlife;
- Suspended sediment - turbidity-siltation-habitat impacts;
- Excessive fertilization/eutrophication - nutrients-N & P;

- Pathogenic organism indicators;
- Low dissolved oxygen; and
- Aesthetics - litter, debris, oil sheen, etc.

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?
- Are there litter and debris that are 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 these waters.

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. 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.

The Evaluation Monitoring program utilizes measurement of toxicity using the US EPA's standard procedures during a stormwater runoff event to assess whether there is potential for the regulated and unregulated chemicals in the runoff waters to be adverse to aquatic life in the receiving waters. The first step of this process is to make measurements of toxicity in the runoff waters near the point where they enter the receiving waters of concern. If sufficient toxicity is found at that point to potentially impair the receiving waters' aquatic life-related beneficial uses, then additional studies are conducted to determine whether the toxicity in the runoff waters is of sufficient magnitude, duration and areal extent to be adverse to aquatic life. If toxicity of this magnitude is found, then studies are conducted of the runoff and receiving waters to determine the cause of the toxicity through a Toxicity Investigation Evaluation (TIE) and the source of the constituents responsible for the toxicity. The latter involves sampling the runoff waters at various locations during a particular runoff event in order to determine the source of the constituents that lead to toxicity in the receiving waters.

Evaluation Monitoring vs. Conventional Receiving Water Monitoring

There are significant differences between conventional receiving water monitoring and EM. Conventional receiving water monitoring typically involves establishing a receiving water sampling program in which a fixed number of samples are taken from pre-selected locations and analyzed for their physical, chemical and biological characteristics over a period of time. Normally, these programs involve determining the concentration of a large number of chemical parameters, such as heavy metals, selected organics, etc., determining the aquatic habitat characteristics of the region and determining the numbers and types of organisms, such as fish, zooplankton, algae and benthic organisms at fixed stations over a period of a year. At the end of this period, an attempt is made to analyze the data to determine whether the numbers, types and characteristics of the organisms present are altered from that expected based on habitat characteristics. Comprehensive programs of this type are often expensive and frequently do not provide definitive information on whether real water quality use impairments occur and the role of stormwater runoff in causing these impairments.

Evaluation Monitoring, on the other hand, is a highly directed study program that specifically focuses on determining the role of stormwater runoff-associated constituents in adversely impacting the designated beneficial uses of the receiving waters of greatest concern to the public. The monitoring and evaluation program is oriented to water quality problem definition and control. For such issues as aquatic life toxicity, the sampling is specifically geared to stormwater runoff events. Further, rather than implementing a mechanical, fixed period and location sampling program as is normally followed in traditional receiving water monitoring, EM focuses the resources on highly directed, site-specific studies, using the latest technical information on a topic area, to determine the actual cause of a water quality use impairment and the source of the constituents responsible for the impairment. Evaluation Monitoring, if properly conducted, can focus the financial resources available on providing information that the stakeholders for a particular waterbody's water quality can use to define the most important water quality-use impairment problems of the waterbody and to develop technically valid, cost-effective control programs for these problems. As the most important problems are defined and resolved, then the financial resources available for monitoring/evaluation can be used to address subtle, less well-defined problems as well as anticipate future problems before they become important.

Evaluation of the Water Quality Impacts of Chemical Constituents and Pathogenic Organism Indicators in Stormwater Runoff

The end-of-the-pipe stormwater discharge monitoring that has been conducted has shown that urban area street and highway stormwater runoff in many parts of the US contains elevated concentrations of a variety of chemical constituents and waterborne pathogenic indicator organisms that represent potential threats that could impair uses of receiving waters for the runoff. As is well-known today, however, the characteristics of these constituents and stormwater runoff events greatly diminishes, and for some constituents, eliminates any use impairment in the receiving waters associated with the elevated concentrations of the constituents in the runoff waters within a short distance in the receiving waters for the stormwater runoff.

The EM program is specifically designed to focus on finding real, significant water quality use impairments in the receiving waters for stormwater runoff that are due to constituents in the runoff. For example, the EM program is designed to screen the receiving waters from real use impairments due to the exceedances of water quality standards for potentially toxic chemicals that could be adverse to aquatic life in the runoff waters by screening for significant persistent toxicity in the receiving waters associated with stormwater runoff events. If no toxicity is found in the receiving waters for the stormwater runoff associated with a runoff event, there is no need to make measurements of specific chemicals that are of concern because of their potential toxicity. Similarly, by screening the receiving water edible aquatic organism tissue for excessive bioaccumulation of hazardous chemicals, it is possible to determine whether the regulated chemicals that are potential threats to excessive bioaccumulation are resulting in excessive bioaccumulation in receiving waters for the stormwater runoff.

If significant toxicity or excessive bioaccumulation or other adverse effects on the beneficial uses of the receiving waters is found that can be associated with stormwater runoff from urban area streets and highways, site-specific studies can be conducted to determine the specific cause and source of the water quality problem. These studies would lead to the development of BMPs that would specifically address the control of real water quality problems.

Key Components of Evaluation Monitoring
Water Quality Use Impairment

The overall approach used in the EM stormwater runoff water quality impact evaluation and management program is to find a real water quality beneficial use impairment that is due to stormwater runoff associated constituents, then control it to the maximum extent practicable using source control and other best management practices. The EM program focuses on examining the receiving waters for stormwater runoff water quality use impairments. Design of the EM program should consider the following types of possible impairment:

Aquatic life toxicity
Bioaccumulation of hazardous chemicals
Dissolved oxygen depletion
Eutrophication/excessive fertilization
Impairment of domestic water supply water quality for surface and groundwaters
Sanitary quality impairment of contact recreation and shellfish harvesting
Sediment toxicity that impairs water quality
Siltation-excessive sediment accumulation and turbidity
Oil and grease accumulation
Litter accumulation

The first step in establishing BMPs for stormwater runoff water quality management is to examine the characteristics of the receiving water for the runoff relative to the designated beneficial uses of these waters. In addition to the waterbodies that directly receive the stormwater runoff from the area of concern, consideration should be given to the designated beneficial uses of "downstream" waterbodies that ultimately receive the stormwater runoff.

Any exceedance of water quality standards (objectives) that may be near the point of discharge where the stormwater runoff enters the waterbody, or throughout the waterbody or a significant part thereof, should be determined relative to the stormwater runoff input. Of particular concern is the assessment of any real use impairment of the waterbodies that receive highway and urban area street stormwater runoff that are of concern to the public, who may use these waters for various purposes, such as domestic, industrial, or agricultural water supply; fish and aquatic life; contact and non-contact recreation; or aesthetic enjoyment, etc.

It is important, in reviewing waterbody water quality information, to ascertain how well water quality use impairment(s) have been assessed. As discussed by Lee and Jones-Lee (1995b) and herein, the concentration of various constituents of stormwater runoff can greatly exceed water quality objectives without adverse impact(s) on the beneficial uses of the receiving waters. It is often found, especially with highway and urban area stormwater runoff, that the alleged "water quality use impairment" represents an administrative exceedance of a water quality standard only. An administrative exceedance arises when the concentrations of the regulated chemical constituents are above the water quality standard yet, after careful evaluation, there is no discernable adverse impact on the designated beneficial uses of the waters that would be of concern to the public. Significant water quality use impairment is defined as impairment of the public's use of the water to such an extent as to be detrimental to the public's interests.

In order for there to be real water quality use impairment for aquatic, life-related, designated beneficial use of waterbodies, the numbers, types, and characteristics of desirable aquatic organisms must be significantly adversely impacted in the waterbody that receives the stormwater runoff. For bioaccumulatable chemicals, such as mercury, the concentration of the chemicals in aquatic organisms in the receiving waters must be sufficiently great to cause a human health advisory for consumption of the organisms as food.

Overview of Approaches to Defining Water Quality Impacts

Figure 3 summarizes the approaches that should be used to develop BMPs for each type of water quality use impairment typically of concern in highway and urban area street stormwater runoff. A summary discussion of the components listed in this figure is presented below. Additional information on each of these components is found in subsequent section of this report.

Aquatic Life Toxicity

Measure aquatic life toxicity using larval fish, shellfish, and zooplankton in the runoff waters and the receiving waters for the stormwater runoff associated with runoff events to determine whether regulated, as well as unregulated, constituents in the runoff are causing sufficient aquatic life toxicity to be potentially adverse to the designated beneficial uses of the waterbody receiving the runoff.

Bioaccumulation

Determine the concentrations of mercury, chlorinated hydrocarbon pesticides, PCBs and dioxins in edible tissue of nonmigratory resident fish and shellfish populations in the area of the stormwater runoff to determine whether excessive concentrations of runoff-derived constituents are present in edible organism tissue that is causing the organisms' tissue to receive or potentially receive a consumption health advisory. Also, consider the concentration of chemical constituents in the whole organism which could represent problems for wildlife that use the organism as food, based on the US EPA's wildlife-based criteria.

Dissolved Oxygen Depletion

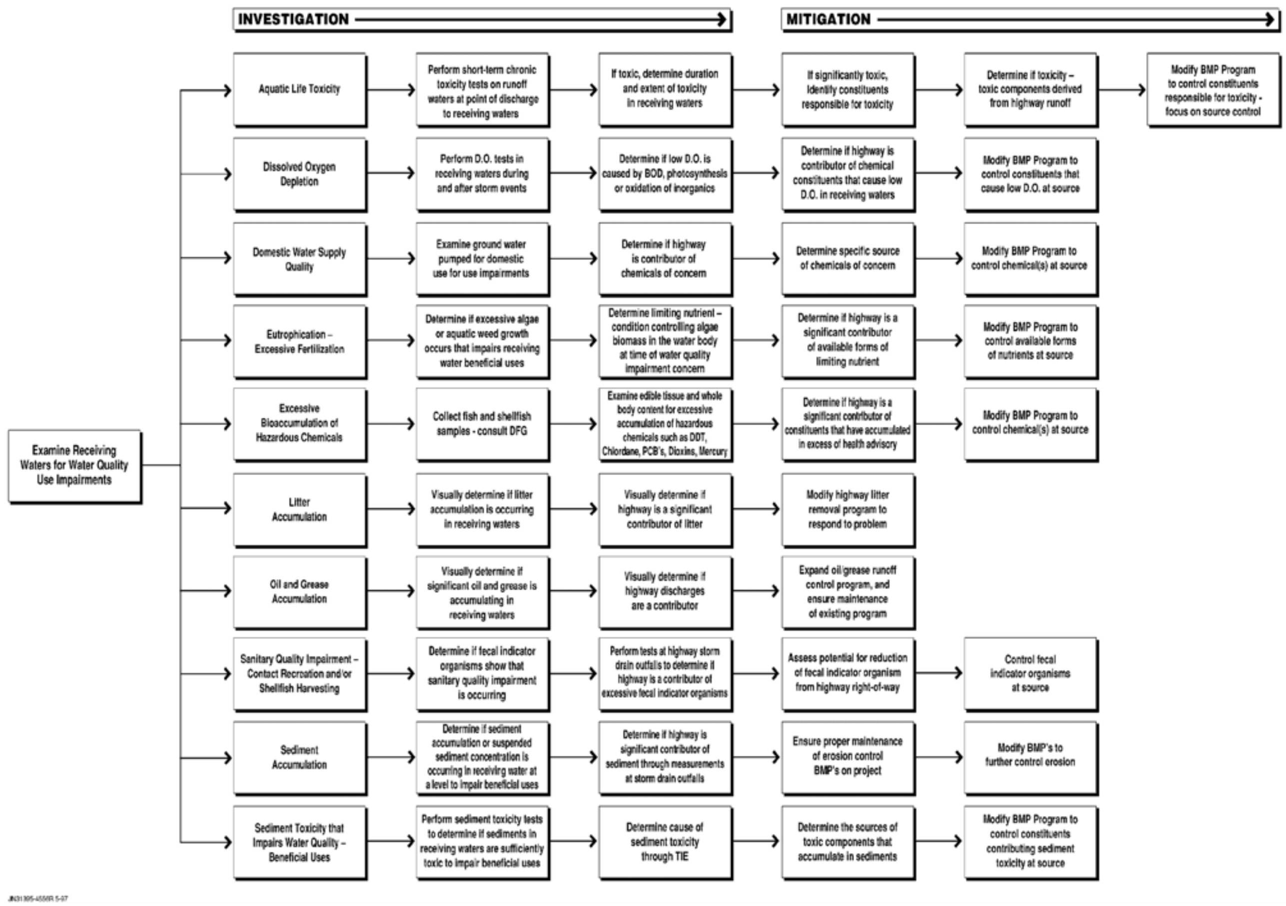
Determine whether there is significant dissolved oxygen (DO) depletion that would impair aquatic life resources of the waterbody that are due to highway and urban area stormwater runoff. Particular attention should be given to early morning concentrations of DO to ascertain any diel changes in DO associated with photosynthetic activity.

Eutrophication

Evaluate whether the aquatic plant nutrients (nitrogen and phosphorus compounds) in stormwater runoff are contributing to excessive fertilization of the receiving waters for the runoff. In making this evaluation it is necessary to estimate the relative significance of runoff-derived available forms of nutrients that control aquatic plant growth in the receiving waters versus the same forms of nutrients derived from other sources.

Figure 3: Evaluation Monitoring Implementation Flow Chart
View enlarged figure with full text

Evaluation Monitoring Implementation Flow Chart



Impairment of Domestic Water Supply

Ascertain the significance of highway and urban area stormwater runoff as a source of the constituents that cause domestic water supply utility problems in treatment and/or increased cost. Consider both surface and groundwater supplies where the stormwater runoff recharges a groundwater system.

Sanitary Quality

Determine the relative contribution of waterborne pathogenic indicator organisms, such as fecal coliforms, from the stormwater runoff compared to that of other sources to assess whether the sanitary quality of the receiving waters associated with stormwater runoff from a particular area is significantly adversely affecting contact recreation or shellfish harvesting.

Sediment Toxicity

Determine whether the receiving water sediments are the cause of significant toxicity related use impairment of the waterbody in which they are located in order to evaluate whether stormwater runoff-associated particulate contaminants are significantly impairing the use of the receiving waters due to runoff-derived contaminant accumulation in receiving water sediments. If such a use impairment is found, evaluate the specific chemical constituent and its chemical form that causes this use impairment and the sources of this chemical constituent.

Siltation

Examine the impact of suspended sediment on water clarity/turbidity in the receiving water column and due to the settled sediment in the receiving waters that is adverse to aquatic organism habitat. Also of concern is shoaling of receiving waters that is sufficient to impair recreational navigation and change the depth of the water sufficiently to enable higher forms of aquatic life (macrophytes) to develop.

Oil and Grease

Evaluate the potential impact of petroleum hydrocarbons (oil and grease) on receiving water quality on a site-specific basis, focusing on determining whether there is petroleum hydrocarbon accumulation in the receiving waters for the stormwater runoff. If there is, assess the significance of this accumulation with particular reference to accumulation in ecologically sensitive areas that could be significantly detrimental to aquatic life, such as through adversely impacting fish spawning or shellfish. Also of concern is whether the oil and grease accumulation is detrimental to the aesthetic quality of the water.

Litter

Conduct visual reconnaissance of the receiving waters for the stormwater runoff to determine whether litter that impairs use of the receiving waters and their shoreline is carried into the receiving waters by this runoff.

Overall Approach

The EM approach is designed to be a tiered use impairment definition approach that, in its initial review of use impairments, considers the easily discernable use impairments that would be of concern to the public. The EM program water quality use impairment assessment should be repeated at least once each five years to detect subtle water quality impact of current stormwater discharges not found in the EM initial use impairment screening and to detect new water quality problems that may develop as a result of new chemicals or elevated concentrations of existing chemicals introduced into runoff. Periodic repeated use impairment screening is also designed to facilitate incorporation of new approaches for assessing water quality impacts of constituents.

Evaluation Monitoring as Part of Watershed Based Water Quality Management

There is considerable interest in adopting the watershed-based approach that is being used in California and nationally for developing water quality management programs. Until recently, water quality management programs focused primarily on point source discharges such as industrial and municipal wastewaters. With the introduction of the national stormwater water quality management programs, some urban areas and industrial facilities are beginning to manage the water quality impacts of stormwater runoff from their areas. However, there are still substantial areas of smaller communities as well as agricultural and other rural areas (non-point sources) where little or no effort is being made to control pollutants derived from these areas. In many areas there is need to regulate agricultural stormwater runoff as well as runoff from other rural areas and from smaller communities to protect the beneficial uses of waterbodies since agricultural runoff contains a variety of constituents that cause water quality use impairments in the receiving waters for the runoff. The watershed approach for developing water quality management programs provides a basis for controlling all pollutants, irrespective of their origin.

The EM program can readily become the technical foundation of a watershed based water quality management program where the water quality use impairments that are occurring in various parts of a waterbody's watershed are defined by technical representatives of the watershed's water quality stakeholders. Consideration should be given to both near-field (near the point of discharge for the stormwater runoff and any wastewater inputs) as well as far-field waterbody-wide water quality use impairments.

Development of BMPs

In developing BMPs to control to the maximum extent practicable the real water quality-use impairment (pollution) of the receiving waters for the stormwater runoff, it is necessary to first find significant pollution of the receiving waters for this runoff. Once this use impairment-pollution has been identified, site-specific studies should be conducted to determine the specific sources of the constituents that are present in urban area street and highway runoff that cause the receiving water use impairment. Once these sources have been identified and quantified, BMPs can be developed to control the constituents of concern at the source to the maximum extent practicable. If source control does not eliminate the significant adverse impact of the constituents in the runoff, treatment of the runoff with site-specific BMPs should be implemented. This implementation program should be part of an area-wide, watershed-based implementation program to control similar types of urban area street and highway stormwater runoff.

Guidance on Defining Water Quality Impacts

This section presents a discussion of some of the issues that need to be considered in implementing the Evaluation Monitoring program for defining the water quality use impairments associated with urban area street and highway stormwater runoff. In addition to the information presented herein, additional discussion of these topic areas is provided in the authors papers and reports. These publications present information developed by the authors on the topic area as well as review the results of others as published in the literature. The readers are urged to review these publications in order to obtain additional information pertinent to reliably developing and implementing an EM program.

One of the areas of particular concern in formulating an EM program is the overall approach for program development. Typically, water quality monitoring programs are formulated without proper consideration and formulation of the goals of the program and the factors that need to be considered in order to achieve these goals. The typical approach of establishing arbitrary sampling programs for a fixed number of sampling locations on a regimented sampling frequency over a one year period where an attempt is made at the end of the period to analyze the data that is collected often provide little in the way of reliable information on the water quality characteristics of the waterbody being sampled and, for a tributary, its impacts on receiving water water quality.

Lee and Jones Lee (1992a) developed "Guidance for Conducting Water Quality Studies for Developing Control Programs for Toxic Contaminants in Wastewater and Stormwater Runoff." This guidance will assist those developing water quality monitoring and management programs in formulating the program in order to address many of the key issues that need to be addressed in determining the water quality impacts of the chemical constituents on water quality in a particular waterbody. The NRC (1990) Committee on Systems Assessment of Marine Environmental Monitoring published guidance on monitoring of marine pollution that covers some of the same issues addressed by Lee and Jones-Lee (1992a). Both NRC and Lee and Jones-Lee stress the importance of properly formulating monitoring program objectives as part of program development. Further, Lee and Jones (1983) discussed the importance of water quality monitoring programs being based on an active on-going review of the data as it is collected where appropriate modifications of the program are made to address issues that develop during the course of the monitoring program. This is a far more technically valid, cost effective approach for assessing the water quality characteristics of a waterbody than the passive approach that is typically used where data analysis is not undertaken until after the sampling program has been completed.

Protective Nature of US EPA Water Quality Criteria

The primary focus of urban area street and highway stormwater runoff regulatory efforts is working toward achieving compliance with US EPA water quality criteria/state standards in the receiving waters for the stormwater runoff. This situation is in accord with Clean Water Act regulatory requirements where

NPDES permit holders are not allowed to cause exceedances of water quality standards of any magnitude for more than once in three years in the receiving waters for permitted discharges outside of a mixing zone for the discharge. Since there are situations where no mixing zones are allowed, this can mean that the urban area and highway stormwater runoff should meet water quality standards in the runoff waters. Even where mixing zones are allowed, rarely are the mixing zones appropriately sized so they protect the designated beneficial uses of the receiving waters for the discharge/runoff without significant, unnecessary expenditures for constituent control.

Typically, it is assumed that if the concentration of a regulated constituent in stormwater runoff is less than the criterion value listed in the US EPA "Gold Book" of water quality criteria (US EPA, 1987) and US EPA Toxic Rule updates (US EPA, 1995c), there is limited likelihood that the constituent in its current form would be adverse to aquatic life and other beneficial uses of the receiving waters for the stormwater runoff. US EPA water quality criteria are designed to protect worst-case or near worst-case situations associated with 100% available forms of the constituent and chronic/extended durations of exposure. Since many chemical constituents exist in aquatic systems in a variety of chemical forms, only some of which are toxic/available, US EPA criteria tend to be significantly over-protective, i.e. their use tends to over-estimate the toxicity/bioavailability of the regulated constituent in the receiving waters.

The problems with trying to achieve US EPA water quality criteria and state standards based on these criteria in the receiving waters for urban area and highway stormwater runoff are becoming more widely recognized. The US EPA (Perciasepe, 1996) has announced that it is the Agency's policy that while NPDES-permitted urban area and highway stormwater runoff must comply with Clean Water Act requirements of meeting water quality standards in the receiving waters for the runoff, failure to meet such standards does not represent a violation of the NPDES permit. Lee and Jones-Lee (1997b) have discussed the inappropriateness of using US EPA water quality criteria and state standards based on these criteria as goals for regulating urban area highway and street stormwater runoff. Lee and Jones-Lee recommend that urban area street and highway stormwater runoff regulatory approaches focus on protection and, where degraded, enhancement of the designated beneficial uses of the receiving waters for the stormwater runoff. This would shift the emphasis from achieving chemical constituent concentrations which may have little relationship to actual water quality issues of concern to the public to real water quality use impairments.

While ordinarily the assumption that meeting US EPA criteria in the receiving waters for the stormwater runoff will be protective, recently Lee and Jones-Lee (1997c) have become involved in chromium water quality issues associated with wastewater discharges to a small creek. As part of this review, it has been found that the US EPA water quality criterion for Cr VI (hexavalent chromium) of 10 μg/L will not necessarily be protective of zooplankton from chromium toxicity.

Environment Canada (1995) has shown that Cr VI can be toxic to certain zooplankton at less that 0.5 µg/L. This situation was known to the US EPA in 1984 and 1995 when the Agency adopted the current Cr VI criterion values. However, the Agency chose not to adjust the chromium criterion downward to reflect the greater toxicity to zooplankton apparently due to the fact that a definitive value for the lower toxicity was not available. At that time, it was known that Cr VI was toxic to zooplankton at less than 2 µg/L (US EPA, 1985), however the actual level of the toxicity was not known.

Lee and Jones-Lee have also found that some regulatory agencies allow Cr III in wastewaters to be discharged to surface waters at concentrations up to 50 µg/L. As discussed by Lee (1996a, 1997c), Cr III can convert to Cr VI under ambient water conditions. Therefore, discharging Cr III at 50 µg/L could lead to aquatic life toxicity as a result of the conversion of Cr III to Cr VI with concentrations of Cr VI on the order of 1 µg/L or so.

Pitt and Field (1990), in summarizing the NURP data, reported total chromium in urban area stormwater runoff at concentrations up to 500 µg/L with median values for parking areas, vehicle service areas, streets, storage areas, etc. ranging from 7 to 60 µg/L. The overall median concentration of chromium in municipal stormwater outfalls found in the NURP studies was 30 µg/L. The median values for filtered chromium found in the NURP studies for various types of sources were typically less than 1 to a few µg/L. Street runoff contained from about 1 to 3 µg/L non-filterable chromium. No information is available as to whether this value represents total (Cr III + Cr VI) or some fraction of the total chromium. From the information available, it appears that there could be chromium toxicity problems in some urban area and highway stormwater runoff situations, even though the chromium concentration is less than the US EPA water quality criterion for Cr VI of 10 µg/L. This is one of the few cases where a criterion value is apparently not protective. This kind of situation further points to the importance of doing toxicity tests in order to determine if the regulated and unregulated constituents in the runoff waters are, in fact, toxic to aquatic life.

<u>Independent Applicability Policy</u>. Beginning in the early 1980s, the US EPA adopted implementation approaches for the Agency's water quality criteria and state standards that focused on total chemical constituents. Further, in the 1990s, without public review, the Agency adopted the Independent Applicability Policy, which required that numeric, chemically-based water quality standards had to be met in the receiving waters for wastewater discharges independent of whether the chemical constituents were in toxic-available forms (Lee and Jones-Lee, 1995b,c).

This Independent Applicability Policy has led to highly unreliable reporting of the water quality impacts of chemical constituents in urban area street and highway stormwater runoff (Lee and Jones-Lee, 1996b). The US EPA and the states are required by Section 305(b) of the Clean Water Act to submit biennial reports on the quality of the nation's waters as part of the National Water Quality Inventory.

These reports are submitted to Congress and provide the basis for establishing priorities for Congressional action on water pollution control programs. The most recent of these reports (US EPA, 1995a,b) follows the approach adopted by the US EPA several years ago of instructing states to report as impaired waterbodies any waterbody in which the concentrations of constituents exceed water quality criteria/standards in the region where the runoff enters the waterbody.

Lee and Jones-Lee (1996b) have discussed the problems associated with the approaches that have been used by the US EPA in its National Water Quality Inventory for assessing the water quality significance of urban area street and highway stormwater runoff. Every two years the US EPA's Report to Congress ranks "Storm Sewers/Urban Runoff" (*"Runoff from impervious surfaces including streets, parking lots, buildings, lawns, and other paved areas."*) as one of the leading causes of water quality impairment in the US. This ranking, however, is artificially high due to the use of exceedances of water quality criteria/standards as a basis for determining "impaired" waterbodies due to urban and highway runoff. Consequently, the US EPA biennial reports to Congress on the quality of the nation's waters significantly over represented the severity of the problem of urban area street and highway stormwater runoff-associated constituents as a cause of water quality impairment. This is especially true for any waterbodies ranked as "impaired" based on total concentrations of heavy metals rather than dissolved metals. As discussed herein, urban area street and highway stormwater runoff contains elevated concentrations of particulate forms of heavy metals which, in general, do not impair the quality of runoff-receiving waters.

The basic problem with the US EPA's National Water Quality Inventory is the same problem that has occurred with traditional structural BMPs for urban area street and highway stormwater runoff where it is assumed that any exceedance of a water quality standard in the runoff represents a significant impairment of the designated beneficial uses of the waterbody receiving the runoff. Exceedances of water quality standards in urban area street and highway stormwater runoff waters are common; however, the impairment of the designated beneficial uses of a waterbody associated with these exceedances (real water pollution) is rare (Lee and Jones-Lee, 1996a). For aquatic life-related beneficial uses, the numbers, types, and characteristics of desirable organisms in the receiving waters for the urban area street and highway stormwater runoff must be significantly impaired before there is a real water quality problem associated with the exceedance of these standards. Such impairments are not being found in the studies of receiving waters for stormwater runoff from highways and urban area streets.

<u>Over-Regulation of Heavy Metals</u>. An example of over-regulation resulting from a failure to focus on actual use impairment is the determination that a water quality use impairment exists when the total concentrations of heavy metals in runoff waters result in an exceedance of a water quality standard at the point at which the heavy metals enter the runoff-receiving waters. This problem has been

compounded by lack of focus of regulatory programs on the appropriate forms of heavy metals.

It has been known since the late 1960s that particulate forms of heavy metals are non-toxic and non-available (NAS/NAE, 1973). In the 1980s, however, the US EPA's implementation of heavy metal criteria and state standards based on total heavy metals resulted in many states failing to adopt water quality standards for heavy metals. This eventually led Congress to adopt a National Toxics Rule, which requires that all states adopt water quality standards for heavy metals and other potentially toxic constituents. The significant over-regulation that is occurring under the implementation of the National Toxics Rule has caused the US EPA to change its approach to the regulation of heavy metals by focusing more closely on toxic-available forms rather than total concentrations. The US EPA announced this approach as its official policy for implementation of the National Toxics Rule in the May 4, 1995, *Federal Register* (US EPA, 1995c). As a result, highway runoff BMPs, such as detention basins, that focus on removing particulate forms of heavy metals are now officially recognized as being technically invalid approaches (Jones-Lee and Lee, 1994 and Lee and Jones-Lee, 1996g).

The US EPA's adoption of regulatory approaches based on dissolved forms of metals does not represent a new understanding of these issues. This was essentially the approach recommended by the National Academies of Science and Engineering in their *Blue Book of Water Quality Criteria* (NAS/NAE, 1973). Even regulating dissolved forms of heavy metals represents over-regulation for many types of discharges due to the fact that many of the so-called dissolved forms are non-toxic and non-available as a result of the metals being present as complexes or colloids.

Heavy metals are not the only constituents being over-regulated; the same problem occurs with many organics, nutrients, etc. In general, regulating chemical constituents based on total concentrations is not an efficient approach to the problem and tends to divert or otherwise consume capital needed for the investigation and control of actual beneficial use impairments in receiving waters.

Unregulated Constituents in Urban Area Stormwater Runoff. Lee and Jones-Lee (1996d,f) have discussed the importance of considering the potential water quality impacts of unregulated chemical constituents in urban area and highway stormwater runoff. Unregulated constituents are those for which there are no water quality criteria. While pesticides are regulated through their federal and state labeling, the evaluation of water quality impacts associated with such labeling is inadequate to prevent widespread aquatic life toxicity in the surface waters of the US. It has been found that where there is toxicity in urban area street and highway stormwater runoff, this toxicity appears to be due to agricultural and/or urban use of pesticides, such as diazinon. The heavy metals and other organics in urban area street and highway stormwater runoff are not being found to be toxic to aquatic life. In some cases, such as in the Sacramento, California area, the spraying of orchards with diazinon in the winter causes urban area street and highway stormwater runoff to be toxic to aquatic life at considerable distances from the point of application, due to airborne transport of the diazinon. Diazinon is an organophosphorus pesticide that is highly toxic to some zooplankton. Studies by Connor (1995), Domagalski (1995), Kuivila (1993), USGS (1993), Kuivila and Foe (1995), MacCoy *et al.* (1995), and Foe (1995a,b) have shown that orchard-derived or other area-derived diazinon causes runoff waters to be toxic for several weeks for considerable distances downstream in the Sacramento and San Joaquin Rivers and in the Sacramento-San Joaquin River Delta system. Katznelson *et al.* (1997) recently reviewed the occurrence of diazinon in stormwater runoff in the San Francisco Bay region and its potential water quality impacts. They conclude that urban stormwater runoff typically contains sufficient concentrations of diazinon to be toxic to some forms of aquatic life. Mount (1997a) recently indicated that, based on his experience, the toxicity of diazinon and other organophosphorus pesticides would be significant to other forms of aquatic life that are key components of larval fish food.

Similar stormwater runoff toxicity results has been reported by Cooper (1996) for urban stormwater runoff in the San Francisco Bay region as well as other parts of the country. Recently the authors, as part of implementing an Evaluation Monitoring program demonstration project for the Eastern Transportation Corridor in Orange County, California, have found substantial aquatic life toxicity in stormwater runoff to Upper Newport Bay. The watershed at this point drains a substantial urban area, and, while not confirmed, it appears that the diazinon was derived from urban stormwater runoff. It was also found that this stormwater runoff contained toxic amounts of chlorpyrifos. The concentrations found in the stormwater runoff just upstream of where a major tributary of Upper Newport Bay enters the Bay were well above the California Department of Fish and Game recommended water quality criteria for these chemicals. Further, the water samples that contained the elevated concentrations of these chemicals were acutely toxic to *Ceriodaphnia*, a US EPA standard zooplankton test organism. Based on TIE studies, it was confirmed that the toxicity found was due in part to diazinon and chlorpyrifos. The stormwater runoff was not toxic under the standard test conditions to algae or fathead minnow larvae.

For political or other reasons, the US EPA and state regulatory agencies have not developed a water quality criterion for diazinon, even though the information necessary to develop such a criterion has been available within the US EPA since the late 1980s. However, the California Department of Fish and Game (Meconi and Cox, 1994 and Meconi and Paul, 1994) has developed proposed water quality criteria for several organophosphorus pesticides. These criteria, however, have no regulatory status.

The organophosphorus pesticide toxicity issue associated with its use in urban areas and/or agriculture is an example of where stormwater runoff water quality management programs that focus on measurement of regulated constituents, such as the heavy metals, selected organics, etc., could readily spend large amounts of money in monitoring stormwater runoff from urban areas and highways, yet fail to detect potentially significant toxicity in the stormwater runoff. The Evaluation Monitoring program is specifically designed to examine the potential toxic impacts of both regulated and unregulated constituents in urban area and highway street runoff.

Aquatic Life Toxicity

Some chemical constituents can be acutely and chronically toxic to aquatic life. Acute toxicity, which is often measured as death of the organism, normally occurs within a few hours to a few days upon exposure of the organism to the toxic chemical. Chronic toxicity, which is usually of concern because of its impact on an organism's growth and reproduction, usually occurs over an extended period of exposure. Acute toxicity, which results in death of the organisms within a short time after a runoff event that is manifested in a fish kill, is readily detectable. However, chronic toxicity that impairs the health of an aquatic population through impacting reproduction, growth rates, etc. is more difficult to detect. It is for this reason that EM focuses a considerable part of its resources on determining whether the runoff waters are potentially adversely impacting the aquatic life-related beneficial uses of a waterbody through being toxic to aquatic life in the receiving waters.

Urban area street and highway stormwater runoff contains concentrations of heavy metals and other constituents above those levels that are potentially toxic to aquatic life under worst-case conditions of 100 percent available forms and extended durations of exposure. Since heavy metals and other constituents exist in urban area street and highway stormwater runoff in a variety of chemical forms, many of which are non-toxic, it is necessary to directly measure toxicity in the receiving waters, during and following a runoff event, to evaluate whether the potentially toxic regulated chemicals which occur in runoff at concentrations above water quality criteria/standards are toxic in the receiving waters. Toxicity measurements are also necessary to evaluate whether there are unregulated chemicals, such as diazinon and other pesticides used on agricultural crops and in urban areas that can cause toxicity in receiving waters for urban area street and highway stormwater runoff.

Davies (1995) in a discussion of "Detecting Toxicity Problems in Urban Runoff" stated,

"Outside of a major fish kill in a receiving water stream, how would toxicity problems be detected? Attempts to analyze water from these systems for all possible toxicants would be extremely difficult and very expensive. Biomonitoring methods should first be used to determine if toxicity exists using, for example, the water flea (Ceriodaphnia dubia) as a test organism. Screening tests for acute

toxicity can be conducted in two days, or a more sensitive life cycle test in seven days. Once toxicity has been established in a particular drainage system, biomonitoring can be used to locate and identify potential sources. With knowledge of types of activities or industries in the defined area, the kinds of potential toxicants can be narrowed and selective analyses performed. Once a toxicant(s) has been identified and attributed to a particular source, control can be implemented through normal regulatory channels."

Basically, Davies is advocating the use of toxicity tests to screen for the presence of toxic amounts of regulated and unregulated chemical constituents in ambient water systems.

Recently, de Vlaming (1995a,b) of the California Water Resources Control Board staff has conducted a comprehensive review of the reliability of toxicity testing using acute or chronic tests in predicting water quality use impairments that are manifested as impaired aquatic organism populations. There are many situations where chemical composition of waters in which potentially toxic elements exceed US EPA water quality criteria that are not associated with water quality impacts in the receiving water for a wastewater discharge. This situation has led to the development of Whole Effluent Toxicity (WET) tests. de Vlaming reported that toxicity measurements on an effluent have been found to predict biological community impacts in the receiving waters for the effluent about 70 percent of the time. The reliability of the toxicity tests for estimating in-stream biological responses was improved when toxicity tests were conducted with ambient water, and when the exposure conditions that organisms would experience in the ambient waters were duplicated in the toxicity test. Overall, de Vlaming concludes that,

"Available literature yields a compelling, weight of evidence, demonstrating that the WET, and other indicator species, toxicity test results are accurate qualitative predictors of instream biological community responses."

In August, 1995, the Society for Environmental Toxicology and Chemistry (SETAC) held a "Pellston" workshop devoted to the reliability of effluent toxicity tests in predicting water quality impacts in receiving waters. The participants in the workshop were experts in this field. According to Denton (1995) and Grothe *et al.* (1996), the workshop participants developed the same conclusion as de Vlaming on the reliability of toxicity tests in predicting biological community impacts.

De Vlaming's review, as well as the SETAC workshop proceedings (Grothe *et al.* 1996), provides considerable support for the validity of the EM assessment of toxicity in which multiple-species, short-term chronic toxicity tests are used on ambient waters in which the duration of exposure and dilutions that occur in the receiving waters for stormwater runoff are simulated in the test conditions. It can be expected that, if toxicity persists in the receiving waters for stormwater runoff under these conditions, there would be adverse impacts on the biological populations in these waters. Under these conditions, the specific cause of this toxicity should be identified through a TIE. Further, in accord with current regulatory requirements, if the cause of toxicity is urban area street or highway stormwater runoff, then BMPs need to be implemented to control the toxicity to the maximum extent practicable.

The EM program approach focuses on assessing toxicity in the receiving waters for the stormwater runoff. Toxicity in the receiving waters is measured before, during, and after a stormwater runoff event. Measurement of toxicity in the stormwater runoff waters does not necessarily translate into significant toxicity in the receiving waters. Caution should be exercised in assuming that the toxicity measured in runoff waters results in significant toxicity in the receiving waters that leads to an impairment of the designated beneficial uses. The US EPA (1991a) in the Agency guidance for implementing the WET test results stated,

"The regulatory authority must carefully look at the test protocols and all the data collected to determine if the facility is actually contributing to toxicity in the ambient water."

The issue is not whether the urban area street and highway stormwater runoff is toxic at the point of discharge; the issue with respect to beneficial use impairment of the receiving waters for the stormwater runoff is whether there is sufficient aquatic life toxicity for a duration and spatial extent to be significantly toxic to aquatic life in the receiving water water column. Lee and Jones (1991a) discussed the approach that should be followed in evaluating the significance of urban area street and highway stormwater runoff toxicity. Toxicity measurements should be made over time within and near the stormwater runoff discharge plume. These toxicity tests should mimic the duration of exposure and concentration time profile for aquatic organisms under the influence of the urban area street and highway stormwater discharge.

The design of the toxicity sampling and measurement program will be highly dependent on the hydrodynamic characteristics of the stormwater runoff discharge plume. The overall objective is to assess toxicity in the discharge plume under laboratory conditions that approximate the conditions that aquatic organisms in the discharge plume would experience. Ideally, the toxicity tests should be conducted in such a way as to mimic the duration of exposure discharge water dilution curve in the discharge plume. This would involve taking samples of the ambient waters and discharge waters, and mixing these on a flow-through basis in proportions to the percent dilution time situation that occurs in the runoff water discharge plume. Since few laboratories are equipped to conduct such tests, it is proposed that a step-wise implementation of this approach be used, in which various dilutions of the discharge plume with the receiving waters are tested to mimic the exposure situation that an organism entrained in the discharge plume would experience.

Consideration must be given, not only to the duration of exposure, but to the dilution of the discharge plume with ambient waters that occur in the plume. Of particular importance is the matching of the exposure conditions for each dilution condition that is tested with the exposure condition that occurs in the field. Consideration must be given to both planktonic organisms, which have limited locomotive ability, as well as nektonic organisms, such as larger fish, that have the ability to determine their location through swimming. Further, both avoidance and attraction to discharge plumes should be considered. Fish may find that foraging in the runoff waters near the discharge is desirable and thereby receive a greater exposure to potentially toxic conditions; however, those fish that have this ability to maintain their position at this location are usually the larger, adult fish that tend to be less sensitive to toxicants than the larval planktonic fish.

While some stormwater quality "impact" studies include toxicity measurements, these measurements are made at the point of stormwater runoff from the area, such as the paved surface of the highway or stormwater discharge point. Under conditions where this runoff immediately enters the waterbody of concern, such measurements are appropriate to determine whether there is potential toxicity in the receiving waters associated with the runoff.

It has been found that the mixing of two waterbodies can be fairly readily traced through field measurement of parameters such as temperature, specific conductance and turbidity. Further, it has been found that drogues (devices that move with the water at the average speed of the watermass) can be used to estimate travel time within the stormwater runoff plume in the receiving water. For shallow waterbodies, oranges have been found to be effective drogues for estimating river velocity. By dumping several oranges in the stormwater runoff at the point where it enters the receiving water waterbody, it is possible to determine the average velocity and, to some extent, the degree of mixing.

Figure 4 illustrates a general sampling regime for stormwater discharges into rivers, lakes, bays and nearshore marine waters. The sampling program for a particular location should be developed based on information derived from following drogues, released at the point of stormwater discharge, that move with the ambient water/discharge water mixture. By sampling at various times along the drogue path, it is possible to estimate the rate of dilution that occurs in the ambient waters, and the times that should be used to estimate the duration of exposure of the test organisms in the toxicity tests to various concentrations of constituents of concern and toxicity in the stormwater discharge.

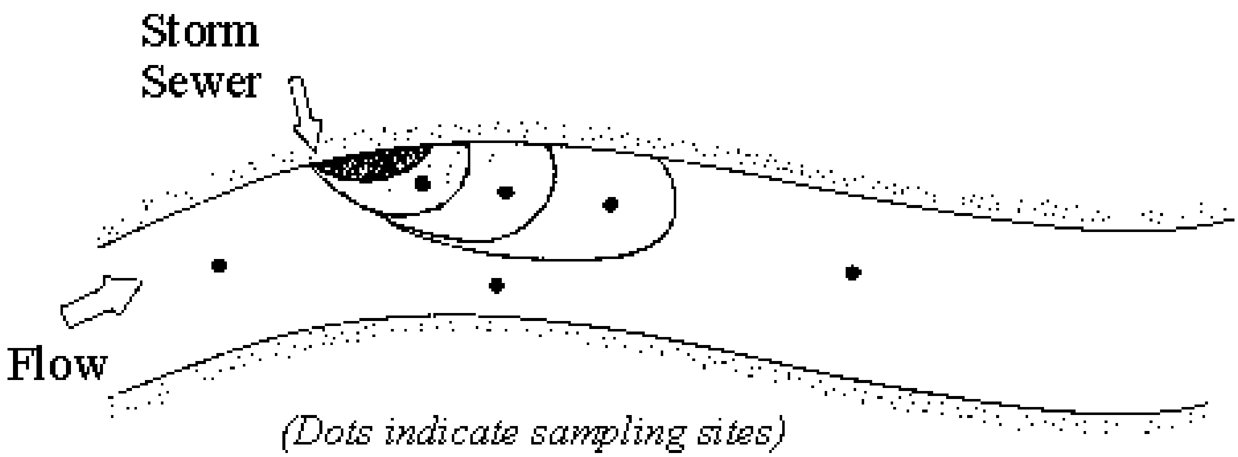
For deeper waterbodies, drogues constructed of 1-meter-square sheets of aluminum, slotted so that they form a cross, attached to a small float by high-strength fishing line, can effectively trace watermass movement at any depth in the receiving waters. The position and velocity of the drogues, as a function of time-from-release, can be estimated based on the use of surveying equipment, sextant, range finder and anchored buoys or stakes in the receiving waters.

Field measurements with submersible temperature and conductivity probes that can be hand-held while wading across a shallow stream, or suspended from a boat, can be used to identify the position of the runoff water plume. By making transects across the receiving waters at various locations downstream of the point of entry of the runoff waters, where temperature and specific conductance are measured as a function of depth at various transect locations, it is possible to define the position of the stormwater runoff water plume. Under shallow water conditions, the location of the measurements can be defined by positioning stakes embedded in the sediments at known distances along the transect.

For deeper waterbodies, buoys, located at specific points, can be used to measure distance along a transect. Also, various types of surveying equipment, including rangefinders, can be used to determine the position at which the temperature and conductivity measurements are made. This approach can lead to the development of a map of the stormwater runoff plume.

For those situations in which there is toxicity in the runoff at the point where the stormwater enters a waterbody, it is suggested that samples should be taken near the origin (before any significant dilution of the discharge plume occurs) at 1-hour, 6-hour, and 1-day intervals down the drogue path. If toxicity is found after 1 day, daily sampling should be conducted along the drogue path, if the discharge plume is still identifiable. If the discharge plume has become well-mixed in the receiving waters, the toxicity of the receiving waters in the vicinity of the mixture with the discharge waters should be assessed. Each of these samples should be tested for toxicity using the short-term chronic toxicity tests discussed herein. The results of these tests should be examined at 1-hour and 6-hour intervals, and daily to see what, if any, toxicity has occurred. Consideration should be given in these tests to whether latent toxicity is manifested in aquatic organisms even though the waters are no longer toxic.

Figure 4: Urban Stormwater Runoff Sampling Regime (Plate 1-1 from Volume 2 of the February 1997 Drainage Report)



Measurements of conservative chemicals (sodium, chloride, calcium, magnesium, and sulfate), as well as electrical conductivity and temperature in the receiving waters and within the plumes carrying the stormwater runoff can be used to estimate the rate of dilution of the runoff plume. With knowledge of the background receiving water concentrations of these various parameters and the concentrations in the runoff waters, it is possible to determine how much of the runoff waters have mixed with the receiving waters. It is also possible to determine the residence times of planktonic organisms in the plume. This residence time is important in developing the potential duration of exposure of planktonic aquatic organisms and the dilution of the runoff waters with receiving waters that should be used in the toxicity tests to evaluate whether toxicity measured in the runoff waters could be adverse to aquatic life in the receiving waters to significantly impair the beneficial uses of these waters.

Since it is possible that the receiving waters for the runoff may be toxic from causes other than due to constituents in the stormwater runoff of concern, it is important to determine the toxicity in the runoff water discharge plume and outside of it. Under these conditions, an assessment should be made of whether the runoff contributes sufficient toxicity for sufficient duration and spatial extent in the receiving waters to be considered of potential significance in impairing the designated beneficial uses of the receiving waters. In evaluating the water quality significance of toxicity found in stormwater runoff waters, it is also important to understand how the toxic response in the toxicity testing procedures compares to the toxic responses possible in the receiving waters for the runoff. The duration of exposure in toxicity tests is often far greater than those that aquatic organisms can receive during a stormwater runoff event.

The focus of the toxicity measurements should be based on short-term, chronic testing using fish larvae and zooplankton. The US EPA has developed guidance manuals for freshwater and marine systems (US EPA 1994a,b, 1995d). Lethality, impairment of reproduction and growth should be used as toxicity end-points in the toxicity testing. Because of the inability to reliably interpret algal toxicity data, it is recommended that algal toxicity tests not be used for this purpose (Lee and Jones-Lee, 1994c).

Measurements representing each of the seasons when precipitation occurs should be made of the receiving waters' toxicity for selected storms each year to determine whether the urban area street and highway stormwater runoff contributes significant toxicity to the receiving waters during the year. There can be significant seasonal toxicity in urban area street and highway stormwater runoff, such as that found in the runoff waters in the Sacramento, California area, where diazinon is used in the winter as a dormant spray in orchards, and is carried for considerable distances through the air that causes toxicity in urban area street and highway stormwater runoff.

If the EM toxicity assessment shows there is potentially significant toxicity in the receiving waters for the runoff, then TIE studies should be conducted to determine the specific source and cause of the toxicity. The US EPA has provided several guidance manuals on how to conduct TIE investigations (US EPA, 1989a,b,c,d; Fava, *et al.*, 1989). Mount (1997b), Mount *et al.* (1997), Bailey, (1997) and Cherr and Higaski (1997) have recently discussed the development and use of TIEs associated with identifying the cause of aquatic life toxicity in ambient waters and waste water effluents. These approaches have been used by a number of investigators to show that diazinon is a widespread cause of aquatic life toxicity in receiving waters for urban stormwater runoff (Hansen, 1995; Bailey *et al.,*1996).

If no toxicity is found in the receiving waters or if the extent, duration and intensity of toxicity in the receiving waters is not sufficient to be significantly adverse to the numbers, types and characteristics of desirable aquatic life in the receiving waters for the stormwater runoff, it can be concluded that at the time of study all of the potentially toxic heavy metals, organics, etc., in the urban area street and highway stormwater runoff, as well as from all other sources, are nontoxic. Therefore, there would be no need for BMPs to control potentially toxic chemicals in urban area street and highway stormwater runoff and other sources of constituents for the waterbody.

An appropriate BMP to control diazinon toxicity in highway runoff is through source control. Since diazinon is dissolved, conventional highway stormwater BMPs, such as detention basins, will have no effect on the diazinon-caused aquatic life toxicity since diazinon would not be removed in detention basins or filters. Those who manufacture, sell, or use diazinon and other pesticides that become part of urban area street and highway stormwater runoff, as well as runoff from the orchards and other agricultural or rural lands, must be able to control the use so that there is no significant toxicity to aquatic life in the receiving waters for urban area street and highway stormwater runoff. Highly specific source control BMPs of this type will likely be the primary mechanism by which potentially significant water quality problems can be effectively addressed and controlled for a variety of constituents that are found to cause water quality use impairments from highway and urban area street runoff.

The general toxicity being found in urban area street and highway runoff that is caused by organophosphorus pesticides, such as diazinon, at various times of the year and at many locations is due to its use on homes for structural treatment and control of insects in lawns. The significance of this home-use, diazinon-caused urban area street and highway stormwater runoff toxicity in adversely impacting receiving water water quality is not known. While the authors and others are finding potentially significant toxicity in stormwater runoff due to these chemicals, the studies that are needed to assess whether the toxicity in the runoff sample represents an impairment of the designated beneficial uses of the receiving waters for the runoff have not been conducted. It will be necessary to define the degree, extent and duration of the toxicity in the receiving waters. There could be situations where this toxicity is rapidly lost in the receiving waters and is of no consequence in causing beneficial use impairment of these waters. In other situations, however, sufficient toxicity could persist for sufficient periods of time to be adverse to the beneficial uses of the receiving waters. Of particular concern would be small, perennial urban streams, which maintain a desirable aquatic life habitat. Such streams could receive sufficient urban runoff-derived toxicity to be adverse to aquatic life in the stream. This type of situation creates the need to develop a BMP to control the diazinon or, for that matter, any other cause of toxicity in the receiving waters for urban area street and highway stormwater runoff.

In addition to organophosphorus pesticides causing aquatic life toxicity in urban area stormwater runoff, the agricultural use of these chemicals is also causing aquatic life toxicity in runoff waters. Kuivila and Foe (1995) have found that diazinon applied as an orchard dormant spray during the winter in the North Central San Joaquin - Sacramento Valleys, California results in diazinon-caused toxicity to *Ceriodaphnia* for a several-week period a few weeks after application as a dormant spray associated with stormwater runoff events. The magnitude of the toxicity and persistence found in the Sacramento River, San Joaquin River and the associated Delta is sufficient to be significantly adverse to zooplankton populations. While not investigated, it is likely also significantly toxic to benthic and epibenthic organisms associated with the sediments of the river systems and the Delta.

In order to translate the concentrations of a potentially toxic chemical in stormwater runoff to a significant water quality impact in the receiving waters for the stormwater runoff, there are a number of physical, chemical and biological factors that must be evaluated. Finding potentially significant toxicity in runoff waters to a river, stream or bay associated with a runoff event does not necessarily translate to a significant adverse impact on the numbers, types and characteristics of aquatic life in the receiving waters for the runoff. Figure 1 can be modified so that the ordinate is toxicity. There is, therefore, for any toxicity level to a particular type of organism, a duration of exposure where the toxic effect is not exerted. However, it has been known for some time that even short-term exposures to some toxicants at sufficiently elevated concentrations can result in a latent toxicity that is manifested by adverse impacts on the organism well after the time when the concentration of the toxicant has been reduced to non-toxic levels even under extended periods of exposure. Brent and Herricks (1996) have recently developed data that addressed this issue to some extent associated with stormwater runoff from urban and industrial areas.

Lee and Jones-Lee (1996d,e,f) have discussed the importance of determining whether measured toxicity in stormwater runoff translates to significant water quality impacts in the receiving waters for the runoff. In order to make a proper evaluation of this issue, it is necessary to trace the stormwater runoff-associated toxicity into the receiving waters in order to determine the magnitude, duration and areal extent of toxicity found in the stormwater runoff as it is manifested in the receiving waters. What might appear to be high levels of toxicity in a stormwater runoff sample, such as those found by the authors in the tributaries of Upper Newport Bay, may be rapidly diluted below toxic levels in the receiving waters. Therefore, caution must be exercised in utilization of toxicity data which are based on extended periods of time for the laboratory tests to be completed relative to the toxicity duration of exposure situations that aquatic organisms can experience in the receiving waters for the toxic urban runoff. This is especially important for slow acting toxicants, since several days of exposure must occur before the toxicity is manifested. For diazinon and chlorpyrifos toxicity, it has been determined that the toxicity found under laboratory conditions for urban runoff samples is rapid-acting, i.e. normally acutely toxic within one day. The basic issue that must be evaluated in any urban runoff toxicity impact assessment is whether toxicity of sufficient magnitude for sufficient duration occurs in the receiving waters for the stormwater runoff to be adverse to desirable forms of aquatic life in the receiving waters.

One of the complicating issues with the organophosphorus pesticide toxicity to aquatic life is that it is highly toxic to some forms of zooplankton and shows limited toxicity to other zooplankton, fish larvae and many other forms of aquatic life. The manufacturers and users of organophosphorus pesticides, such as diazinon and chlorpyrifos, have raised the issue of what does it mean for Sacramento River water to be toxic to *Ceriodaphnia* and some other zooplankton for a several-week period after an orchard dormant spray application and runoff occurs as the water passes down the Sacramento River through the Delta into Upper San Francisco Bay. A few weeks after this pulse of toxicity has passed through the system, the zooplankton populations are back to pre-toxic conditions. There is, however, a week to two weeks where larval fish and other organisms that utilize the zooplankton that are sensitive to diazinon as food would be deprived of that source of food. It is argued that there are other sources of food that could be utilized by larval fish, and therefore the pulse of toxicity which lasts for several weeks may not be significantly adverse to fish populations. However, there is increasing recognition that the dormant spray diazinon/chlorpyrifos toxicity as well as similar situations associated with the application of organophosphorus pesticides to crops at other times during the year that result in pulses of toxicity that pass through large river systems over periods of days to a week or more are likely adverse to aquatic life and, therefore, should be controlled.

The situation with respect to interpreting the water quality significance of urban stormwater runoff toxicity, however, is unclear. The pulses of toxicity are likely to be much shorter and occur to a much lesser extent than for the agricultural dormant spray or other applications. It could be that the toxicity found in urban stormwater runoff due to homeowners' use of diazinon and chlorpyrifos that causes stormwater runoff to be toxic in a storm drain outfall may be of limited water quality significance to the designated beneficial uses of waterbodies receiving the stormwater runoff. Certainly before any attempt is made to restrict homeowner use of diazinon and chlorpyrifos, appropriate studies should be conducted to determine if, on a site-specific basis for a particular receiving water, significant adverse impacts on designated beneficial uses of the receiving waters are occurring. This same situation should apply to evaluating whether toxicity measured in stormwater runoff or estimated through exceedance of water quality criteria is of sufficient magnitude and extent to warrant control of the constituent responsible for the runoff toxicity at the source and/or through treatment of the runoff.

Determination of the source of toxicity found in urban area street and highway stormwater runoff in a waterbody's watershed will require forensic studies that will usually involve a combination of aquatic chemistry and toxicity measurements. If the TIE is able to determine the constituent responsible for the toxicity and the constituent has a relatively simple aquatic chemistry involving only one chemical form, then it may be possible to use chemical measurements at various locations in the watershed to identify the specific source(s) of toxicity responsible for the toxicity at the point of water quality concern. It is important not to assume, as is frequently done, that all sources of a constituent, such as copper, represent sources of toxic forms of copper. Rarely will this be the case. Usually, potential toxicants have a variety of chemical forms, only some of which are toxic. Under these conditions, appropriate use of aquatic chemistry and toxicity measurements will need to be used to properly define the source(s) of the constituent that contributes the toxic form of the constituent.

Bioaccumulation of Hazardous Chemicals

Certain chemicals, such as chlorinated hydrocarbon pesticides, PCBs, dioxins, and mercury, which are known or suspected to cause cancer in man, and/or are neurotoxins, tend to bioaccumulate in edible aquatic organism tissue to a sufficient extent to cause regulatory agencies to issue a health advisory for the consumption of that organism. While, ordinarily, the presence of large amounts of these chemicals in urban area street and highway stormwater runoff is rare, it is important as part of any EM program to determine whether excessive bioaccumulation of chemical constituents is occurring that could lead to health advisories in the receiving waters for the runoff.

Also of concern is the bioaccumulation of chemicals in aquatic organisms that represents a significant threat to higher trophic level organisms, such as fish-eating birds and mammals, endangering the health and reproduction of these organisms. The US EPA (1993a) has issued guidance on the development of criteria designed to protect wildlife from the consumption of aquatic life containing excessive concentrations of hazardous chemicals. This guidance was developed for the US-Canadian Great Lakes but it has some applicability throughout the United States. It is important to understand, however, that the Great Lakes conditions that impact bioaccumulation can be significantly different from the conditions that exist in other waterbodies. Therefore, site-specific verification of bioaccumulation factors should be undertaken to be sure that the factors that were developed for the Great Lakes are applicable to the waterbody of concern.

The traditional approach for assessing bioaccumulation in urban area street and highway stormwater runoff is to measure the concentrations of chemicals that are of concern because of their potential to bioaccumulate in aquatic life tissue in runoff waters and attempt to extrapolate from these concentrations to the concentrations that could be found in aquatic organism tissue; however, this approach is not reliable. The accumulation of many organics and mercury in aquatic organism tissue is basically a partitioning process, in which the concentrations in the water or sediments equilibrate through partitioning with aquatic organisms. Typically, the factors controlling the uptake vary from site to site and are controlled primarily by the amounts and types of carbon compounds in the water, sediments and the aquatic organism tissue-fat content.

Unlike toxicity, excessive bioaccumulation is based on excessive concentrations of a specific chemical. Therefore, the chemical responsible for the health advisory or potential advisory is known. However, chemical constituents exist in aquatic systems in a variety of chemical forms, only some of which can bioaccumulate in aquatic organism tissue to excessive levels. It is unreliable to assume, because an elevated concentration of a chemical constituent is found in aquatic organism tissue upon exposure to a particular source of the chemical, that the source will be responsible for causing or contributing to excessive bioaccumulation in aquatic organisms of concern to the public because of their use as food, or because they are important food for higher trophic level birds or mammals.

While the US EPA and the COE (US EPA/COE, 1991; 1994) have developed some standardized equations for estimating bioaccumulation based on concentrations in water, these equations are not reliable for predicting uptake by organisms in various types of waterbodies. At this time, the only way to reliably assess whether constituents in urban area street and highway stormwater runoff bioaccumulate in aquatic organisms to excessive levels is to measure the concentrations in the urban area street and highway stormwater runoff-impacted receiving water organism tissue. If excessive concentrations are found relative to a properly developed health based "standard," then site-specific evaluations need to be made to determine whether the urban area street and highway stormwater runoff is the source of the chemical of concern.

There is considerable confusion about how to reliably assess excessive concentrations of chemicals in aquatic organism tissue. There are a number of inappropriate approaches being used today in assessing whether excessive concentrations of a chemical are present in aquatic life tissue. It is important not to assume that an elevated concentration in organism tissue causes an adverse impact to that organism or higher trophic level organisms unless the necessary studies have been conducted which show that the accumulation of the chemical in the organism tissue is, in fact, adverse to the organism or higher trophic level organism. For human health, this would represent the development of a health advisory on the consumption of the organism's edible tissue.

Some agencies, in an attempt to try to find a way to use chemical data associated with analysis of aquatic organism tissue, have contrived a variety of approaches which superficially appear to have some validity in the interpretation of bioaccumulation data. Concentrations above the mean or median concentration normally found in organism tissue, the so-called National Academy of Science values used only in California, are not valid for assessing the beneficial use impairment that a tissue residue represents.

Over the years, considerable attention has been given to attempting to evaluate the water quality and public health significance of tissue residues in various forms of aquatic life. After careful review, it is generally concluded that there are few chemicals where reliable information is available on what constitutes an excessive concentration of a chemical in aquatic organism tissue. Aquatic organisms and many mammals, including man, are known to accumulate a variety of fat-soluble chemicals in their tissue without any discernable significant adverse impact on the organism and man. Therefore, the valid approach available today for interpreting bioaccumulation data is a Food and Drug Administration (FDA) Action Level or a US EPA or other agency risk-based human health advisory. Further, for human health advisories, it is important to focus bioaccumulation evaluation on edible tissue of organisms that are actually used as food and not on zooplankton, worms, or some lower trophic level organisms which are not used as human food.

The US EPA developed a series of manuals on assessing excessive bioaccumulation of chemicals in aquatic life tissue (US EPA, 1992b, 1993b, 1994c, 1995e). The US EPA has developed a risk-based approach for determining the allowable tissue levels of potential carcinogens and mercury that will protect the public who use these organisms as food. These guidance manuals should be consulted for further information on the evaluation of excessive concentrations of chemicals in edible aquatic organism tissue.

If excessive concentrations above health advisories or US EPA wildlife criteria based on tissue concentrations are not found in the receiving waters for appropriately tested aquatic organisms, then, except for occasionally confirming the situation, there is no need for further monitoring of chemical constituents in urban area street and highway stormwater runoff for those chemicals that are of concern because of their potential to bioaccumulate to excessive levels. If, however, excessive accumulations of potentially hazardous chemicals are found, site-specific studies will likely require a combination of laboratory uptake studies which simulate receiving water conditions and field studies using caged organisms in the areas where urban area street and highway stormwater runoff could likely be responsible for the excessive bioaccumulation.

If it is not possible to sample the resident nonmigratory fish and shellfish, then caged fish and shellfish can be used to determine whether there are hazardous chemicals potentially bioaccumulating to sufficient levels to impair the beneficial uses of the waterbody. Newbry and Lee (1984) have provided information on inexpensive cages that can be used for conducting field studies of bioaccumulation and toxicity. It is important, however, in conducting caged organism studies to ascertain whether there is a real bioaccumulation problem and not rely solely on the accumulation of chemicals within mussels, such as associated with the NOAA or State of California Mussel Watch program. It has been found (Salazar, 1995) that a variety of factors, which are poorly understood, influence the degree of accumulation of potentially hazardous chemicals within mussels. Therefore, it is not possible to use the results of caged fish and mussel studies to determine water quality use impairment. However, the caged fish/shellfish studies can help determine the origin of the bioaccumulatable chemicals that are impairing the use as a source of human food. As discussed herein, in addition to considering bioaccumulation impacts on human health, consideration must be given to adverse impacts on wildlife that use aquatic organisms as food.

The US EPA/COE (1991,1994) provide information on conducting laboratory-based bioaccumulation studies. Bridges *et al.* (1996) presented a summary of a workshop on interpreting bioaccumulation data collected during evaluation of dredged sediments using US EPA procedures. It is the authors (Lee and Jones-Lee, 1996h) experience that the US EPA/COE approaches tend to overestimate the actual bioaccumulation that will occur in a waterbody in higher trophic level organisms.

In September 1996, the US EPA held a conference devoted to a review of the role of aquatic sediment-associated constituents as a source of bioaccumulatable chemicals that cause aquatic organism tissue to be considered a health hazard for use as human food as well as for food by higher trophic level organisms. The purpose of this conference was to review the current state of information on this topic. The proceedings from the conference are to be available in 1997. Following the conference, Lee and Jones-Lee (1996h) prepared a summary of the issues they find should be considered in evaluating whether chemical constituents in a particular source such as urban area or highway stormwater runoff or a particular constituent in the ambient water column or sediments is a significant source of constituents that cause aquatic life to contain excessive concentrations of the constituent in their tissue compared to those that are considered of risk for human health and higher trophic level impacts. They point out that based on the US EPA September 1996 conference presentations, the situation has not changed from that which was well established in the 1970s of being unable to reliably predict, based on water and/or sediment concentrations, the amount of bioaccumulation that will occur in higher trophic level aquatic organisms such as fish. While there are various theoretical and empirical approaches for estimating bioaccumulation factors (BAFs) and Biota-to-Sediment Accumulation Factors (BSAF), these procedures tend to over-estimate the actual bioaccumulation that will occur in higher trophic level organisms of greatest concern to man, such as edible fish.

It is also apparent that the situation is still the same as it was in the 1970s with respect to being able to relate aquatic organism body burdens of potentially hazardous chemicals to adverse impacts on the organism carrying the body burden. At this time, body burden information is still only useful to indicate that the organism has been exposed to available forms of a chemical constituent that have accumulated in the aquatic organism tissue. The level of accumulation, however, as typically measured does not provide an indication of harm to the organism.

A bioaccumulatable chemical that is receiving increasing concern across the US is mercury. In some areas, such as for Minnesota lakes and San Francisco Bay, many of the fish contain concentrations of mercury above that which is considered safe for human consumption. The increased attention being given to mercury today arises primarily from the situation where significant decreases in allowable concentrations of mercury in fish are being adopted as part of protecting human health. Using risk-based assessments, the US EPA and some state regulatory agencies are decreasing the allowable concentrations of mercury in fish flesh considered safe for human consumption by factors of 10 to 100. This is causing a significant increase in the number of human health fish consumption advisories across the US associated with excessive mercury in fish.

As part of examining bioaccumulation of hazardous chemicals in fish taken from San Francisco Bay, the Regional Water Quality Control Board, San Francisco Region (SFRWQCB 1995) developed a summary of screening values for excessive concentrations of hazardous chemicals in fish that would be a threat to human health based on consuming 30 grams of fish per day (one meal per week). While the FDA action level for mercury is 1 mg/kg, the SFRWQCB screening value is 0.14 mg/kg. Similarly, the FDA action limit for total DDT is 5 mg/kg, the SFRWQCB screening value is 0.069 mg/kg. For total PCBs, the FDA action level is 2 mg/kg and the SFRWQCB screening level is 0.003 mg/kg. These screening values causes many of the higher trophic level predator fish to contain excessive mercury and several chlorinated hydrocarbon pesticides, PCBs and dioxins. This, in turn, has caused the California Department of Health Services to issue a health advisory for consumption of fish from San Francisco Bay due to mercury and several chlorinated hydrocarbons.

Lead is one of the chemicals of concern in urban area and highway stormwater runoff for which neither the FDA nor the US EPA (SFRWQCB 1995) has developed critical tissue concentration values. Recently, Cox (1997) determined that lead concentrations in fish tissue above 0.3 mg/kg would represent hazardous levels to children who consume an average of 54 g/day of fish. This fish consumption amount is slightly higher than the US EPA value of 30 g/day, but is on the order of one meal per week. Consuming fish with concentrations of lead above this value would represent a threat to a child's health similar to the threat associated with drinking two liters of water per day with concentrations of lead above the US EPA action level of 15 μg/L.

Lee and Jones-Lee (1996h) have summarized the US EPA's recently developed information for determining excessive concentrations of bioaccumulatable chemicals. As they discussed, the US EPA has a major effort underway devoted to developing guidance on excessive bioaccumulation issues. However, a key issue that the US EPA has not yet addressed is that of properly translating the US EPA water quality criterion for mercury, such as the "Gold Book" criterion, into excessive mercury concentrations in fish tissue. This issue could be important for urban area and highway stormwater runoff water quality managers.

While there is limited data on mercury content in urban area and highway stormwater runoff, there is an indication from these data that the concentrations of mercury in such runoff may be in excess of the US EPA water quality criterion of

0.02 µg/L. Unfortunately, mercury was not one of the parameters that was measured in the US EPA NURP urban area stormwater studies. Barrett, *et al.* (1995) have compiled a summary of literature data on concentrations of constituents in highway stormwater runoff where they report a mercury concentration of about 3 µg/L. If this value is representative of what is present in urban area and highway stormwater runoff, then mercury is another of the constituents in such stormwater runoff that exceeds the US EPA water quality criterion.

It would be important for stormwater managers who find "excessive" mercury in their runoff waters to determine, using the EM approach, whether the fish in the receiving waters for the stormwater runoff contain excessive mercury in their edible tissue. If these fish do not contain excessive concentrations of mercury then there should be no need for the implementation of BMPs to control mercury in the runoff. If, however, excessive mercury is found in the fish, then there would be need to determine whether the highway and urban area stormwater runoff to the waterbody is causing or is significantly contributing to the excessive mercury concentrations in fish tissue.

It is recognized that the key to excessive mercury in fish tissue is the methylation of mercury to form methyl mercury in the waterbody sediments. Methyl mercury is the primary form of mercury that bioaccumulates to excessive levels in fish tissue. Mercury is one of the heavy metals that the US EPA does not allow regulation based on dissolved forms. The justification for this is that the methylation process appears to take place in aquatic sediments under reducing (anaerobic) conditions. While the processes governing methylation of mercury in sediments are not well understood, it appears that it is not proportional to the total mercury content of the sediments. There appear to be differences in the ability of microorganisms present in the sediments to convert various forms of mercury, presumably particulate mercury, into methyl mercury.

An approach that could be used to determine whether the mercury in the highway and urban area street stormwater runoff significantly contributes to the rate of methyl mercury formation in the receiving water sediments involves taking samples of receiving water sediments to determine the rates of methyl mercury formation under standardized laboratory conditions with and without the addition of stormwater runoff associated mercury. If the stormwater runoff associated mercury does not significantly alter the rates of methyl mercury formation, then it could be concluded that, at least to the extent that the laboratory methylation studies replicate the processes that occur in the receiving waters, there would be no justification for developing BMPs for reducing the mercury input associated with stormwater runoff.

If it appears that the stormwater runoff associated mercury increases the rate of methylation of the mercury in the receiving water sediments, then efforts should be made to control mercury at the source for the highway and urban area stormwater runoff. Of particular concern is the mercury content of the atmosphere since it is being found that one of the major sources of mercury in water bodies is mercury emitted to the atmosphere through various combustion processes such as the burning of fossil fuel, municipal solid waste incineration, etc.

As with aquatic life toxicity due to stormwater runoff associated constituents, site-specific BMPs can be developed to control those constituents in urban area street and highway stormwater runoff which lead to excessive bioaccumulation in aquatic organisms in the receiving water for the runoff. It is important not to assume, as is often done, that all sources of a bioaccumulatable chemicals, such as mercury or chlorinated hydrocarbon pesticides and PCBs, contribute chemical forms of the constituents that are that are bioaccumulatable. As with toxicity, only certain forms of constituents in the water column and sediments are bioaccumulatable. It is therefore, important in identifying sources of constituents that are bioaccumulating to excessive levels, to specifically focus on determining those sources that lead to excessive bioaccumulation in the waterbody aquatic life of concern to the water quality use impairment due to excessive bioaccumulation.

Through forensic studies involving a combination of chemical and bioaccumulation measurements, the specific source(s) of bioaccumulatable chemicals can often be determined. Benthic organisms, while not a reliable indicator of the actual bioaccumulation that will occur in higher trophic level organisms of concern because of the human health hazard that they represent to their use as food, can be used to help identify the source(s) of bioaccumulatable chemicals for higher trophic level organisms in a waterbody.

Often the measurement of the chemical characteristics of aquatic life tissue as part of bioaccumulation studies shows a variety of unidentified chemicals within the tissue. These typically show up as unidentified instrument responses in a specific analytical program such as associated with GC or GCMS analysis of aquatic organism tissue. As part of conducting EM bioaccumulation evaluation of potential bioaccumulation problems in a waterbody, it is important to record the presence of the unidentified analytical instrument peak. The finding of the same unidentified peak in an aquatic organism tissue over time can and should lead to specific studies to determine the nature of the chemical(s) responsible and, once identified, its potential health hazard.

As part of the examination of aquatic life for bioaccumulatable chemicals in an EM program water quality problem definition study, an aquatic organism physiology expert should examine the collected organisms for tumors within various organs to determine whether there are chemicals in the waterbody that are causing tumors or other organ abnormalities in aquatic life. Since not all laboratories have the expertise to conduct this type of analysis it may be necessary to contract with individuals who have the expertise.

Sediment Toxicity Issues

It is possible that chemical constituents in urban area street and highway stormwater runoff could accumulate in receiving water sediments, thereby causing a significant use impairment of these waters through sediment toxicity, and/or serving as a source of chemicals that lead to excessive bioaccumulation in aquatic organism tissue. Concern for this issue is heightened to some degree as a result of the US EPA no longer regulating ambient water particulate forms of some heavy metals. US EPA NURP (Pitt and Field, 1990) confirmed what had been found earlier, that many of the heavy metals in urban area and highway stormwater runoff are in particulate forms. This causes sediments near urban area street and highway stormwater runoff to typically contain elevated concentrations of constituents in the receiving water sediments. The accumulation of chemicals in sediments can be due to either particulate forms of the constituent in the urban area street and highway stormwater runoff or dissolved forms in the runoff which become particulate in the receiving waters through sorption, precipitation and/or bio-uptake by lower trophic level organisms, such as algae, which die, settle and become part of the sediments.

An area of significant confusion exists with respect to the relationship between the concentration of a chemical constituent in sediments and the water quality impacts of this constituent. The concentration of constituents in sediments is usually expressed as mg of constituent per kg of sediment. For water-based concentrations, the expression of the concentration, i.e. mg/L or mg/kg where one liter equals about one kg of water, the characteristics of the liter of kilogram are the same, i.e. water. For sediments, the bulk matrix of the sediment which makes up the mass is of variable physical and chemical characteristics. A kg of sediment from one location can be significantly different in its bulk characteristics than a kg of sediment from another location. The bulk constituents of concern include different sized fractions, clays, silts, sands and different chemical characteristics for bulk organic and inorganic constituents. Some sediments are primarily composed of silica, while others are composed of carbonates, organics, etc.

A variety of chemical reactions occur in aquatic sediments which detoxify heavy metals and other constituents, rendering them inert. This detoxification is primarily controlled by the bulk characteristics of the sediments. For heavy metals, the detoxification is controlled primarily by the sulfide content where high sulfide content in sediments can have higher concentrations of heavy metals without being toxic. This is due to the metals forming highly insoluble metal sulfide precipitates which are non-toxic and non-available to aquatic life. For organics, such as pesticides, the total organic carbon content of the sediments is the primary detoxification factor. Many organic constituents of concern tend to sorb on organic particles, rendering them non-available and non-toxic. It has been found that the fraction of the heavy metal or other constituent of concern in sediments that is dissolved in the interstitial (pore) water in the sediment is the fraction that is potentially toxic. The part of the heavy metal or other constituent that is bound to the sediment particle is in a non-toxic, non-available form. In general, because of the detoxification capacity of aquatic sediments and the forms of constituents in urban area street and highway stormwater runoff, it would be rare that heavy metals, and many other constituents in urban stormwater runoff from highways, streets and residential areas, as well as many commercial and industrial areas, would be toxic in aquatic sediments to a sufficient extent to impair the designated beneficial uses of the waters associated with the sediments.

It has been known for over 25 years that it is not possible to use heavy metal concentrations in sediments to reliably predict water quality problems associated with heavy metals. It is necessary to use biological effects-based evaluations of potential water quality impacts (toxicity and bioaccumulation) to determine if heavy metals, or other constituents in sediments, are significantly impairing the beneficial uses of a waterbody. Since the mid-1970s, the US EPA and the US Army Corps of Engineers (COE) have been regulating excessive concentrations of chemicals in sediments associated with navigational waterway dredging and dredged sediment disposal as they may impact the beneficial uses of the waterbody in which the disposal takes place. Based on research in the 1970s under the COE's Dredged Material Research Program, the US EPA and the COE adopted an effects-based approach involving direct measurement of sediment toxicity and estimates of bioaccumulation. In 1991, the US EPA and the COE updated their testing manual for ocean disposal of contaminated sediments (US EPA/COE, 1991). The Agency and Corps are now updating their freshwater dredged sediment disposal manual, based on similar approaches to those used for nearly 20 years (US EPA/COE, 1994). The US EPA (1992c, 1993c, 1994d) has published additional information on sediment quality evaluation procedures. A discussion of the development and use of these procedures is provided by Lee and Jones (1992a) and Lee and Jones-Lee (1994d).

Biological effects-based techniques are well-established to determine whether potentially toxic constituents that accumulate in sediments are adverse to the waterbody. As with water column effects, the EM program should be conducted to define real water quality use impairments associated with any accumulated runoff-derived constituents in the receiving water sediments. Lee and Jones-Lee (1993a, 1994d, 1996i) have reviewed issues pertinent to evaluating the water quality significance of chemical constituents in aquatic sediments. As they discuss, both aquatic life toxicity to a suite of sensitive aquatic organisms and bioaccumulation in aquatic organism tissue of chemicals that are of potential concern to human health and wildlife should be evaluated as part of a biological effects-based sediment quality evaluation. Selected chemical analysis of the sediment should be made as part of the TIE evaluation conducted to determine the cause of the toxicity for the regulated chemicals, such as heavy metals, PAHs, and ammonia, and for the constituents in aquatic sediments that tend to detoxify/immobilize regulated chemicals (total organic carbon [TOC], sulfides, carbonates, etc.).

Similar approaches to those developed by the US EPA and COE could readily be used to address the issue of whether chemical constituents in urban area street and highway stormwater runoff are responsible for significantly adversely impacting the beneficial uses of the waterbody receiving the runoff through accumulation of dissolved and particulate constituents in the runoff in the receiving water sediments. Toxicity tests, field bioaccumulation studies and benthic aquatic organism assemblages (numbers, types and characteristics) can be used in a non-numeric, best professional judgment, weight-of-evidence triad to determine whether aquatic sediments in the vicinity and downstream of an urban area street and highway point of runoff are a significant contributor to the impairment of the designated beneficial uses of the receiving waters for the runoff. Further information on this approach is provided by Lee and Jones (1992) and Lee and Jones-Lee (1993a).

Sediment toxicity should be assessed by direct measurement using several types of sensitive aquatic organisms at several times over a year for at least a year. Further, since the sediment toxicity assessment requires testing of toxicity in a sediment versus that of a reference site which is supposed to have the same physical, chemical and biological characteristics as the test site except for the presence of anthropogenically-derived chemical constituents of potential concern as a cause of sediment toxicity, it is essential in reliably assessing sediment toxicity that several reference sites be tested at several times during the year in order to evaluate whether the sediments of concern do, in fact, contain potentially significant toxicity. The approach of using a single sediment sample versus a single reference sample with a single test organism can readily lead to an erroneous assessment of sediment toxicity. Further, chemically-based estimates of toxicity such as those derived from Long and Morgan and/or AET co-occurrence-based values (Long and Morgan, 1990; Long *et al.*, 1995; MacDonald, 1993; WSDOE, 1991) as well as the US EPA's equilibrium partitioning approaches (US EPA, 1993f) are not reliable for estimating sediment toxicity.

There is increasing information that shows that co-occurrence-based approaches and equilibrium partitioning approaches can lead to significant errors in evaluating sediment toxicity (Lee and Jones-Lee, 1996,i,j,k) as well as references contained therein). The authors have found that the review by Dragun and Chiasson (1991) provides useful information on the expected concentrations of various elements in soils that can be used to determine whether an aquatic sediment contains various constituents above the normal soil concentrations. It is important to emphasize, however, that even greatly elevated concentrations of heavy metals in sediments compared to expected concentrations in the soils should not be interpreted to mean that the constituents in the sediments are adverse to aquatic life and other beneficial uses of a waterbody. Site-specific investigations must be conducted to determine if the elevated concentrations of the constituents are in a form that is toxic and/or bioavailable to aquatic life.

There are some who attempt to justify the use of detention (settling) basins and filters as BMPs based on the removal of heavy metals in urban area and highway stormwater runoff that can cause sediment toxicity in the receiving waters. Such an approach, however, is not valid since it is not possible to translate, with any degree of reliability, particulate heavy metals in stormwater runoff to sediment toxicity in the receiving waters. The aquatic chemistry of particulate heavy metals in stormwater runoff is significantly different from the aquatic chemistry of bedded sediments. There is widespread agreement among those knowledgeable in this topic area that sediment toxicity issues should be regulated based on site-specific characterization of the sediments, rather than trying to regulate based on concentrations in runoff waters. Attempts to use the latter approach will almost certainly lead to significant errors in estimating the water quality significance of particulate forms of heavy metals in runoff waters.

Often, total chemical concentration data are developed on the chemical characteristics of sediments. While it has been well known for about 30 years that there is no relationship between the total concentration of a constituent in sediments and its water quality impacts, various approaches have been contrived to try to use total concentration data in assessing the water quality significance of chemical constituents associated with aquatic sediments. Various regulatory agencies, including parts of the US EPA, are attempting to estimate sediment quality based on co-occurrence-based approaches, such as Long and Morgan values. A part of the US EPA is attempting to conduct a draft National Sediment Quality Survey (US EPA, 1996c) and a draft "National Sediment Contaminant Point Source Inventory: Analysis of Facility Release Data" (US EPA, 1996d) where the Agency is using co-occurrence-based values to estimate sediment quality. While the US EPA discusses at length the significant deficiencies with the use of co-occurrence-based values which assume there is some type of relationship between the total concentration of chemical constituents in aquatic sediments and the impact of the constituents on water quality, the Agency persists with using these values to develop guidance for Congress on the magnitude of the national sediment quality problem and the role of point source and non-point source discharges in causing this problem. However, as discussed by Lee and Jones-Lee (1996,i,j,k), it has been known since the early 1970s that any attempt to relate the total concentration of a chemical constituent to adverse impacts is fundamentally flawed and is not reliable.

Lee and Jones-Lee (1996l,m) have discussed the inappropriate approaches used by the US EPA in developing reports to Congress on national sediment quality issues. Rather than following a technically valid approach of properly assessing whether sediments in a particular waterbody are adverse to the designated beneficial uses of the waterbody due to the presence of chemical constituents which could be toxic and/or lead to excessive bioaccumulation, the Agency is persisting in using overly-simplistic, technically invalid approaches that can lead to significant errors in evaluating the real water quality significance of chemical constituents in sediments. Rather than trying to estimate sediment toxicity through technically invalid approaches, procedures of the type developed by the US EPA and COE for managing contaminated sediments involving direct measurement of toxicity should be used.

The approach that should be used to determine whether sediment toxicity is potentially significantly adverse to the beneficial uses of a waterbody should involve a best professional judgement (non-numeric), triad assessment of sediment toxicity data, appropriately developed and used aquatic chemistry information and organism assemblage data. The aquatic chemistry information should not be based on chemical concentration data relative to some supposed adverse impact such as occurs in the use of Long and Morgan values and/or AETs, but instead should be based on a TIE type evaluation to assess whether sediments contain sufficient concentrations of detoxifying constituents to render a particular chemical of concern non-toxic. For heavy metals, the detoxifying agent is sediment acid volatile sulfides (AVS) under anoxic conditions and hydrous ferric hydroxide under oxic conditions. For non-polar organics such as some of the chlorinated hydrocarbon pesticides and PAHs, the detoxifying agent is total organic carbon..

The organism assemblage data focus on the numbers, types and characteristics of the benthic and epibenthic organisms that should be present in a waterbody sediment relative to the physical, chemical and biological habitat characteristics. For freshwater systems, the procedures of Plafkin *et al.* (1989) can be used to develop organism assemblage data that can be used in a triad best professional judgement evaluation of sediment quality information. None of the three components of the triad can and should be used as the primary criterion. All three components must be used in a technically valid, appropriate, non-numeric manner to evaluate whether the presence of regulated or unregulated chemicals in a sediment derived from urban area or highway stormwater runoff or, for that matter, any other source are significantly adverse to the beneficial uses of the waterbody in which the sediments are located to cause the implementation of a BMP to control further input of those constituents from that source as well as the remediation of the sediments to remove the constituents that cause the adverse impact.

One of the issues discussed by Lee and Jones-Lee (1996i) that is not normally considered in making sediment quality evaluations is the role of natural toxicity in sediments in influencing sediment quality. Many aquatic sediments are naturally toxic due to low dissolved oxygen, hydrogen sulfide and ammonia. This situation arises from the fact that the natural input of aquatic plant nutrients and allochthonous (terrestrially-derived), biodegradable particulate organics exert a biochemical oxygen demand in the receiving water sediments. This oxygen demand uses up the dissolved oxygen within the sediments which then sets off anaerobic reactions that result in the production of hydrogen sulfide and ammonia accumulation in the sediments. Low DO, hydrogen sulfide and ammonia are toxic to many forms of aquatic life. This is especially true for some of the more important forms such as fish and shellfish larvae. In addition to natural sources of nutrients (nitrogen and phosphorus) which cause algal growth in a waterbody that results in sediment oxygen demand, the activities of man in a waterbody's watershed can greatly increase the nitrogen and phosphorus loads to waterbodies and therefore increase the low dissolved oxygen, hydrogen sulfide and ammonia toxicity that occurs in sediments.

As discussed by Lee and Jones-Lee (1996i), the US EPA through their EMAP studies has shown that low DO, hydrogen sulfide and ammonia toxicity are the primary causes of toxic conditions in many sediments. While some regulatory agencies focus their activities only on traditional Priority Pollutant parameters as a cause of sediment toxicity, such an approach is technically invalid since the natural and nutrient-based toxicity may be as important, if not more important, in influencing the numbers, type and characteristics of important benthic organisms in a particular waterbody.

Another complicating factor in this situation is the fact that many waterbodies, such as eutrophic lakes, have high levels of aquatic life toxicity associated with the sediments, yet have outstanding fisheries. The presence of sediment aquatic life toxicity as measured in the standard toxicity tests does not necessarily mean that the designated beneficial uses of the waterbody of concern to the public are significantly impaired. Lee and Jones-Lee (1996i) point to the importance of the US EPA, other regulatory agencies and others devoting considerable resources to developing guidance on how to translate laboratory-based sediment toxicity results to water quality use impairments of concern to the public that would cause the source of the constituent inputs to a waterbody, such as nutrients that stimulate algal growth, heavy metals and/or organics present in stormwater runoff, to be controlled. Without this type of information, it is likely that significant over-regulation of sediment toxicity will continue to occur.

It is possible to conduct a sediment-based TIE to determine the cause of the toxicity for those sediments that are found to have sufficient toxicity to impair the beneficial uses of the waterbody. Ankley *et al.* (1991) have developed guidance on conducting TIEs on aquatic sediments. The information developed from the TIE can then be used to develop a technically valid, cost-effective approach for implementing stormwater runoff BMPs.

If significant water quality use impairments are found with sediment-associated constituents derived from urban area street and highway stormwater runoff sources, then site-specific BMPs focusing on source control can be developed which will specifically address the dissolved and/or particulate constituents in the runoff that are responsible for the sediment constituent-associated impairment of the waterbody's beneficial uses.

Aquatic Organism Assemblages

The EM program discussed herein focuses on utilizing biological effects-based test responses, such as toxicity tests, that can provide an indication of a water quality use impairment that is occurring in the receiving waters for the urban area street and highway stormwater runoff. The bottom line issue, with respect to the development of BMPs to control aquatic life resource impairment, is whether the numbers, types, and characteristics of the aquatic organisms in the receiving waters for the urban area street and highway stormwater runoff are sufficiently adversely impacted so that control of the constituents responsible for the use impairment through the development of BMPs to the maximum extent practicable should be implemented. In those situations where the testing procedures, such as ambient water toxicity tests, predict significant impairment as a result of finding widespread prolonged toxicity associated with a runoff event, the EM program should include examination of the numbers, types, and characteristics of the biological organisms within the receiving waters to be certain that the toxicity tests have reliably predicted the adverse impacts.

The US EPA is developing biological criteria specifically designed to evaluate whether the numbers, types, and characteristics of the organisms in a waterbody have been adversely impacted by input of chemical constituents. The Agency has developed a biological criteria manual that provides guidance in making this type of evaluation (US EPA, 1990b, 1996g). Further, the Agency has recently revised its Water Quality Criteria Handbook, which should be consulted for further information on this and related topics (US EPA, 1994f). It is important, however, in making an evaluation of this type, to clearly distinguish between: (1) the impacts of habitat characteristics and physical factors, such as climate, flows, storms, etc., that may influence aquatic organism assemblages, and (2) those that are due to chemical constituents derived from urban area street and highway stormwater runoff. Lee and Jones (1982) have provided guidance on how to utilize aquatic habitat information in determining whether chemical constituent input to a waterbody (streams) is adversely impacting the numbers, types, and characteristics of organisms that could be present in the waterbody, based on the waterbody's habitat characteristics.

Another factor that must be considered in evaluating changes in aquatic organism assemblages is the biological effect due to predation by organisms that are present in an area for a short period of time. Migratory species as well as the introduction of exotic species of organisms (biological pollution) into an area can significantly adversely impact the numbers and types of organisms in a region from those that would be expected based on habitat characteristics. In addition to predation, consideration must be given to exotic organisms that become so dominant in an area as to change the availability of food for native species. This situation appears to be occurring with the introduction of exotic clam species into San Francisco Bay which have altered the phytoplankton populations to a sufficient extent to adversely affect the growth of other organisms. Hollibaugh and Wong (1996) discussed the influence of grazing by clams in limiting phytoplankton populations as an important factor influencing estuarine organism populations in San Francisco Bay.

For the purposes of an Evaluation Monitoring program, "significant impairment" of biological resource beneficial uses should be defined on a site-specific basis.

The receiving waters are assessed and a determination is made as to whether the receiving water is "significantly impaired" relative to each of the key components of potential water quality impairment discussed herein (organism assemblages, toxicity, bioaccumulation, litter, sediment, etc.). This determination should made in consultation with regulatory agencies and others as appropriate. The ultimate goal of the program is the protection of the designated beneficial uses of the waterbody receiving stormwater runoff. Technical stakeholders should utilize a best professional judgement, non-numeric weight-of-evidence approach to assess whether significant impairment has or will likely occur.

Contaminated Soils

One of the areas of particular concern to stormwater dischargers in California is the Department of Toxic Substances Control's (DTSC) definition of "hazardous waste" which includes a total lead content of the wastes. Any soil or sediment that is a waste that has over 1,000 mg/kg dry weight total lead is, according to current California policy, a hazardous waste. This regulatory total threshold limit concentration (TTLC) is causing Caltrans District 7 (Los Angeles District) to spend many millions of dollars per year cleaning out Caltrans highway stormwater runoff catch basins where the removed material is handled as a hazardous waste since the concentration of lead in the material exceeds the DTSC limit for total lead in a waste. This situation arose out of a court order where the Environmental Defense Fund filed suit against Caltrans for failing to properly implement its stormwater runoff water quality management programs required under its NPDES permit. The judge concluded without adequate review in issuing his ruling on the lawsuit, that any material that is classified as a hazardous waste must be adverse to the environment. However, as discussed below, a critical review of this situation shows that the lead in stormwater runoff from urban areas and highways is in a non-toxic, non-available form and is not adverse to aquatic life in an aquatic environment. The DTSC hazardous waste classification was not based on aquatic environment considerations, but based on human health which can include ingestion of the wastes and the solubilization of the lead in the wastes at the low pH that occurs in a child's stomach.

Mahmood (1996) developed a review of lead contamination in soils near highways. His review shows that while many soils near highways and in storm drainage ponds contain lead at less than 500 mg/kg, some soils near highways have lead concentrations above 500 mg/kg and few above 1,000 mg/kg. Lee and Jones-Lee (1992b) have reported that urban area soils and sediments near highways and streets frequently contain lead at concentrations above 500 mg/kg. There are some soils and sediments near major highways and in urban area centers that have lead in excess of 1,000 mg/kg. The high lead values arose from the use of lead as an additive in gasoline. While leaded gasoline is no longer used in automobiles the US, gasoline still contains sufficient lead from natural sources to cause elevated lead in highway and street stormwater runoff. This lead is in a particulate form and tends to accumulate in stormwater conveyance structures and is removed in detention basins and filters. There is a potential for concentrations of lead in the sediments and soils associated with urban streets and highways to exceed the DTSC 1,000 mg/kg TTLC value.

The California DTSC is in the process of re-examining its hazardous waste classification system which causes wastes in California to be classified as hazardous wastes but are not classified as hazardous wastes by the US EPA and other states. This California-only hazardous waste is placing a significant economic burden on the California public. The current DTSC hazardous waste classification review could lead to a more appropriate assessment of whether highway and urban area street stormwater runoff-associated lead that accumulates in stormwater conveyance and treatment structures, such as detention basins, requires management as a hazardous waste. Recently DTSC has proposed to raise the TTLC value for lead from 1,000 to 8,500 mg/kg. Since urban soils typically contain total lead concentrations from 500 to 1,500 mg/kg, the proposed revised TTLC value for lead could eliminate the classification of soils/sediments associated with highway and urban streets that accumulates in highway and urban street stormwater conveyance and treatment structures as being classified as a hazardous waste. Adoption of this approach would more appropriately regulate the lead in soils and sediments associated with stormwater runoff from highways and urban streets than is being done today.

Lee and Jones-Lee (1992b) have reviewed the information available on the significance of lead in soils as it may impact children's health. Lead is recognized as one of the most significant environmental causes of adverse impacts to the health of children. Young children tend to be impacted by lead through neurological damage at much lower concentrations than have been found to impact adults (ATSDR, 1993). Chronic exposure of children to lead is also adverse to children's growth (Kim *et al*, 1995). Of particular concern is children's ingestion of lead-based paints. Also of concern is the ingestion of lead containing soils. While there are well established links between children being exposed to lead-based paint and blood lead levels that are considered adverse to a child's health, the linkage between lead in soils in which children play and blood lead levels is tenuous. Tsuji and Serl (1996) found that there was a poor correlation between children's blood lead levels and soil lead concentrations below 1,000 mg/kg.

Lee and Jones-Lee (1992b) reviewed the various regulatory approaches that have been adopted in the US and other countries to protect children from adverse impacts from soil lead. In the early 1990s there were a number of regulatory agencies that established critical soil lead levels of 50 to 100 mg/kg. The Society for Geochemistry and Health (Wixson and Davies, 1993) developed recommended guidelines for lead in soils which involved a complex relationship between soil lead concentrations and blood lead levels. Additional information on the significance and control of soil lead and lead based paint children's health issues is available in the conference proceedings edited by Beard and Iske (1995).

The US EPA (1994g) developed an integrated exposure uptake kinetic model for lead in children. Based on this modeling approach, it is recommended (Alliance, 1994) that soil lead concentrations below 400 mg/kg not be of concern. In the concentration range of 400 to 2,000 mg/kg, restrictions should be implemented to reduce children's exposure to the bare soil. No further investigation is generally considered necessary in this concentration range. Above 2,000 mg/kg soil lead, a public notice of the lead contaminated soils should be issued and the conditions should be monitored. Interim controls to establish barriers to the contaminated soil should be implemented. Above 5,000 mg/kg, the US EPA recommended approach requires removal and replacement of soils or establishment of permanent barriers.

From the information available today the DTSC waste lead classification, which classifies any soil that is a waste with a lead concentration above 1,000 mg/kg as a hazardous waste, is significantly out of date and highly overprotective. This is the impetus behind DTSC's current proposal to raise the lead hazardous waste classification limit to 8,500 mg/kg. Even the 1,000 mg/kg value appears to be overprotective for children's occasional contact with soils containing lead at this value. The current Caltrans situation of court ordered spending of large amounts of public funds for control of soils and sediments associated with highway stormwater runoff because some of the particulates in this runoff that accumulate in conveyance structures and treatment works contain concentrations of lead above 1,000 mg/kg, is technically invalid.

Since today's highway and urban street stormwater runoff frequently contains total lead at concentrations above the US EPA water quality criterion and state standards based on this criterion value, there is concern that the stormwater runoff from urban areas and streets will cause an exceedance of the lead standard in the receiving waters for the runoff. This is especially true for those states that are using total heavy metal concentrations rather than soluble heavy metal concentrations as the regulatory basis for regulating lead and several other heavy metals. As of May 1995, the US EPA (1995c) has adopted soluble lead as the regulatory basis for regulating lead in ambient waters where the issue of concern is impact on aquatic life.

Peterson (1973) working under the supervision of the senior author, Dr. G. Fred Lee, conducted a PhD dissertation devoted to the aqueous environmental chemistry of lead in Wisconsin lakes. Of particular concern were the high concentrations of lead found in highway and urban area street runoff. At that time, late 1960s-early 1970s, extensive use of leaded gasoline was practiced. This caused stormwater runoff from streets and highways to contain high concentrations of particulate lead. The Peterson studies showed that this lead remained in a particulate, non-toxic, non-available form in the receiving waters water column and sediments for the highway and street stormwater runoff. Regulating lead as soluble lead rather than total lead has been recognized as the appropriate approach since the early to mid-1970s. The NAS/NAE (1973)Blue

Book of Water Quality Criteria of 1972 recommended that lead be regulated on toxicity testing since it was not possible, through chemical measurements, to predict toxic forms. The US EPA (1976) in its Red Book of Water Quality Criteria recommended that lead be regulated based on soluble lead rather than total lead.

While some stormwater managers, such as in the city of Sacramento, California, are devoting considerable efforts to develop lead control programs in stormwater runoff from city streets because of the exceedance of water quality standards for total lead in the runoff waters, such an approach can result in large expenditures of public funds with no impact on the beneficial uses of the receiving waters for the stormwater runoff. Because of the extensive work that has been done on the potential environmental impacts of highway and street stormwater runoff associated lead on receiving water aquatic life and other beneficial uses, it will be indeed rare that real water quality problems occur in the receiving waters for the stormwater runoff due to an exceedance of the water quality standard for total and soluble lead.

Stormwater quality managers should determine total and soluble lead in the runoff waters. If the concentrations are less than the US EPA criterion value, then it can be appropriately assumed that the lead in these waters does not likely represent a significant water quality problem in the water column and sediments. If, however, the concentrations are above the ambient water standard then the first step that should be followed before any lead runoff control program is formulated, is to investigate whether the "excessive" lead in the stormwater runoff is causing a real water quality use impairment in the receiving waters for the runoff. This will typically require a site-specific investigation of the water quality impacts of the elevated lead in the stormwater runoff. By following the Evaluation Monitoring procedures presented in this report focusing on aquatic life toxicity assessment and appropriate use of TIEs, it is possible to determine whether the lead in the stormwater runoff that exceeds water quality standards is causing a real water quality problem - use impairment in the receiving waters for the runoff. This is a far more technically valid, cost effective approach that the approach being used by some stormwater managers to address the exceedance of the lead water quality standard in stormwater runoff waters.

Excessive Fertilization-Eutrophication

The excessive fertilization of waterbodies is one of the major causes of water quality use impairment. This impairment is manifested primarily as an impact on the aesthetic quality of waters where excessive algal and waterweed (macrophyte) growth impacts the use for recreational purposes. For domestic water supplies, excessive fertilization leads to a number of problems, such as increased taste and odors, shortened filter runs, and in some instances increased trihalomethane precursors (Lee and Jones, 1991c). As discussed by Jones and Lee (1982, 1986) and Lee and Jones (1991b), while increasing the fertility of a waterbody results in an overall increased fish biomass, increased fertility generally results in a deteriorated quality of fish where less desirable, rough fish, such as carp, become predominate. Lee and Jones (1991a) have discussed the importance of evaluating the potential significance of urban area street and highway stormwater runoff-derived nutrient loads compared to other sources of nutrients for a waterbody in causing excessive fertility of a waterbody. Rast and Lee (1984) and Lee and Jones (1988b) have provided guidance on how this can be accomplished.

Per unit area, highway, street and urban areas tend to export more nitrogen and phosphorus per year than most agricultural/rural lands. An important exception occurs with dairies and some other animal husbandry activities. There are situations where urban street runoff has caused excessive fertilization of small urban lakes (Lee and Jones, 1980). Ordinarily, however, excessively fertile waterbodies near urban areas and highways obtain most of their nutrients from domestic wastewater sources, agricultural and rural land runoff, the atmosphere or from nitrogen compounds in groundwater that discharge to the waterbodies.

There are several important issues that need to be addressed in developing nutrient-based BMPs for urban area street and highway stormwater runoff. One of these is the need to focus the nutrient control program on those forms of nutrients (N and P) that can stimulate algal growth in the receiving waters. For most freshwater systems, the nutrient control program must be focused on algal-available phosphorus and not total phosphorus. Similarly, for those waterbodies in which nitrogen is the chemical controlling algal biomass that develops in the waterbody, the control programs must focus on available forms of nitrogen compounds. While for most fresh waterbodies, phosphorus is the element limiting algal biomass, there are situations, such as Lake Tahoe in California-Nevada, where nitrogen is the limiting element controlling algal growth. Under these conditions, it is the algal available nitrogen in the urban area street and highway stormwater runoff and those unavailable forms that are converted to available forms in the receiving waters relative to other sources of these nitrogen compounds that must be evaluated. Lee and Jones-Lee (1994e) have reviewed the Lake Tahoe nutrient (nitrogen) source situation where they have reported that the most significant source of nitrogen compounds (nitrate and ammonia) is the atmosphere, through direct precipitation on the Lake's surface. As they discussed, BMPs directed toward controlling nitrogen from associated land runoff will not be effective in controlling the excessive fertilization of Lake Tahoe that is occurring today since land runoff derived sources represent a small part of the total available nitrogen load to the Lake.

For marine waters, it is typically the algal available nitrogen that is the key constituent in controlling algal biomass in the receiving waters, although there may be situations where phosphorus can become an important element in controlling algal growth in near-shore marine waters. A site-specific evaluation of the relative significance of nitrogen versus phosphorus in controlling excessive fertilization of a waterbody must be made in order to determine whether algal-available forms of the controlling element present in urban area street and highway stormwater runoff are significant contributors to the excessive fertility of the waterbody.

Lee *et al.* (1980) have provided guidance on the determination of available forms of aquatic plant nutrients in runoff waters and sediments. Basically, for nitrogen it is the nitrate plus ammonia as N plus part of the organic nitrogen in the runoff waters that become available in the receiving waters to support algal growth. For phosphorus, it is the sum of the soluble orthophosphate plus about 20 percent of the particulate phosphorus that is available to support algal growth in urban area street and highway runoff. Site-specific determinations of available N and P can be assessed through the use of algal bioassays.

Lee and Jones (1988a) have provided guidance on the approaches that can be used to determine whether nitrogen or phosphorus is the key limiting element in controlling algal biomass in a waterbody. As they point out, a number of the approaches that are used, such as the ratios of N and P in the waterbody relative to typical algal stoichometry, are not necessarily reliable and can readily lead to incorrect conclusions on the significance of nitrogen or phosphorus in controlling algal growth. It is important to ascertain whether the proposed limiting nutrient is, in fact, decreased to algal growth rate limiting concentrations during peak algal biomass. If it is found that, during the peak of the algal bloom, the algae still have available to them surplus amounts of available forms of nitrogen and phosphorus, then these elements are not limiting the algal biomass.

It is also important to consider the hydraulic/morphologic characteristics of the waterbody (flushing time) receiving the urban area street and highway runoff at various times of the year. If it is found that nutrients added to the waterbody during one time of the year are effectively flushed out before the period of the year when excessive algal growth occurs, then the nutrients contributed to the waters during the non-growth periods are not contributing to the eutrophication-related water quality problems.

Further, a distinction should be made between: (1) eutrophication-related water quality problems, which are manifested as excessive growths of planktonic algae, and (2) the growths of attached algae, attached and floating macrophytes, and emergent vegetation. With respect to the latter, there is a poor understanding of nutrient load-concentrations/eutrophication response relationships.

Jones and Lee (1982, 1986) have provided guidance on how to evaluate the potential benefits of controlling phosphorus inputs to a waterbody to a certain degree on the eutrophication-related water quality of a waterbody. They recommend the use of the Vollenweider-OECD eutrophication study results. These results provide the technical base upon which estimates can be made of the site-specific benefits associated with controlling phosphorus inputs to a waterbody to a certain degree, relative to the total nutrient load to the waterbody.

Lee and Jones (1986) have found that at least a 25 percent reduction in the total available phosphorus load to the waterbody must occur before a discernible improvement in the planktonic algal-related water quality will occur. At this time, similar relationships have not been developed for nitrogen. However, it is likely that at least the same magnitude of control of algal available nitrogen must occur before there will be a discernible improvement in eutrophication-related water quality of a waterbody due to nitrogen input control.

Except for small urban lakes which receive their nutrients almost exclusively from urban area runoff, there will be few situations where control of nitrogen and phosphorus inputs associated with urban street and highway runoff to a waterbody will result in an improvement in eutrophication-related water quality of the waterbody. This is because urban area street and highway stormwater runoff-associated nutrients can rarely be controlled to a sufficient degree to reduce the total algal available nutrient loads to the waterbody sufficiently to cause a discernible impact on the eutrophication-related water quality of a waterbody.

It is sometimes stated that there is need to restrict the use of fertilizers on lawns, golf courses, highway right-of-ways and other areas in order to prevent excessive fertilization downstream from the point of urban area street and highway stormwater runoff. The development of BMPs to restrict use of these fertilizers should be done where it has been demonstrated that the current use is, in fact, causing a significant water quality problem in the receiving waters for the urban area street and highway stormwater runoff and where it can be shown that the projected restrictions will result in the improvement of the eutrophication-related water quality downstream of the urban area street and highway stormwater runoff discharge.

It is concluded that it will be rare that restrictions on lawn fertilization would be beneficial to the eutrophication-related designated beneficial uses of waterbodies receiving urban area street and highway stormwater runoff. The areas of greatest concern will be small urban lakes that only receive nutrients from urban area street and highway stormwater runoff. Typically, the amount of the algal-available aquatic plant nutrients derived from urban area street and highway stormwater runoff is small compared to that derived from other sources such as rural runoff and domestic wastewater inputs.

Upper Newport Bay, Orange County, California is experiencing excessive fertilization where attached algae cause significant water quality use impairments in the Bay each summer. This situation arises from excessive input of nitrogen and phosphorus to the Bay. One of the key issues that must be addressed as part of the application of the Evaluation Monitoring program to excessive fertilization issues is whether limiting the nutrient input to the waterbody annually and/or at certain times of the year would be expected to reduce the magnitude of the excessive fertilization problems that exist in the waterbody of concern to the public. To address this issue, a good understanding of the hydrologic regime and the limiting nutrient situation relative to excessive algae or aquatic plant growth must be developed. Failure to gain this understanding could result in waste of public and private funds attempting to control the aquatic plant nutrient input into the Bay.

The substantial amounts of work conducted on excessive fertilization of waterbodies in the 1960s and 1970s showed that particulate forms of nitrogen and especially phosphorus are largely unavailable to stimulate algal growth in waterbodies. Therefore, the construction of detention basins, filters, etc. for the control of excessive fertilization problems through reducing the particulate nitrogen and/or phosphorus input to a waterbody is not normally a technically valid BMP since it is largely ineffective in controlling the forms of N and P that stimulate excessive algae and other aquatic plant growth in a waterbody.

BMPs for the control of excessive fertilization should focus on dissolved phosphorus, nitrate and ammonia since these are the forms that are available in a waterbody to stimulate aquatic plant growth. Further, as discussed herein, excessive fertilization control programs should focus on controlling the aquatic plant nutrient input that limits algae and other aquatic plant growth in the waterbody during the period of excessive aquatic plant growth. Frequently, nitrogen or phosphorus are present in a waterbody in large surplus of that needed for further aquatic plant growth during the time that excessive growth is occurring. For some waterbodies that are experiencing high levels of excessive fertilization, neither nitrogen nor phosphorus are limiting nutrients for algal growth. It is important to understand the nutrient dynamics in the receiving waters for stormwater runoff sufficiently well so the Evaluation Monitoring program focuses on defining whether the control of nitrogen and/or phosphorus in stormwater runoff inputs to a waterbody will, in fact, lead to control of excessive fertilization within the waterbody.

One of the basic issues that has to be addressed is whether excessive algal or other aquatic plant growth in the waterbody is controlled by the annual load of available forms of a nutrient(s) or by the load of nutrients added to the waterbody under shorter periods of time. For Upper Newport Bay, the attached algae water quality problems occur primarily during late spring, summer and early fall. While in some years there may be late fall, winter and early spring algal blooms, these conditions appear to be fairly rare and are not the problems of primary concern to the majority of the public whose recreational activities associated with Upper Newport Bay are impaired.

Upper Newport Bay is an marine bay with a ten-day average flushing time. This means that most of the available forms of nitrogen and phosphorus added to the Bay in any particular stormwater runoff event will be flushed through the Bay into the Pacific Ocean within ten days or less after addition to the Bay. This is important in terms of determining whether there is need to control nitrogen and phosphorus inputs on a year-round basis in order to address the excessive fertilization problem that occurs in the late spring, summer and early fall. The water quality use impairment problems associated with the excessive fertilization of Upper Newport Bay are driven by recently added nitrogen and phosphorus inputs to the Bay. Nitrogen and phosphorus inputs during the winter will have limited impact on the excessive fertilization problems of the following summer. Therefore, there is little need or, for that matter, justification for controlling N and P inputs during late fall, winter and early spring.

It is important to focus the stormwater runoff monitoring program on the amounts of available forms of nutrients that are added to the waterbody during the critical periods of the year when these nutrients could cause water quality use impairments through stimulating excessive growths of algae or other plants. Site-specific understanding of the aqueous environmental chemistry of nitrogen and phosphorus added to the waterbody must be developed in order to define what the important sources of N and P are that lead to excessive fertilization problems during the critical eutrophication water quality use impairment period of the year.

For waterbodies that are experiencing excessive fertilization, such as Upper Newport Bay, it is important to determine whether the concentrations of nutrients in the Bay waters become growth rate limiting. For example, if there is significant surplus nitrate in the Bay waters compared to growth rate limiting concentrations for the aquatic plants of concern, then controlling nitrate input by a small amount that will not reduce the concentration during the period when there are excessive fertilization problems will be ineffective in controlling these problems. It is important not to get trapped into the "every little bit helps" syndrome, but instead focus the resources on understanding the problem sufficiently well so it can be controlled in a technically valid, cost effective manner. For Upper Newport Bay, it has been found that the nitrate concentrations during the summer when there is excessive algae are still well above growth rate limiting concentrations. The rate of growth of algae under these conditions would not be changed by adding additional nitrate to the waterbody during this time. Further, in order to limit the algal biomass that occurs during the summer months to any significant extent, it will be necessary to control the nitrate input during the early summer months to achieve a significant reduction in the concentrations that are available to the attached algae for growth.

It is the authors' experience that there are many waterbodies where the background inputs of key nutrients (growth rate limiting available forms of nitrogen and/or phosphorus) to a waterbody are sufficiently great from uncontrollable sources so that controlling the available forms of nitrogen and phosphorus in urban area and highway stormwater runoff will have no impact on the eutrophication-related water quality problems in receiving waters for the runoff. The Evaluation Monitoring program should be designed to specifically address this issue to ensure that funds spent for nutrient control associated with stormwater runoff are, in fact, effective in controlling real water quality problems.

Excessive fertilization issues are complex issues that cannot be reliably addressed in a superficial way such as that followed in typical receiving water monitoring programs. The Evaluation Monitoring approach, if properly used, can help direct the monitoring resources to focus on obtaining the information needed to determine whether controlling nitrogen and/or phosphorus inputs associated with stormwater runoff will likely improve the beneficial uses of a waterbody experiencing excessive algal or other aquatic plant growth.

Oxygen Demand

Frequently, urban area street and highway stormwater runoff monitoring programs will include measurement of biochemical oxygen demand (BOD) and/or chemical oxygen demand (COD) as part of the monitoring of the runoff. While urban area street and highway stormwater runoff can readily have measurable amounts of BOD, it is unlikely that this BOD will be of any significance in affecting the oxygen resources of the receiving waters for the runoff. Aquatic plant nutrients added to a waterbody can stimulate algal growth which, in turn, leads to oxygen depletion in a waterbody's sediments and for a stratified waterbody, its hypolimnion.

If low dissolved oxygen (DO) water quality use impairments are found in receiving waters, then specific studies would be conducted to determine the origin of the chemical constituents that lead to the dissolved oxygen depletion. Such depletions can be caused by BOD, algal and aquatic plant photosynthesis-respiration, and chemical reactions between constituents in runoff waters or stirred into the water column during runoff events from the sediments and the dissolved oxygen in the bay waters and runoff waters.

In thermally or salinity-stratified waterbodies, it is possible, especially during the summer months, that low DO waters near the bottom could be mixed into the water column associated with runoff events. This can result in a fish kill due to low DO and the toxicity of hydrogen sulfide and ammonia. In some situations, such as in shallow streams and bays, runoff waters will disturb the sediments so as to release sufficient quantities of ferrous iron and sulfide into the water column to cause depletion of the DO. Both ferrous iron and sulfide react rapidly with dissolved oxygen in the neutral pH range where the reactions take a few minutes to an hour or so for completion. Algal and aquatic weed-caused DO depletions show a cyclic diel pattern related to photosynthesis and respiration. This pattern points to the importance of measuring dissolved oxygen concentrations in the early morning hours in order to determine if critical concentrations of DO occur at that time. BOD-caused depletions are slow-acting, taking several days for significant exertion of the oxygen demand associated with the bacterial respiration due to the use of organics as a source of food.

Site-specific evaluation of the oxygen resources of a waterbody should be conducted to determine if BOD associated with urban area street and highway stormwater runoff is a significant contributor to the impairment of a waterbody's beneficial uses due to low DO. If such impacts are found, appropriate BMPs can be developed to control the BOD input to the waterbody from urban area street and highway stormwater sources. The approach that would be followed would focus on defining the specific sources of the high BOD materials in the stormwater runoff and controlling these constituents at the source.

Petroleum Hydrocarbons - Oil and Grease

This discussion focuses on the bulk effects of accumulated oil and grease and does not address the aquatic life toxicity of petroleum hydrocarbons present in petroleum products. Those problems are considered under aquatic life toxicity for the water column and sediments. The stormwater runoff from urban area streets and highways typically contains small amounts of petroleum hydrocarbons which can, under certain situations, cause water quality problems in receiving waters for the runoff. In most situations, there is no need to try to treat the urban area street and highway stormwater runoff to remove oil and grease since the small amounts of oil and grease ordinarily in this runoff do not cause significant water quality use impairments in the receiving waters. However, there are situations where petroleum hydrocarbons derived from oil and grease can be an important cause of water quality use impairments for urban area street and highway stormwater runoff.

As part of the EM program, the receiving waters should be periodically visually examined to determine if there are areas where oil and grease from the urban area street and highway stormwater runoff accumulate to a sufficient extent to be detrimental to aquatic life and other beneficial uses of the waterbody. Of particular concern would be fish spawning areas which accumulate sufficient amounts of petroleum hydrocarbons to be adverse to fish reproduction.

If the receiving waters are found to accumulate oil and grease from urban area street and highway stormwater runoff to a sufficient extent to be adverse to the designated beneficial uses of the waterbody, a site-specific BMP can be developed which would control the input of oil and grease to the maximum extent practicable and, if necessary, treat the runoff waters to remove the oil and grease to the extent necessary to prevent adverse impacts. Before treatment is undertaken, however, attempts should be made to control the petroleum hydrocarbon contribution to the urban area street and highway runoff based on source control activities.

Aquatic Life Carcinogens

Aquatic life in some areas, especially associated with petroleum hydrocarbon refining and industrial processes that introduce large amounts of PAHs into a waterbody, has been found to have tumors, lesions and other illnesses associated with the chemicals that are carcinogens. While this is apparently not a problem associated with urban area street and highway stormwater runoff, it would be important to examine some of the aquatic organisms in an area receiving such runoff to determine if they have tumors, liver or other organ lesions, abnormal organs, etc. that could be attributable to the constituents in the runoff. If problems of this type are found that are tied to urban area street and highway stormwater runoff, then site-specific BMPs can be developed to control at the source and, if necessary, treat the stormwater runoff to control the problem.

Sanitary Quality Contact Recreation/Shellfish

Urban area street and highway stormwater runoff typically contains elevated concentrations of fecal coliforms and other organisms that are indicators of waterborne enteric pathogens. The sanitary quality (contact recreation--swimming, wading, and shellfish harvesting) of the receiving water for urban area street and highway stormwater runoff can be adversely impacted by fecal coliforms (total coliforms for shellfish). The development of BMPs for urban area street and highway stormwater runoff to address the control of enteric pathogenic organism indicators, such as fecal coliforms, should be based on finding excessive concentrations of these organisms in receiving waters for the runoff that impair the use of these waters.

Excessive concentrations of fecal indicator organisms are usually manifested in beach or swimming area closures and/or restrictions on shellfish harvesting. If such closures/restrictions of use are issued for receiving waters for urban area street and highway stormwater runoff, it is necessary to determine whether the runoff is, in fact, a significant contributor to the frequency of closure/restrictions. If excessive concentrations of fecal indicator organisms are found, it will be important to determine whether there are connections between the sanitary sewerage system and the stormwater sewerage system which allow domestic wastewaters to enter the stormwater system during runoff periods.

Lee and Jones (1991d) have reported on the results of a study conducted in Lubbock, Texas where an evaluation was made of the impact of urban stormwater runoff-derived fecal coliforms and streptococci on recreational water quality in the Yellowhouse Canyon Lakes. These lakes are a chain of small lakes in a city park that receive appreciable stormwater runoff from the urban area. It was found that, immediately after a stormwater runoff event, the sanitary quality of these lakes decreased to the point where they were considered unsafe for contact recreation, such as swimming. However, within a week to two weeks after the runoff event, the water in the lakes again met sanitary quality standards for contact recreation. During this period there was sufficient removal of the fecal indicator organisms, through die-off and sedimentation, to reduce their numbers below the fecal coliform standards.

Often today, there are attempts to distinguish between fecal indicator organisms derived from humans versus animals through determination of fecal coliform-fecal strep ratios in swimming area closure situations. If these ratios indicate that the fecal indicator organisms are derived from animal rather than human sources, it is generally determined that there is less need for the closure of the contact recreation area. However, justification for this approach is questionable based on the fact that *Cryptosporidium* is derived, at least in part, from cattle and possibly other animals. This organism is becoming recognized as an important cause of enteric disease associated with domestic water supplies and contact recreation (Lee and Jones-Lee, 1993b, 1994f, 1995d). This is the organism that was responsible for causing approximately 400,000 people in Milwaukee, Wisconsin, to become ill and about 100 people to die in a water supply waterborne epidemic in the spring of 1993. The source of this organism was believed to be from cattle where stormwater runoff waters containing cattle feces entered the Milwaukee raw water supply.

While it has been known for many years that enteroviruses and cyst-forming protozoans can cause disease in humans, it was not until recently that it was beginning to be realized that these organisms are significant causes of disease through treated water supplies that meet coliform standards. Further, it is becoming recognized that there is a significant potential for contact recreation acquired diseases due to the presence of these organisms in the recreation waters. Haile, *et al.* (1996) have presented the results of "An Epidemiological Study of Possible Adverse Health Effects of Swimming in Santa Monica Bay" which has shown a relationship between contact recreation in nearshore Santa Monica Bay waters and the input of dry weather storm sewer flows to the Bay. Of particular concern was the presence of enteric viruses in the dry weather storm sewer inputs.

Because of the significant difference in resistance to destruction by chlorination as practiced in water supply and disinfected wastewaters that are free of fecal coliforms, humans can acquire disease due to the inability of typical chlorination-based disinfection in controlling enteroviruses and cyst-forming protozoans. An area that is receiving increasing attention as a potential source of enteric pathogenic organisms is the use of reclaimed wastewaters for irrigation of ornamental shrubbery and other areas such as highway right-of-way shrubbery. As discussed by Lee and Jones-Lee (1995d,e; 1996n), some regulatory agencies, such as the California Department of Health Services, allows the irrigation of ornamental shrubbery and golf courses with reclaimed domestic wastewaters that have not been adequately disinfected to control enteric viruses and cyst-forming protozoans such as *Cryptosporidium*. Disinfecting a domestic wastewater to just meet fecal coliform standards does not provide adequate disinfection to necessarily kill all the pathogenic enteric viruses and protozoan cysts. The use of partially treated reclaimed wastewaters to irrigate shrubbery along highways, parks, golf courses, etc. could lead to potential water quality problems associated with urban area street and highway stormwater runoff.

While it is possible to treat domestic wastewaters to reduce the risk of acquiring disease due to contact with areas that have been irrigated with reclaimed wastewaters or that have received stormwater runoff from these areas through advanced waste treatment, this level of treatment is not necessarily practiced. Lee and Jones-Lee (1995d,e; 1996n) recommend that reclaimed domestic wastewaters and runoff from areas irrigated with reclaimed wastewaters be monitored for fecal indicator organisms, such as coliforms, as well as enteroviruses and protozoan cysts, such as *Cryptosporidium* and *Giardia*. In those situations where there are beach or shellfish bed closures and/or domestic water supplies that are impacted by excessive concentrations of pathogenic organism indicators, it would be important to determine whether the use of reclaimed wastewaters in the watershed significantly increases the threat of human disease associated with stormwater runoff from the irrigated areas.

Lee and Jones-Lee (1996o) and Taylor and Lee (1997) conducted a review of the pathogenic indicator organism situation in Upper Newport Bay. It was found that Upper Newport Bay, California, which receives urban stormwater runoff as well as some illegal discharge of sanitary waste by boaters and raw sewage discharges from problems with the municipal sewerage systems associated with blockage, electrical failures, etc., has, at times, significant water quality problems due to excessive concentrations of fecal indicator organisms in Bay waters. The concentrations of fecal indicator organisms increased significantly with stormwater runoff events.

Domestic Water Supply Water Quality

Since chemical constituents and pathogenic organisms in urban area street and highway stormwater runoff are threats to domestic water supply raw water quality, it will be important to evaluate whether stormwater runoff from these areas is significantly adverse to a water utility's use of a waterbody as a raw water supply. For most water quality parameters, the EM approach discussed herein, which focuses on defining real water quality problems of significance to aquatic life and recreational uses of waters, will, in general, detect significant water quality problems for domestic water supplies. There are, however, some exceptions to this situation.

There are certain chemical constituents and pathogenic organisms in waters which are of concern because of their impact on raw water supply water quality. Examples would be low molecular weight organics which are potential carcinogens which do not bioaccumulate in fish tissue to a sufficient extent to cause health hazards for human consumption or consumption by higher trophic level organisms. Chemicals of this type are the VOCs (low molecular weight chlorinated solvents and volatile organics such as benzene). Ordinarily these types of chemicals are not considered to be the cause of water quality problems in stormwater runoff from urban areas and highway due to their high volatility since they are rapidly lost to the atmosphere. An important exception to this situation is the recent wide spread finding of MTBE (methyl tertiary butyl ether), a gasoline additive, in surface and groundwaters. While the full understanding of the sources, water quality significance and fate of MTBE is not known at this time, it appears from the information available that its recent introduction into gasoline as an additive is causing wide spread pollution of surface and groundwaters that may be associated with stormwater runoff from highways and streets. Tratnyek *et al.* (1997) organized a session of the American Chemical Society held in April, 1997 devoted to environmental fate and effects of gasoline oxygenates. MTBE has been found in over 51 public water supply systems. Further information on the potential significance of MTBE as a water pollutant is available in the various papers from the Tratnyek *et al.* (1997) ACS session.

The impact of urban area street and highway stormwater runoff on domestic water supply water quality needs to be considered from two perspectives; surface, and groundwater-based water supplies. The basic issue is whether urban area street and highway stormwater runoff introduces new constituents in sufficient amounts to be a significant threat to domestic and other water supply water quality. Both human health (hazardous chemicals and pathogenic organisms) and aesthetic quality should be considered, including taste and odor producing compounds, hardness, TDS, and other constituents that can impact domestic water supply water quality. In those situations associated with new developments where there is already appreciable urban area street and highway stormwater runoff contributed to a domestic water supply, the issue then becomes one of whether the additional load of urban area street and highway stormwater runoff-derived constituents represents a significant additional load that either causes the water utility to start treating to remove the constituents or to increase treatment costs to remove the additional load of constituents.

A chemical that could become extremely important in affecting domestic water supplies, but not other beneficial uses of waterbodies, is arsenic. Depending on the arsenic concentration the US EPA selects as the new Maximum Contaminant Level (MCL), arsenic could become one of the most important parameters influencing raw water quality. It is of concern because of its potential to cause cancer and other diseases in people. Some stormwater runoff studies have shown arsenic from urban areas to be at concentrations above some of the US EPA's proposed MCLs. In time, considerable attention will be given to specific sources of arsenic which cause a waterbody to have concentrations of arsenic that require treatment for use of the water for domestic water supply purposes. When this occurs, the sources of arsenic in urban area street and highway runoff will need to be determined to ascertain if the elevated concentrations of arsenic in the runoff can be controlled at the source.

Another group of chemicals of potential concern are the trihalomethane precursors (dissolved organic carbon [DOC]) that are derived from the decay of terrestrial and some forms of aquatic vegetation. Eventually, the US EPA and state regulatory agencies will be attempting to control sources of DOC for waterbodies in an effort to reduce the DOC content of the raw water. While various types of land use have differing DOC export coefficients (g of

DOC/m^2/yr), insufficient information is available at this time to indicate that stormwater runoff from highways and urban areas is a particularly significant source of DOC. This is an area that needs attention in any EM program. Further information on evaluation and management of domestic water supply raw water quality is found in the review by Lee and Jones (1991c).

For domestic water supplies that are based on groundwater sources, the issue becomes one of assessing the potential for urban area street and highway stormwater runoff-derived constituents to adversely impact the groundwater that is recovered from the area where urban area street and highway stormwater runoff-derived constituents are recharged into the aquifer system. While many aquifers have an appreciable ability to remove chemical constituents in recharged waters through soil aquifer treatment, there is a potential for build-up of persistent chemicals and/or transformation products of treated chemicals within the aquifer system. As discussed by Lee and Jones-Lee (1993c, 1994g,h), concern must also be given to whether constituents in recharged waters could cause the aquifer to become contaminated to a sufficient degree to lead to the need for aquifer remediation in a Superfund-like program.

All groundwater-based water utilities should be monitoring the characteristics of the recharged waters near the point of recharge to detect incipient water quality problems. Urban area street and highway stormwater runoff-derived constituents of potential concern should be added to the list of aquifer-based monitored parameters. Similarly, surface-based water supply systems should be conducting a detailed monitoring program of the raw water quality. If any of the urban area street and highway stormwater runoff-derived constituents represent a threat to the surface water quality, groundwater or aquifer quality, then site-specific BMPs should be developed to control the constituents at the source or to treat the urban area street and highway stormwater runoff to protect the water supply water quality.

<u>Groundwater Recharge</u>. In many areas, urban area street and highway stormwater runoff recharges groundwater basins. The chemical constituents and pathogenic organisms in the runoff can be a threat to groundwater quality. While in most instances the constituents in urban area street and highway stormwater runoff will not significantly alter the potential for the receiving waters to impair the uses of groundwater, there may be unusual situations where groundwater quality could be impaired by constituents in urban area street and highway stormwater runoff. Typically, the additional loads of constituents in runoff water are such that they do not significantly change the concentrations of constituents of concern for groundwater quality through the recharged waters. Further, many of the constituents with elevated concentrations in urban area street and highway stormwater runoff are in particulate forms which are removed from the recharge waters as the receiving waters plus the runoff waters percolate into the aquifer system.

Some of the dissolved constituents in highway runoff will be sorbed into the vadose zone (unsaturated) and saturated zone of the aquifer and thereby not cause groundwater quality-use impairment. The aquifer mobile fractions of the chemical constituents in the runoff waters such as nitrate, chloride, sodium, etc. are normally present in urban area street and highway stormwater runoff waters at concentrations that do not represent threats to groundwater quality. An exception to this situation is detention/infiltration basins where the constituents in the urban area street and highway stormwater runoff are not diluted in the receiving waters for the runoff. Under these conditions, it is possible to build up sufficient concentrations of some chemical constituents in the recharge waters to be a threat to groundwater quality.

At a location where urban area street and highway stormwater runoff is recharged directly or is a significant component of receiving waters that recharge an aquifer, such as in areas where infiltration of stormwater is used for stormwater runoff management, a site-specific evaluation should be made to determine whether the recharge waters are adversely impacting the quality of the waters in the aquifer. Typically, this is best done by sampling the groundwaters immediately under the recharge areas and down groundwater gradient of the recharge point. If excessive concentrations of chemical constituents found in the groundwaters can be attributed to recharge, evaluations should be made as to whether these constituents are derived to a significant extent from urban area street and highway stormwater runoff.

A special area of concern with respect to groundwater pollution by stormwater runoff is the potential for accidental spills of chemicals to cause pollution of aquifer systems. It is important, as part of developing an accidental spill contingency plan, to be able to contain the spill as much as possible in areas in which there are low-permeability aquifer materials, or paved surface as a barrier between the spilled chemicals and the water table. Further, in the event of a spill, those responsible for managing urban area street and highway stormwater runoff should be prepared to quickly begin remediation of the contaminated parts of the aquifer to prevent the spread of the spilled chemicals through the unsaturated-vadose zone and into the saturated ground waters.

Litter and Debris

Urban area street and highway stormwater runoff can carry appreciable quantities of litter and debris, which can impair the use of areas receiving the runoff. A key part of EM is determining whether litter and debris typically associated with urban area street and highway stormwater runoff is present in the receiving waters to a sufficient extent to impair the uses of the waterbodies and their nearshore associated areas. If visual inspection of the receiving waters shows that areas of this type occur, improved litter and debris control can be implemented to eliminate the use impairment that is occurring associated with the materials carried in the runoff.

Sediment Accumulation

Suspended sediment, derived from erosion or particulate matter, associated with urban area street and highway stormwater runoff can have an adverse impact on runoff receiving water quality. In addition to increasing the turbidity of the receiving waters, which can affect light penetration and the aesthetic quality of the water, sediment accumulation in the receiving waterbody can be adverse to aquatic organism habitat. Of particular concern is an adverse impact on fish spawning areas, changing the substrate for benthic organism development and changing the depth of the water so that rooted aquatic macrophytes are able to develop. Further, sediment accumulation can be sufficient in some instances to impact navigation.

One of the areas of often stated concern associated with suspended sediment-turbidity is an adverse impact on aquatic plant photosynthesis. Ordinarily, the turbidity associated with stormwater runoff events, while temporarily reducing the magnitude of photosynthesis due to decreased light penetration, does not significantly adversely impact the trophic status of the waterbody.

Suspended sediment is also of concern because of the potential for adverse effects on aquatic organisms gills, due to abrasion. As reported by Lee and Jones (1992), it has been found that aquatic organisms can tolerate high concentrations of suspended sediment for extended periods of time without significant adverse impacts. Aquatic organisms periodically experience high levels of suspended solids in many waterbodies due to storm or high flow induced suspension of deposited sediments without adverse impacts on them.

Physical verses Chemical Impacts of Stormwater Runoff

Increasing recognition is being given to the physical impacts of urban area and highway stormwater runoff which alters aquatic life habitat especially for urban area streams. For years, the primary focus of stormwater runoff management was the conveyance of floodwaters through an area in order to prevent flooding. As practiced in the past, enhancing floodwater conveyance is often highly destructive of aquatic life habitat. Snodgrass, in the WEF/ASCE (1996) draft Manual of Practice for Urban Runoff Water Quality Control has reviewed the impact of hydrologic modifications on aquatic life habitat. As he points out, these impacts can be highly significant. It is therefore important for stormwater runoff water quality managers to clearly distinguish between adverse impacts associated with hydraulic modification of a waterbody as they impact aquatic life habitat and the adverse impacts associated with chemical constituents in the receiving waters for stormwater runoff. Lee and Jones (1982) provided guidance on determining whether chemical constituents are adversely impacting the beneficial uses of a stream relative to the aquatic life habitat characteristics of the stream.

Application of Evaluation Monitoring to Industrial/Commercial Stormwater Runoff

As part of developing a national urban stormwater management program, the US EPA established special requirements for managing stormwater from industrial and commercial properties. These requirements included having to meet water quality objectives in the stormwater when it leaves to private property. Further, industrial/commercial entities were required to conduct a monitoring program of the stormwater leaving the property. Considerable controversy exists concerning the appropriateness of requiring industrial/commercial property owners to meet water quality standards in the stormwater runoff from the property, especially since in many cases the industrial/commercial stormwater runoff in urban areas enters municipal storm sewer systems where there is often appreciable dilution of any constituents in the industrial/commercial property stormwater runoff that occur above water quality standards in the stormwater runoff before entering public waters.

Also of concern is the nature of the monitoring program that industrial/commercial entities need to conduct to satisfy the NPDES stormwater permit requirements. In California, the State Water Resources Control Board (1997) followed the US EPA's guidance of requiring that industrial/commercial stormwater dischargers monitor a certain number of storms for pH, total suspended solids, specific conductance (dissolved solids) and total organic carbon (TOC), plus any toxic constituents that could be present in the stormwater runoff. Oil and grease may be substituted for TOC monitoring. This edge-of-the-property monitoring approach, like the urban stormwater and highway storm sewer outfall, or edge-of-the-pavement monitoring, provides little in the way of useful information on the water quality impacts of stormwater runoff-associated chemical constituents from industrial/commercial property stormwater runoff. It was both under-protective for the unregulated chemicals and, in most cases, over-protective for the regulated chemicals for which there are water quality criteria/standards.

As part of serving on a state of California Water Quality Task Force subcommittee devoted to developing proposed revisions of the Water Resources Control Board's General Industrial Storm Water Permit, Lee (1996b) and Lee and Jones-Lee (1996p) suggested that industrial/commercial stormwater dischargers should be encouraged to work with other public or private stormwater dischargers to a particular storm sewer system to determine the collective impacts of the constituents in the storm sewer on the designated beneficial uses of the receiving waters. Basically, the authors are suggesting that industrial/commercial establishments that are required to receive NDPES permits for stormwater runoff work with all other stormwater dischargers, as well as any point source dischargers, to define on a site-specific basis what, if any, real water quality use impairments are occurring in the receiving waters for the stormwater runoff-associated constituents derived from various types of land use in the watershed for a particular storm sewer system. The Evaluation Monitoring approach should be used to guide the investigation of the impacts of a storm sewer's discharge on the designated beneficial uses of the receiving waters for the discharge. Where real use impairments are found in a storm sewer's discharge to a particular waterbody, then forensic studies should be initiated to determine the specific cause and the specific source(s) of the constituents causing the real water quality use impairments.

It would be up to the industrial/commercial stormwater discharger to develop control programs that would protect the designated beneficial uses of the receiving waters for the storm sewer discharge. A key part of this approach is the requirement that all industrial/commercial establishments be required to eliminate any illegal discharges and illicit connections to the storm sewer system, as well as practice good housekeeping in preventing the discharge of potentially hazardous/deleterious chemicals as well as pathogenic organisms to the storm sewer system. Adoption of this approach would provide for a far more technically valid, cost effective approach for managing stormwater runoff water quality impacts than is occurring under the current system.

Evaluation Monitoring in a Watershed Based Water Quality Management Program

The US EPA has initiated a national program designed to develop watershed-based water quality management programs. The urban area and highway stormwater runoff management programs being implemented by the US EPA and state regulatory agencies (SWRCB, 1996) are, in general, recognized as part of the US EPA's Watershed Initiative as a basis for managing water quality. The Watershed Initiative approach has arisen from the need to control non-point source pollution of waterbodies. Thus far, since the development of the Clean Water Act in 1972, the focus of water pollution control programs in the US has largely been devoted to point source dischargers, such as municipal and industrial wastewater dischargers. Urban area and rural stormwater runoff dischargers have not been regulated or have only been regulated to a minimal degree.

The US EPA is in the process of developing guidance on implementation of a watershed alternative for managing wet weather flows (US EPA, 1997). This guidance is designed to provide the regulatory approach for implementation of the Agency's 1994 NPDES Watershed Strategy (US EPA 1994h) and 1996 Watershed Framework (US EPA, 1996h). While this guidance is still in its formative stages, it offers the promise of more appropriately regulating water quality than has been accomplished through the Agency's Point Source Discharge Permit program.

The US EPA has developed several Urban Wet Weather Flows Federal Advisory Committees of the Watershed Work Group. Recently, this Work Group (US EPA/FAC, 1997) released draft guidance for a watershed based water quality monitoring program. As currently formulated, the EM approach discussed herein is compatible with the draft guidance and would be strongly supportive of the Agency's efforts to expand water pollution control to focus on water quality use impairment within a waterbody's watershed independent of the source of the constituents responsible for the impairments.

While urban area, highway and industrial/commercial stormwater runoff is regulated under the US EPA's national stormwater runoff management program, agriculture and other rural runoff sources are not being regulated. As discussed herein, the organophosphorus pesticide orchard dormant spray issue, where over 200 miles of the Central Valley of Northern California contain rainfall and fogfall for several weeks per year that is highly toxic to some forms of aquatic life, is a prime example of the lack of adequate regulation of agricultural activities that are adverse to the beneficial uses of the receiving waters for stormwater runoff from areas where the pesticides are applied as well as areas that they are transported to through airborne transport and precipitation and fogfall. For many watersheds where more than a few percent of the watershed is devoted to agricultural activities, it is unlikely that a true watershed-based water quality management program can be formulated. As long as agricultural activities are exempt from meaningful regulation, it will be difficult to impossible to develop watershed-based water quality management programs.

The Evaluation Monitoring approach can readily serve as the focal point of a watershed-based water quality management program. By focusing on what real water quality use impairments occur in a waterbody in which the stakeholders concerned with sources of true pollutants and water quality impacts on beneficial uses of a waterbody, work with regulatory agencies and others in defining what real water quality problems exist in the waterbody, it is possible to focus the resources available for monitoring on first identifying the problems that need to be considered. Once these problems have been identified and quantified, then the second phase of the Evaluation Monitoring approach can be implemented devoted to determining the cause of the problems, such as the chemical species causing aquatic life toxicity and the specific source(s) of the constituents responsible for the problem. At this point, it may be possible to get the stakeholders and regulatory agencies to work together to develop meaningful control programs. It is likely under these conditions that the unregulated communities, such as agriculture and some other special interests, will "voluntarily" develop control strategies that will eliminate real water quality use impairments in the receiving waters for the stormwater runoff.

The EM demonstration project currently underway is part of the Santa Ana Regional Water Quality Control Board's watershed water quality management program for Upper Newport Bay. Over the next three years, this program will provide information on how to implement the EM approach to address specific water quality issues of concern in the Bay. One of the issues that has already surfaced from Phase 1 of the EM Demonstration Project is the finding that methomyl, a carbamate pesticide that is used for agricultural uses in Orange County, is a cause of aquatic life toxicity in San Diego Creek as it enters Upper Newport Bay (Taylor and Lee, 1997). It is not known at this time whether there are readily available substitutes for methomyl that could be used on the various crops where its use is now leading to stormwater runoff transporting sufficient quantities of the pesticide to cause aquatic life toxicity in San Diego Creek as it enters Upper Newport Bay. It will be of interest to determine whether it will be possible to gain rapid control of the methomyl caused toxicity, especially if there are no readily available substitutes for this chemical.

TMDL Development

The Clean Water Act, Section 303(d), requires that the US EPA and state regulatory agencies assess whether a waterbody's designated beneficial uses are impaired. For those waterbodies that are determined to have impaired designated beneficial uses, the regulatory agency for the waterbody is required to develop a waste load allocation and total maximum daily loads (TMDL) that can be discharged for the constituent(s) responsible for the impairment in order to control the impairment. The US EPA (1991b) has developed guidance for developing TMDLs. However, few TMDLs have been developed. As a result of the failure of the US EPA and state regulatory agencies to develop TMDLs for waterbodies that are found to have "impaired" water quality, environmental groups have filed lawsuits against the US EPA and other regulatory agencies. Consequently, a major effort is being made by regulatory agencies to develop TMDLs for many waterbodies that have been classified by state and federal regulatory agencies as having their uses impaired.

This raises the questions of how TMDLs should be developed for urban area and highway as well as rural stormwater runoff situations. Rossman (1995) has discussed the conventional approach for developing TMDLs for stormwater runoff and wastewater sources. This discussion, however, does not address the issues of focusing on toxic, available forms of constituents in formulating technically valid, cost effective TMDLs. Lee and Jones-Lee (1996q, 1997d) discussed the importance of properly evaluating the water quality significance of chemical constituent(s) in stormwater runoff that are inputted to a waterbody that is considered to be responsible for a use impairment of the waterbody. Of concern is the situation where much of the constituent, such as a heavy metal, in stormwater runoff from an area is in a non-toxic, non-available form. It is technically invalid to establish a TMDL for a stormwater input of a constituent that is present in non-toxic, non-available forms and therefore does not impact the beneficial uses of the waterbody.

<u>Control of Pollution vs. Achieving Standards</u>. One of the frequent causes of a water quality "use impairment" is an exceedance of a water quality standard. This can be an administrative use impairment in which the constituent that causes the exceedance of the standard is in a non-toxic, non-available form and, therefore,

there is no real use impairment of the waterbody of concern to the public. As discussed herein, this is one of the primary reasons why Lee and Jones-Lee (1995c) advocate the termination of the US EPA's Independent Applicability Policy. While, in principle, it may be possible to obtain adjustments of the standard through the development of site-specific standards, in practice, this can be a very expensive process that, as currently allowed by the US EPA, does not allow for proper incorporation of the aqueous environmental chemistry of constituents which reflect the toxic, available forms that are present in waterbodies compared to those that are used in the site-specific standard development toxicity testing.

In 1990, the US EPA, as part of adopting the national urban stormwater quality management program (US EPA, 1990a), recognized that significant over-regulation could occur if NPDES-permitted urban area street and highway stormwater runoff was required to meet water quality standards at the point of discharge into the receiving waters. The Congress, in adopting the national urban stormwater management program, established the requirement that NPDES-permitted municipal separate storm sewer systems must control pollution caused by the discharges to the maximum extent practicable using BMPs. Neither Congress nor the Agency defined what was meant by "maximum extent practicable," nor did they establish required BMPs.

Koorse (1995) has reviewed, from a legal perspective, the development of the regulatory background of the US EPA's Final Rule governing the regulation of stormwater runoff water quality from industrial and urban areas. He points out that there is considerable confusion on how best to manage the water quality impacts of stormwater runoff-associated constituents.

At this time, there is considerable confusion about the need to achieve water quality standards in the urban area street and highway stormwater runoff waters. Some recently issued municipal areawide stormwater NPDES permits include receiving water limitations as a measure of effectiveness of approved BMP-based municipal stormwater quality programs. Further, in California the inappropriateness of requiring NPDES-permitted urban area street and highway stormwater runoff to meet water quality standards (objectives) in the receiving waters was recognized by the State Water Resources Control Board, when a 10-year exemption from meeting these standards/objectives was granted to all NPDES-permitted urban area street and highway stormwater runoff dischargers in April 1991. While that exemption no longer exists, because of a court decision voiding the April 1991 objectives and the associated Inland Surface Water Plan and Enclosed Bays and Estuaries Plan, it is expected that, with the repromulgation of these plans currently underway, this exemption could again be adopted.

In addition, the United States House of Representatives, as part of legislation to reauthorize the Clean Water Act, proposed to allow a 15-year period of exemption from meeting water quality standards in permitted urban stormwater discharges. These proposed exemptions are based on the recognition that the application to stormwater discharges of the current water quality criteria/standards significantly over-regulates urban area street and highway stormwater runoff. In an effort to correct this problem, H.R.961 proposed to provide $100 million to support US EPA research designed to develop appropriate wet weather criteria/standards that would be specifically designed to regulate urban area street and highway stormwater runoff, without significant overregulation of permitted discharges.

At the May 1996 State of California Stormwater Quality Taskforce meeting, A. Strauss, of the US EPA Region IX, announced that a draft US EPA policy had been released governing the need to achieve water quality standards in NPDES permitted stormwater discharges from urban areas. This draft policy states that while such discharges must achieve water quality standards in the receiving waters for the discharge, failing to achieve these standards does not represent a violation of the NPDES permit. It is the Agency's policy that urban area stormwater discharge impacts on receiving water quality shall be controlled to the maximum extent practicable, using BMPs. This policy was officially adopted by the Agency in August 1996 (Perciasepe, 1996).

The copper situation in San Francisco Bay is a prime example of inappropriate regulatory approaches for controlling constituents in urban area and highway stormwater runoff. Lee and Jones-Lee (1996q,1997e) have discussed the overregulation of copper that is in the process of being implemented for stormwater runoff from urban areas and highways to San Francisco Bay. The total and soluble copper in San Francisco Bay waters exceeds the site-specific water quality objective developed by the San Francisco Regional Water Quality Control Board for copper in Bay waters. This leads to the requirement to develop a waste load allocation and TMDL for copper inputs to the Bay. A phased approach was adopted by the Regional Board in which an arbitrary reduction of copper loads to the Bay from all sources was implemented as phase 1 requirements for a copper TMDL. It is clear, however, that because of copper in the sediments and the shallow nature of the Bay the phase 1 reductions, or for that matter total reduction of all copper input to the Bay will not lead to a situation where there will be no exceedance of the site-specific copper objective (standard) of more than once in three years. Ultimately, over $1 billion of public funds could be spent trying to control copper in stormwater runoff to the Bay and still have administrative exceedances of the Bay's site-specific objective.

As discussed by Lee and Jones-Lee (1997e), extensive data has been collected on the toxicity of copper to aquatic life in Bay waters and sediments. It has been repeatedly found over a several year period that the copper present in the Bay is in a non-toxic, non-available form and therefore the exceedance of the water quality objective is an administrative exceedance that does not represent a real beneficial use impairment to the numbers, types and characteristics of desirable forms of aquatic life in Bay waters. If the US EPA does, in fact, drop or at least modify its Independent Applicability Policy as has been announced in its Advanced Notice of Proposed Rulemaking (ANPRM) (US EPA, 1996i), then the need for a TMDL for copper in San Francisco Bay could be eliminated.

It was estimated by the Santa Clara Valley Nonpoint Source Pollution Control Program that 35% of the total copper entering South San Francisco Bay is derived from auto brake pads in stormwater runoff from urban area streets and highways. This situation has caused some environmental groups and others to call for a national ban on the use of copper in automobile brake pads. Such a ban appears to be readily feasible since the US auto manufacturers (GM, Ford and Chrysler) do not use brake pads that contain copper. The City of Palo Alto (Moran, 1997) and an environmental group, Common Ground for the Environment and Sustainable Conservation, have initiated an effort to cause automobile brake pad manufacturers to "voluntarily" stop using copper in automobile brake pads (Common Ground, 1996). Lee and Jones-Lee (1996r) question the appropriateness of changing the copper concentrations in brake pads based on the extensive studies over the past three years on San Francisco Bay waters and sediments that have shown that the "excessive" copper in the waters is in a non-toxic, non-available form. Further, as reported by Thompson (1996), there is an inverse relationship between the copper concentrations in San Francisco Bay sediments and sediment toxicity.

The environmental group's efforts to control the so-called copper "pollution" of San Francisco Bay is a misdirected source control effort that does not address real water quality problems. It is important that before any source control effort be claimed to be a BMP for control of pollution that real pollution-use impairment be found in the receiving waters for the stormwater runoff that can be addressed by the source control BMP. The mechanical, technically invalid approach used by Common Ground for the Environment (1996) and the City of Palo Alto (Moran, 1997), in which the aqueous environmental chemistry of copper associated with brake pads and its toxicology is ignored, could lead to significant real water quality problems due to the substitution of constituents in brake pads for copper that are or could be adverse to the public and/or the environment. It is, therefore, important that pollution control or pollution prevention be based on good science and engineering in order to avoid the waste of public and private funds and significant adverse impacts to the environment.

The management of stormwater runoff to San Francisco Bay is an area where the Evaluation Monitoring approach could provide valuable information and ultimately save the public large amounts of funds in unnecessary urban area and highway stormwater runoff management. While the San Francisco Bay copper "problem" provides a focal point in demonstrating the need for a more appropriate approach, there are a number of other issues that also need to be addressed, such as the organophosphorus pesticide issue in urban stormwater runoff. As discussed herein, at least thus far after considerable study, no real water quality use impairments have been found in San Francisco Bay waters or sediments associated with the exceedance of the site-specific water quality copper objective. There is no technical reason to restrict copper inputs to the Bay beyond the current control programs. This does not mean that at some time in the future that a copper problem would not be identified. This same issue exists for many chemicals which could lead to the inappropriate approach of requiring everyone to treat all water inputs to the Bay, both point and non-point sources, to achieve distilled water. Even distilled water discharged to the Bay would be a pollutant. It is, therefore, necessary that the financial resources available for monitoring and water quality management be focused first on real, significant, discernible problems-use impairments of the Bay. The administrative problem of overly-protective national as well as site-specific water quality criteria and standards, the US EPA's Independent Applicability Policy and its current TMDL formulation and implementation approaches are administrative problems that cannot be addressed through technical solutions; they need to be addressed as part of revising regulations.

The focus of the San Francisco Bay stormwater runoff water quality monitoring should be directed towards determining what Bay-wide problems-use impairments exist that are attributable to chemical constituent input. As discussed herein, it would be important to recognize the highly significant changes that are occurring in San Francisco Bay as the result of biological pollution caused by invading species. The bay-wide San Francisco Estuary Regional Monitoring Program that is being conducted through the San Francisco Estuary Institute is providing significant data that are helping to define what real water quality use impairments exist within the Bay. This program, however, is not necessarily focused on problem definition. The point and non-point source dischargers to the Bay should implement an Evaluation Monitoring approach specifically designed to define what real water quality use impairments are occurring in the Bay, the cause of these impairments and the specific source of the constituents responsible for the impairments. It is through this approach that it would be possible to determine what, if any, additional chemical constituent control from point and non-point source discharges/runoff needs to be implemented in order to improve and protect true water quality in the Bay. Funds that are now being used for edge-of-the-Bay discharge/runoff monitoring should be reallocated on a cooperative basis where the stakeholders would use these funds to begin to define more appropriately than has been done thus far, the real water quality problems of San Francisco Bay and how best to manage them. In addition to Bay-wide problems, attention needs to be given to near-input problems which impair the beneficial uses of the nearshore or Bay waters in a specific area.

Determining the Source of Constituents Causing Water Quality Use Impairment

For many water quality use impairments, the constituent(s) responsible for the use impairment are known. For example, when excessive bioaccumulation of mercury in fish is found, then there is need to determine the source(s) of the mercury responsible for the excessive bioaccumulation. However, for toxicity, usually the constituent causing the toxic response to the test organisms will not be known. Under these conditions, appropriately conducted TIEs are used to identify the particular constituent causing the toxicity. As discussed by Mount (1997), Mount *et al.* (1997), Bailey (1997) and Cherr and Higashi (1997), TIEs have proven to be successful in identifying the cause of aquatic life toxicity in wastewater effluents and ambient waters. These authors stress the importance of having those conducting the TIEs be familiar with dilute aqueous and analytical chemistry in order to conduct cost effective TIEs.

Once a water quality use impairment has been identified in the stormwater runoff receiving waters being evaluated, studies should be initiated to determine the origin of the constituents that cause the use impairment. These studies typically will involve sampling the runoff waters at various locations upstream from the receiving waters to determine the source of the constituent(s) of concern. Usually, this type of forensic study will determine the specific source(s) of constituent(s) that are responsible for the water quality use impairment. In many cases, it is possible, through TIEs, to determine the specific chemical responsible for the toxicity. In this situation, it would be possible to trace the specific chemical back to its source. However, it is important to recognize that the same chemical from various sources can have significantly different amounts of toxic forms; therefore, any chemical tracing must be accompanied by toxicity measurements to be certain that the tracing does not lead to an erroneous conclusion on the significance of a source of a chemical by focusing on the inert forms of the chemical.

The same situation applies to determining the origin of chemicals that bioaccumulate to excessive levels in aquatic life tissue. It should not be assumed that all sources of mercury are equally available as a source that, when present in the receiving water sediments, will be methylated to methyl mercury that will bioaccumulate to excessive levels in fish or other organism tissue. Specific studies need to be conducted to determine whether a source of mercury or some other constituent, when present in the receiving waters, is in a form that leads to or contributes to excessive bioaccumulation. As discussed herein, a combination of chemical and bio-uptake studies under controlled conditions can be used to trace back to the source(s) those constituents that lead to excessive bioaccumulation.

Development of BMPs

Another area that is poorly understood is appropriate BMP selection for stormwater runoff water quality management (Jones-Lee and Lee, 1994, Lee and Jones Lee, 1994b, 1995f,g,h). The current approach for stormwater runoff BMP selection typically involves mechanically selecting one or more BMPs from a list of BMPs that are presented in various BMP manuals such as the California BMP manuals (CDM *et al.,*1993; APWA, 1993; ASCE/WEF, 1992; WEF, 1993; WSDOT, 1995), the Federal Highway Administration (FHWA, 1996), the US EPA Coastal Zone (US EPA, 1993a), Washington Council of Governments (MWCOG, 1992) and the soon-to-be-released Water Environment Federation/American Society of Civil Engineers (WEF/ASCE, 1996). This selection is made without first finding a real water quality problem-use impairment that needs to be addressed associated with the discharge of chemical constituents or pathogenic organisms in stormwater runoff to a particular waterbody. The BMPs that are listed, such as detention basins, filters, grassy swales, etc., are, in fact, often ineffective in controlling the chemical constituents in stormwater runoff that cause real water quality use impairments in the receiving waters for the runoff. While as discussed by Lee and Jones-Lee (1996e), these devices can be effective if properly designed, operated and maintained to remove particulate forms of constituents, such as heavy metals, it has been known since the early 1970s (NAS/NAE, 1973) that particulate forms of constituents are not toxic and not available to adversely impact aquatic life. Therefore, BMPs that are designed to remove particulate metals and other particulate chemical constituents that are of concern because of their potential toxicity to aquatic life are not true BMPs.

In May 1995 the US EPA (US EPA, 1995c) officially recognized this situation for most of the heavy metals where the Agency no longer requires that ambient water particulate heavy metals, such as copper, zinc, nickel, chromium and cadmium, be considered in evaluating whether there is an exceedance of a water quality standard. It is, therefore, important that those developing BMPs for stormwater runoff-associated constituents determine on a site-specific basis that the particulate forms that are being removed are, in fact, significantly adversely impacting the water quality in receiving waters for the stormwater runoff. It is the authors' experience that this would, indeed, be rare.

Herricks (1995), editor of the conference proceedings, <u>Stormwater Runoff and Receiving Systems: Impact, Monitoring, and Assessment,</u> 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."

Jones-Lee and Lee (1994) have reviewed the issues that need to be considered in appropriately selecting real BMPs for control of real water quality problems associated with stormwater runoff-derived constituents. As they point out, the first step in determining the need for a BMP for a particular stormwater runoff situation is conducting an assessment of what real, significant water quality problems are occurring in the receiving waters for the stormwater runoff. This requires a site-specific evaluation of the characteristics of the receiving waters to determine what, if any, real water quality problems exist in these waters that are attributable to stormwater runoff-associated constituents. For example, for constituents that are of concern because of aquatic life toxicity, the receiving waters for stormwater runoff should show aquatic life toxicity in these waters that is of sufficient magnitude, areal extent and duration to adversely impact the numbers, types and characteristics of desirable forms of aquatic life. Likewise, for excessive bioaccumulation of hazardous chemicals in aquatic life tissue, the first step in developing BMPs to control chemicals that are present in stormwater runoff that could bioaccumulate to excessive levels in aquatic life tissue is to determine if excessive bioaccumulation of these chemicals is, in fact, occurring in the receiving waters for the stormwater runoff.

If the stormwater runoff does not have toxicity, does not have sufficient toxicity to be adverse to the aquatic life-related beneficial uses of the receiving waters or there is not excessive bioaccumulation in the receiving water aquatic life tissue that would cause these organisms to be considered a human health hazard, then it can be concluded that, at least with respect to the recent past, the stormwater runoff as well as all other sources of constituents for the waterbody are not causing impairment of the beneficial uses of the waterbody for constituents that tend to cause aquatic life toxicity or bioaccumulate in receiving water aquatic organisms to excessive levels. Similar kinds of assessments can be made for other potential water quality problems, such as the runoff of pathogenic organism indicators, excessive fertilization due to nitrogen and phosphorus compounds, oil and grease accumulation, debris, etc.

Lee and Jones-Lee (1996a) published the results of a national survey that they conducted on urban area and highway stormwater runoff water quality impacts. Based on the results of this survey, it is concluded that it will indeed be rare that the conventional stormwater runoff structural BMPs being widely used today will be the BMPs that will be used in the future to address real water quality problems associated with urban area and highway stormwater runoff-derived chemical constituents. The basic problem is that the current BMPs are based largely on hydraulic considerations with little or no attention to the aquatic chemistry and aquatic toxicology of the constituents being removed in them.

The conventional "BMPs" that are being widely implemented today, such as detention basins, filters, etc., for urban and highway stormwater runoff will not be the BMPs that will be used to control real water quality problems associated with chemical constituents that lead to significant aquatic life toxicity, excessive bioaccumulation, excessive fertilization, etc. The BMPs that will ultimately have to be used for those situations where real water quality use impairments are occurring in receiving waters due to soluble constituents will, because of cost, almost certainly be based primarily on source control. The treatment of stormwater runoff from urban areas and highways to remove chemical constituents (soluble forms) that can cause aquatic life toxicity or lead to excessive bioaccumulation will be very expensive and could be on the order of $1 to $2 per person per day in urban areas (JMM, 1992). These costs are based on the typical costs that are associated with treating municipal and industrial wastewaters to remove potentially toxic constituents in the wastewater discharges. Because of the high flows that can occur in stormwater runoff, very large treatment works that employ advanced waste treatment practices will be needed to control soluble forms of constituents that are adverse to the beneficial uses of the receiving waters for the stormwater runoff. Before these types of expenditures are made, it is appropriate to find real water quality problems in the receiving waters for the stormwater runoff that cannot be mitigated by source control.

The current approach for urban stormwater runoff water quality BMP development which is based on the so-called "standard practice" should be discontinued. Large amounts of public and private funds are being wasted in developing so-called BMPs for urban area and highway stormwater runoff. While this situation has been recognized for a number of years and has been well publicized in the stormwater runoff water quality management literature, unfortunately, the current, technically invalid approach for BMP selection is being perpetuated by governmental agencies, such as the Federal Highway Administration (FHWA, 1996), through the release of a badly outdated "Evaluation and Management of Highway Runoff Water Quality" guidance manual. This manual reflects an early 1980s level of understanding of water quality evaluation and management. While those responsible for development of the manual (FHWA- F.G. Bank) justify the development of this manual based on past practices, such approaches are, obviously, technically invalid and provide departments of transportation with unreliable information on how to evaluate whether real water quality problems are present in receiving waters for highway stormwater runoff.

A similar situation will soon occur with the WEF/ASCE (1997) "Manual of Practice, Urban Runoff Water Quality Control." The WEF management and those responsible for developing this guidance manual refused, over a two year period, to incorporate into the manual a chapter discussing how to determine whether a BMP was needed to control constituents in stormwater runoff to a particular waterbody based on the constituents causing a real water quality use impairment of the waterbody. It was the position of the WEF president, W. Turner, (Turner, 1997) and, according to Turner, L. Roesner, WEF Task Force Chairman and B. Urbonas, WEF Task Force Vice-Chairman, that since evaluation of water quality problems before selection of BMPs was not "standard practice" today, that it was inappropriate to provide advice to stormwater managers in a 1997 manual of practice for urban runoff water quality control on how to determine whether a BMP was needed and whether a particular standard BMP would be effective in controlling real water quality use impairments associated with the stormwater runoff to a waterbody. There is concern that the consulting firms who have built large programs around developing standard BMPs for stormwater runoff would lose business if stormwater managers evaluated the need for and the appropriate selection of BMPs on a site-specific basis.

This situation raises concern about the appropriateness of consultants failing to reliably inform stormwater managers about the need to evaluate whether there is a real water quality use impairment associated with a particular stormwater runoff situation on the beneficial uses of the receiving waters for the runoff. Lee and Jones-Lee (1995i) have discussed the professional ethics associated with consultants failing to provide the public with a full disclosure discussion of environmental issues before undertaking a particular project. Certainly any stormwater runoff water quality consultant that does not work with a stormwater manager to define real water quality impacts associated with stormwater runoff from an area and proceeds to implement structural BMPs without first determining if the BMPs recommended will, in fact, address real water quality problems that exist in the receiving waters for the runoff is practicing questionable professional engineering ethics.

The key to meaningful water quality-based chemical constituent control BMP development is a proper evaluation of the real water quality impacts that chemical constituents and pathogenic organisms in the runoff waters have on the receiving waters for the runoff. The current stormwater runoff water quality monitoring approach does not and cannot serve as a reliable basis for developing technically valid, cost effective BMPs. On the other hand, the Evaluation Monitoring approach discussed herein (Lee and Jones-Lee, 1996e,f; Silverado, 1997) is specifically designed to provide the data needed by stormwater managers to evaluate on a site-specific basis whether there is need for a stormwater runoff water quality BMP beyond good housekeeping.

Source Control BMPs

With an increasing recognition that conventional BMPs, such as detention basins, filters, grassy swales, etc., that are used for stormwater runoff "water quality" management have limited utility in controlling real water quality problems associated with chemical constituents in the runoff coupled with the high cost of treating stormwater runoff to remove dissolved constituents that could be adverse to receiving water quality is causing increased attention to the use of source control BMPs. A corollary to this situation is the increased emphasis being given to "pollution prevention" as part of a watershed management water quality-based program for stormwater runoff water quality management. The authors have encountered a number of situations where so-called pollution prevention or control programs have been directed toward controlling one or more constituents at the source as part of stormwater runoff "water quality" management. However, a critical review of the situation shows that those advocating source control are doing so without proper evaluation of whether the constituents being controlled cause real water quality use impairments in the receiving waters for the stormwater runoff. A prime example of this situation is copper in auto brake pads for some types of automobiles. As discussed above, municipalities and environmental groups have concluded without proper review that the copper in auto brake pads that becomes part of the runoff from highways and streets is significantly adverse to the beneficial uses of San Francisco Bay because the concentrations of copper exceed the water quality standard for the Bay. However, after extensive study, it is clear that the copper from all sources, including that from auto brake pads, is in a non-toxic, non-available form.

The notion sometimes advocated in water pollution control programs that every little bit of "pollution control" helps is not necessarily technically valid and can be detrimental to developing meaningful water quality management programs for a region. For every water quality pollution control program there should be developed, as part of its implementation, a clear, well-defined assessment of the receiving water designated beneficial use benefits that will accrue as a result of implementation of the pollution control program. Considering current fiscal limitations within the public sector, capital and maintenance expenditures must be focused on the most acute water quality problems, rather than implementing sweeping, but less intensive, programs that are only partially effective, or are ineffective.

An example of this type of situation occurs in urban area street and highway stormwater runoff where detention basins have been adopted as a water quality BMP in which property developers and private, state and federal highway agencies and municipalities acquire lands and provide the maintenance for the development and operation of a detention basin that removes particulate forms of constituents in urban area street and highway stormwater runoff. While detention basins can be justified if there is a significant erosion problem that cannot be controlled at the source, there is no valid justification for using detention basins to control particulate forms of constituents in urban area street and highway stormwater runoff as a result of the US EPA's May 1995 adopted approach of focusing control programs on ambient water soluble forms of heavy metals. Detention basins and other structural BMPs, such as grassy swales, vegetative areas, etc., should only be constructed where there is a technically valid, well-founded, expected significant improvement in the designated beneficial uses of the waterbody for the urban area street and highway stormwater runoff.

Frequently, the advocates of pollution prevention programs focus their efforts on the control of chemical constituents such as heavy metals in stormwater runoff without regard to whether the heavy metals in such runoff are in toxic-available forms. An example of this type of situation occurs in San Francisco Bay, where it is advocated that there is need to force the automobile brake pad manufactures to remove copper from the brake pads since the wear of the brake pads results in elevated concentrations of copper in highway and street runoff. However, it has been found that the copper in San Francisco Bay from all sources, including highway runoff, is not adverse to the beneficial uses of the bay waters. Therefore, the control of copper in automobile brake pads does not represent a control of a pollutant, i.e., a constituent that impairs use, but represents control of a chemical constituent that will have no impact on the beneficial uses of San Francisco Bay.

A similar situation exists today with respect to the Santa Monica Bay Restoration Program, where this program is directed toward the control of chemical constituents in urban stormwater runoff, independent of whether these constituents have any impact on Santa Monica Bay water quality - beneficial uses (Lee, 1995). Such approaches can be wasteful and result in misdirecting pollution prevention programs to unimportant areas. It is important, therefore, in developing technically valid pollution prevention programs, to focus these programs on those constituents, i.e., specific forms of chemicals, which are pollutants. This will require the use of an EM program of the type described herein in formulating and implementing the pollution prevention program.

The finding that stormwater runoff from large areas of north-central California during certain times of the year are toxic to certain forms of aquatic life due to organophosphorus pesticides that through airborne transport associated with their use as winter dormant spray represents a situation where source control BMPs will be the key to control of this problem. An appropriate BMP to control diazinon and chlorpyrifos toxicity in urban area street and highway stormwater runoff is through source control. Since diazinon is dissolved, conventional stormwater BMPs, such as detention basins, will have no effect on the diazinon-caused aquatic life toxicity since diazinon would not be removed in conventional detention basins or filters. However, storing the stormwater for extended periods of time, i.e. for a few days to a week or so, before release to the receiving waters could result in its hydrolysis and conversion to a non-toxic chemical. It will be rare, however, that this approach will be feasible since the storage volumes (areas) will have to be large compared to normal detention basis.

Those who manufacture, sell, or use diazinon and other pesticides that become part of urban area street and highway stormwater runoff, as well as runoff from the orchards and other agricultural or rural lands, should be able to control the use so there is no significant toxicity to aquatic life in the receiving waters for urban area street and highway stormwater runoff. As discussed herein, it will be important to evaluate on a site-specific basis whether the organophosphorus pesticide-caused toxicity in the urban area and highway stormwater runoff is significantly adverse to the designated beneficial uses of the receiving waters for the runoff. For those situations where significant adverse impacts are projected to be caused by the organophosphorus pesticide toxicity, highly specific source control BMPs will likely be the primary mechanism by which potentially significant water quality problems can be effectively addressed and controlled for a variety of constituents that are found to cause water quality use impairments from urban area street and highway stormwater runoff.

Currently unimpacted, ecologically sensitive areas should receive particular attention in developing BMPs for urban area street and highway stormwater runoff. Important fish and shellfish spawning areas that are not now receiving substantial amounts of urban area street and highway stormwater runoff should also receive special attention. For example, the oil and grease and other petroleum hydrocarbons from a new major highway that enters a pristine area stream used for salmonid reproduction where the hydraulic characteristics of the water would promote the accumulation of oil and grease in the spawning bed area, should be prime targets for BMP development to control oil and grease runoff from the highway.

Accidental Spill Containment

One of the areas of particular concern in developing BMPs for highway runoff is the containment of accidental spills of chemicals and fuel that occur on the highway or its shoulder. In developing BMPs for a highway, it is important to incorporate approaches into the stormwater runoff management program that can be readily used to contain accidental spills of chemicals that can occur in areas where the spill could rapidly enter a sensitive waterbody. Efforts should be made to assist the local transportation agency/stormwater management agency in implementing accidental spill containment contingencies through the design of emergency runoff control structures, such as easily implemented check-dams, stormwater outlet flow control devices, etc., to the maximum extent possible to prevent spilled chemicals and fuel from entering waterbodies.

Evaluation of BMP Efficacy

Typically, stormwater management agencies/entities report the efficacy of BMPs for removal of constituents based on removing chemical constituents across the structural BMP unit, such as a detention basin. This approach is, with few exceptions, cosmetic and technically invalid, unless it can be shown through site-specific studies that the removal of the constituent causing the real water quality use impairment in the receiving waters for the stormwater runoff is directly related to an improvement in the designated beneficial uses of the receiving waters for the stormwater runoff. The fallacy in this approach lies in the belief that the removal of any chemical constituent in a structural BMP is of value in managing water quality. This approach ignores real water quality issues, such as aquatic chemistry, aquatic toxicology, and transport and mixing (hydrodynamics) considerations that must be evaluated in developing technically valid, cost-effective BMPs for urban area and highway stormwater runoff. To determine the percent removal of a constituent, such as a heavy metal, across a detention basin, filter, grassy swale, etc. without determining that the removal of this constituent has any impact on the beneficial uses of the receiving waters for the stormwater runoff is technically invalid and gives a false assessment of BMP efficacy.

The Evaluation Monitoring approach provides a direct, reliable measurement of BMP efficacy. Changes in the ambient water toxicity, decreases in the aquatic organisms' body burdens of bioaccumulated chemicals, improvements in the sanitary quality of the receiving waters at the location where sanitary quality is of concern, reduced litter, etc. are all direct measures of BMP efficacy.

BMPs and Hazardous Wastes

Some of the structural BMPs that are being developed today for urban area street and highway stormwater runoff, such as detention basins and filters, are accumulating sufficient concentrations of chemical constituents originally present in the runoff to cause the sediments that collect within the structures to be classified as a hazardous waste. Because of the significant difference in cost in managing waste depending on whether it is classified as a hazardous waste or not, it is important in designing and operating structural BMPs for urban area street and highway stormwater runoff to consider whether the materials that accumulate within them are classified as hazardous wastes since such a classification greatly changes the cost of residue management. It is also important to design stormwater runoff conveyance structures, drop inlets, etc. so they do not accumulate particulates in urban area street and highway stormwater runoff that could be classified as a hazardous waste. While such classification may be based on inappropriate, arbitrarily developed definitions, this classification is costing some stormwater management entities large amounts of money to manage as hazardous waste, the residues that accumulate within the stormwater management conveyance systems. It is important to note that, with few exceptions, these materials are not particularly hazardous to workers who may come into contact with them or to the environment. They are, however, hazardous wastes based on the arbitrary approaches that have been used to define hazardous wastes, which consider how the materials would behave in a sanitary landfill, and therefore, must be managed as such, unless a variance is issued exempting this type of management.

Potential Adverse Impacts of Highway Runoff

Stormwater runoff from highways is often singled out as a cause of water quality problems in the receiving waters for the runoff. This situation arises from several factors. First, is that the concentrations of a variety of chemical constituents in highway runoff exceed the US EPA water quality criteria and state standards based on these criteria. Another reason is that highway departments are considered to have "deep pockets" to help fund environmental group activities through litigation settlements. Also of concern is that some groups consider the automobile and highways to be the major cause of some social problems, such as urban sprawl, air pollution, etc.

The studies of Stenstrom and Strecker (1993a,b), Kerri *et al.* (1985), and Racin *et al.* (1982) provide information on the concentration of chemical constituents in highway runoff in California and especially Southern California. The Al-Kazily *et al.* (1995) report to Caltrans, in addition to discussing the various components of a stormwater runoff monitoring program, provides Caltrans data on the amounts of some chemical constituents in runoff from Caltrans highways. Al-Kazily *et al.* (1996, 1997) have provided highway stormwater runoff management literature reviews which provide additional information on the characteristics of highway stormwater runoff. Dammel (1997) has recently summarized the information on Caltrans highway and freeway stormwater runoff characteristics. While traditional edge-of-the-pavement monitoring of highway stormwater runoff provides information on the chemical characteristics and pathogenic indicator organism concentrations in the runoff, this type of data provides limited information on the potential impacts of the chemical constituents in the runoff on the beneficial uses of the waterbodies receiving the runoff.

Korbriger (1984a,b), Korbriger and Gupta (1984), and Korbriger and Geinopolos (1984) conducted studies for the Federal Highway Administration on the characteristics of highway and urban area street stormwater runoff. While these studies are often cited as sources of information on the potential pollutional impacts of highway and urban area street stormwater runoff, a review of the details of these studies shows that they did not distinguish between chemical constituents in stormwater runoff and those constituents that impair the designated beneficial uses of the receiving waters for the runoff. This was a significant deficiency in these studies because, while elevated concentrations of chemical constituents were found in the runoff, the studies contained no evaluation of whether these constituents were present in toxic-available forms and whether the elevated concentrations of the constituents in stormwater runoff relative to US EPA water quality criteria and state standards occurred for a sufficient period of time in the receiving waters to be adverse to the beneficial uses of these waters.

Kerri *et al.* (1985) and Racin *et al.* (1982) have also presented information on "pollutant" loads from highway runoff. These studies, again, fail to properly distinguish between chemical constituents in highway runoff and pollutants, i.e., those materials that impair the beneficial uses of a waterbody.

Driscoll *et al.* (1990) reported on "pollutant loadings and impacts of highway stormwater runoff." A review of this report shows that while information is provided on constituent concentrations in highway stormwater runoff, the authors did not evaluate whether the chemical constituents in the highway runoff were in toxic-available chemical forms and would be present for sufficient duration at "excessive" concentrations in the receiving waters to be adverse to aquatic life and other beneficial uses of the runoff receiving waters.

Driscoll *et al.* used the event mean concentration of a highway stormwater runoff event to "characterize" the potential impacts of the chemical constituents in highway stormwater runoff. While this approach reduces the data obtained in monitoring a particular or series of runoff events to a single value, it is an unreliable approach for assessing water quality impacts of highway and other area stormwater runoff. As discussed by Lee *et al.* (1982a,b) and Lee and Jones-Lee (1994b), aquatic organisms respond to "concentration of toxic-available form," "duration-of-exposure" relationships. The event mean concentration approach does not adequately or reliably incorporate key information needed to determine whether excessive concentrations of heavy metals or organics, etc. in highway and urban area street stormwater runoff relative to water quality standards are adverse to aquatic life-related beneficial uses.

The event mean concentration, in addition to failing to focus on toxic-available forms, also fails to properly consider the duration-of-exposure impact relationships that must be incorporated into a reliable analysis of the impacts of stormwater runoff-associated constituents. Overall, the studies of Driscoll *et al.* do not provide the information needed to reliably assess whether the runoff of chemical constituents from highways represents a potentially adverse impact on the beneficial uses of the runoff receiving water.

Barrett *et al.* (1995) have developed a review of the literature pertaining to the chemical characteristics of highway stormwater runoff. This review, like others, fails to properly distinguish between constituents in runoff waters that are in a toxic, available form and those that are inert in the runoff waters and in the receiving waters for the runoff.

Stenstrom and Strecker (1993a,b) used similar approaches to those of Driscoll *et al.* to estimate the so-called chemical "pollutant" loads to Santa Monica Bay from highway and urban area street stormwater runoff from the Santa Monica Bay Watershed. While the results of their investigations were presented as "pollutant" loads, in fact, they should have been labeled "chemical constituent" loads. According to tradition and technical validity, a pollutant is a constituent that impairs the beneficial uses of a waterbody. This is in accord with the current Clean Water Act definition set forth in Section 502(19) of the Clean Water Act (US Congress, 1988) which states,

"The term 'pollution' means the man-made or man-induced alteration of chemical, physical, biological, and radiological integrity of water."

According to Perciasepe (1997), this is the definition of pollution that the US EPA is now using as part of implementing its 1990 stormwater runoff regulations which require the control of pollution in the receiving waters for stormwater runoff to the maximum extent practicable using BMPs. The application of this definition to urban area street and highway stormwater runoff requires that a constituent in runoff from these areas cause an alteration of the characteristics of the receiving waters for the runoff that impacts its beneficial uses. It is not possible to use either the event mean concentration or total mass of constituents from highway or urban area street stormwater runoff to estimate the pollution that will occur in the runoff receiving waters.

The inappropriateness of the Santa Monica Bay Restoration Project in developing the management plan for the restoration program in which the Stenstrom and Strecker (1993a,b) results are used as a basis for formulating BMPs has been discussed by Lee (1995). The implementation of this proposed plan involves the development of over $40 million in structural BMPs to primarily control heavy metals in urban area street and highway runoff. This is being done without finding a real water quality use impairment in Santa Monica Bay that is caused by these heavy metals. As discussed by Lee (1995), there is need to find a real water quality problem in Santa Monica Bay first and then develop a restoration plan to control this problem in a technically valid, cost-effective manner.

The Department of Transportation Federal Highway Administration (FHWA) has released a guidance manual, "Evaluation and Management of Highway Runoff Water Quality," (FHWA, 1996) that summarizes previous FHWA-sponsored studies devoted to evaluation and management of highway stormwater runoff water quality. While according to Bank (1996), this manual is designed to provide guidance to state departments of transportation, a review of the manual shows that it is badly out-of-date with respect to discussing what is known about the real water quality impacts of stormwater runoff from highways. This manual perpetuates the highly inappropriate approach that has been used over the years by FHWA and its contractors of failing to properly distinguish between inert chemical constituents in highway stormwater runoff and those that could be adverse the designated beneficial uses of the receiving waters for such runoff.

Further, the manual recommends approaches for evaluation of water quality impacts such as associated with aquatic plant nutrients which are at least 25 years out-of-date and which do not reflect the large amount of information that was developed in the late 1970s - early 1980s as part of the OECD eutrophication studies. In addition, this manual inappropriately assumes that any exceedence of a water quality standard in stormwater runoff from a highway represents a significant adverse impact that requires the development of a structural BMP to control the impact. The manual does not mention the fact that many constituents in highway stormwater runoff such as heavy metals that are of concern because of potential toxicity have been found since the 1960s to be in non-toxic, non-available forms. One of the most significant deficiencies in the manual is that it fails to provide guidance on the use of aquatic life toxicity tests of the type that have been used for over 25 years in the water quality evaluation and management field to determine whether constituents in a water sample are toxic to aquatic life.

There is an urgent need for the FHWA to provide up-to-date, technically valid guidance to departments of transportation on how to evaluate the water quality impacts of highway stormwater runoff-associated constituents. Further, for those few situations where significant adverse impacts are found, the FHWA needs to develop guidance on how to formulate technically valid BMPs that will control the real water quality use impairments associated with highway stormwater runoff in a cost-effective manner.

Management of Highway Bridge Deck Runoff

An area that is receiving increased attention by regulatory agencies and others is the potential for highway and street bridge deck runoff to cause water quality problems in the receiving waters for the runoff. In the past, the approach that has been used to manage stormwater runoff from highway and street bridge decks involved the construction of drains that would allow the runoff waters to directly enter the area below the bridge. In some areas, highway departments are being forced to develop special stormwater runoff management approaches that are "justified" based on the alleged adverse impacts of chemical constituents in bridge deck runoff on receiving water quality. At some places, state departments of transportation (DOTs) are being forced to spend several hundred thousand to over a million dollars to manage so-called water quality problems arising from stormwater runoff from bridge decks. At one location, for a long bridge over an estuarine wetlands, in order to have the highway project approved, the state DOT had to construct a collection pan under the bridge to collect all stormwater runoff in order to prevent it from entering the wetlands. The cost of this program was in excess of $1 million. There was justifiable concern that this so-called mitigation measure was an unnecessary waste of public funds that could be more appropriately used for other highway development and maintenance programs.

The bridge deck stormwater runoff water quality impact situation is a prime example of where there is need to use Evaluation Monitoring to determine if there are real water quality problems associated with stormwater runoff. While it is conceivable, especially under conditions where long bridges and nearby highway areas would discharge stormwater runoff to a small, ecologically sensitive stream that would be used for salmonid or other high-value aquatic life reproduction where there would be need to exercise special stormwater chemical constituent control in order to protect the beneficial uses of the receiving waters, it is likely that such situations would be rare and that, in general, the traditional, least expensive, stormwater runoff management approaches that have been used for highway and street bridge decks are cost-effective, technically valid approaches. Lee and Taylor (1997) have recently completed a review on the approaches that should be used to evaluated whether stormwater runoff from highway bridge deck areas represents a potentially significant source of constituents that are adverse to receiving water quality. As they discuss, the Evaluation Monitoring approach can be used to provide guidance on whether real water quality use impairments would be expected from highway and street bridge deck runoff.

Hazardous Chemical Sites

An area of special concern with respect to stormwater runoff impacts that needs attention are Superfund and other hazardous chemical sites. Such sites are defined as those sites where typically, complex mixtures of hazardous chemicals have been manufactured, used or disposed of. Lee and Jones-Lee (1998) have recently developed a review covering the development of a stormwater runoff water quality evaluation and management program for hazardous chemical sites. They discuss that often the stormwater runoff monitoring program from such sites which involves edge-of-the-site monitoring of a few storms per year for a suite of Priority and conventional pollutants falls far short of defining the real water quality impacts of the regulated constituents as well as the unregulated constituents in the stormwater runoff from these areas. Lee and Jones-Lee (1998) recommend that an Evaluation Monitoring approach be adopted for stormwater monitoring for hazardous chemical sites in order to determine what real water quality use impairments occur associated with stormwater runoff-derived constituents from such sites. Evaluation Monitoring provides an approach for developing technically valid, cost-effective management of chemical constituents and pathogenic organisms in hazardous chemical site stormwater runoff that will protect the designated beneficial uses of the receiving waters for the runoff without unnecessary expenditures for chemical constituent control.

Evaluation Monitoring Beyond Initial Evaluation

The initial screening evaluation monitoring discussed herein will detect significant water quality use impairments in the receiving waters for the stormwater runoff. After completion of the initial screening, it would be beneficial to continue the EM program where ongoing studies would be conducted that are designed to detect subtle impacts of runoff-associated constituents on the beneficial uses of the receiving waters that are not detected in the initial screening. As real water quality use impairments are controlled, and as additional information is gathered on the receiving waters, less obvious use impairments may become evident. Further, through the development of new chemicals and changes in the use of existing chemicals, it is possible that new water quality problems will develop in the future that do not exist now, or are not recognized now. As more is learned about the impacts of chemicals on aquatic organisms, new adverse impacts are being found that need to be considered in any water quality evaluation. The traditional, end-of-the-pipe constituent monitoring will not reliably detect new water quality problems; however, the EM program, which focuses on detecting receiving water impacts, can detect the new problems and provide a technical base for their control.

The Evaluation Monitoring program is best implemented as an ongoing program where all use impairments may not addressed at one time. Instead, the expected use impairments of a waterbody are prioritized in terms of importance to the public, and over a 5-year NPDES permit period, each of the potentially significant water quality use impairments would be addressed. This same type of use impairment would then be examined again at approximately 5-year intervals. The periodic revisiting of potential use impairments should not only determine whether major water quality use impairment problems exist, but also whether incipient problems are developing.

Politics of Evaluation Monitoring

While it would be hoped that an Evaluation Monitoring program could be developed for a waterbody that is based on current good science and engineering principles and practice, there will be situations where various political or other entities will try to control the results of the Evaluation Monitoring program. For example, a situation could develop where representatives of a political entity would not want existing sanitary problems of a recreation area to become known since this could hurt tourism business in an area.

Similar problems can exist for other kinds of issues that have to be addressed. For example, if a city council, city council member, a city staff member or other political entity or agent decide they do not want a particular activity to proceed, they may choose to ignore or attempt to discredit the fact, based on the results of an Evaluation Monitoring program, that the activity of concern would not be adverse to the beneficial uses of the waterbody.

Another frequent problem is one in which environmental groups who have adopted a position on a particular issue will be reluctant to admit that their previously adopted position on the issue is technically incorrect associated with reaching a consensus on the results of an Evaluation Monitoring program that has come to the conclusion that there may not be need to control chemical constituent input from highway and urban areas since it is not causing major, discernible water quality problems in the waterbody of concern.

By having representatives of the various groups that have adopted positions on issues that subsequently prove to be technically invalid or that place self-interest above those of the public as active participants in the formulation and implementation of the Evaluation Monitoring program, it may be possible to address the issues raised by a particular stakeholder group through a consensus-building process. The organization and development of the Evaluation Monitoring stakeholder meetings is a key part of the success of the program. Such meetings require strong leadership by individuals who are knowledgeable in the topic area. Without such leadership, large amounts of time can be wasted in committee meetings on activities that can take hours, rather than the few minutes that they deserve.

Those who develop and implement the Evaluation Monitoring program for a particular waterbody need to be fully cognizant of the political situations they may encounter where political or other entities will attempt to exert their pre-conceived position on issues that are contrary to the science and engineering that is applicable to the topic that evolves from the Evaluation Monitoring program. Many of the decisions made today on water quality management are not based on the best possible, readily available science and engineering. In an effort to address this problem, the authors have found that a full, public peer review of technical issues approach can, if properly implemented, help counteract the biased, self-serving positions that stakeholders in a particular waterbody's watershed attempt to impose on the Evaluation Monitoring program results. While there will likely be disagreements among technical experts on issues that arise in an Evaluation Monitoring program, if those who disagree are required in a full, public peer review arena to present their position and any supporting information to the stakeholders, it may then be possible to have good science and engineering play a bigger role in decision-making than occurs under the current approach. Lee and Jones-Lee (1995i) have discussed this issue and provide recommendations on the use of a peer review approach for technical issue resolution.

Characteristics of the Evaluation Monitoring Team

Evaluation Monitoring is best implemented based on a watershed-based water quality evaluation/management approach where a technical advisory committee representing the waterbody's watershed's stakeholders, who have an interest in the water quality within a particular waterbody or waterbody system (watershed), work in a cooperative manner to define real water quality use impairments, determine their cause and develop control programs for those significant use impairments that are identified as part of the EM process. While the implementation of conventional stormwater runoff water quality monitoring requires limited understanding of technical issues pertinent to water quality evaluation and management, EM should be implemented based on the stakeholders having available, either within their group or as advisors/consultants, individuals who have high degrees of expertise in mid-1990 level of understanding and practice of the various technical, economic, social, political and legal aspects of water quality evaluation and management. Rather than following the traditional "brute force" approach toward assessing the water quality significance of chemical constituents as they may impact the beneficial uses of a waterbody, a properly developed and implemented EM program makes use of the information readily available in the literature and university-level text books in the fields of aquatic chemistry, aquatic biology/toxicology, hydrology, hydrodynamics and other areas that are pertinent to evaluating how chemical constituents present in runoff waters from a particular source may impact the various designated beneficial uses of waterbodies receiving the runoff.

The area that probably is the most significantly deficient in most water quality evaluation programs is aquatic chemistry. It is essential that one of the team members have high degrees of expertise in the aqueous environmental chemistry of constituents in water as they may impact the chemical species that are present. It is important to understand that chemistry, as needed to properly develop EM, is more than a list of the chemical characteristics of water or sediments. Those involved from a chemical perspective should be familiar with aquatic chemistry at least at the level that is presented in Stumm and Morgan (1996). Also of importance is information on the analytical chemistry of constituents in dilute aqueous solutions since knowledge in this area is necessary to understand the relationship between the chemical forms measured in various analytical procedures that are used relative to the forms that are potentially adverse.

Because of the importance of toxicity as one of the issues of concern in properly evaluating the water quality impacts of chemical constituents on the beneficial uses of a waterbody, it is important that a member of the technical advisory group include an individual with high degrees of expertise in aquatic toxicology, at least to the level that is available in Rand and Petrocelli, (1985).

A third member of the team that is essential to developing reliable information on the impact of chemical constituents on the aquatic life-related beneficial uses of a waterbody is an individual with understanding of the characteristics of a biological and aquatic-oriented terrestrial life associated with the waterbody. Such individuals can help the EM technical advisory panel understand the important biological resources in a waterbody that need to be evaluated with respect to adverse impacts on their numbers, types and characteristics.

The fourth technical area component of the technical advisory team that is essential to developing technically valid assessments of the impact of constituents is someone with a hydraulics/hydrodynamics/hydrology background who can help the other members of the team understand the transport mixing processes that occur in the waterbody of concern. If the waterbody of concern is estuarine/marine, then this person should have an understanding of tidal and estuarine related circulation and water movement.

The fifth member of the team should be an individual with high degrees of expertise in water and wastewater treatment processes. This individual should have expertise in how various processes remove specific constituents of concern.

It is important that the various technical components representing each of these areas of expertise have an orientation to water quality issues. Simply having expertise in the topic area without expertise in water quality and how the topic area relates to water quality issues is inadequate to represent the area on the team. Assembling a team with this expertise to address water quality issues associated with urban area and highway stormwater runoff would bring to bear far more expertise that is typically used in urban area and/or highway stormwater runoff impact evaluation and management programs that are typically developed today. Such a team with appropriate support for site-specific studies of the impacts of runoff-associated constituents can and usually will be highly cost effective in first defining the real water quality impacts of constituents in the stormwater runoff on the receiving water beneficial uses and second, helping to select and then implement technically valid, cost effective BMPs.

While the development of a stormwater management program based on the EM approach is initially more expensive than the traditional approach, it is in accord with current regulatory requirements of controlling **pollution** to the MEP using BMPs. Most importantly, ultimately, EM can save the public and other entities large amounts of money in the development and implementation of stormwater runoff water quality management programs compared to that associated with the conventional stormwater runoff water quality monitoring programs and the development and implementation of BMPs which are largely ineffective in addressing real water quality issues that impact the designated beneficial uses of receiving waters for the stormwater runoff.

Regulatory Issues

Because of the significant problems that are occurring in implementing the US EPA's (1990) urban area stormwater runoff water quality management program, municipal stormwater agencies across the US through national, as well as regional, organizations joined together to work towards developing revisions of the Clean Water Act as part of the Act's reauthorization that would address some of the significant over-regulation that is occurring today in managing urban area stormwater runoff-associated chemical constituents. Of particular concern is the requirement that water quality standards be met in receiving waters for stormwater runoff during runoff events. It has been known since the 1960s through the work of the senior author and others that urban area stormwater runoff contains a variety of chemical constituents at concentrations above US EPA water quality criteria and state standards based on these criteria. It has also been found that if the same approach is used in regulating stormwater runoff from urban areas, as is now being practiced for municipal and industrial wastewater discharges, of having to meet water quality standards at the edge of a mixing zone for the discharge where there is no exceedance of any magnitude more than once in three years, that the costs to urban dwellers would be on the order of $1 to $2 per person per day. These costs cover the construction of the large treatment works that would be needed to treat the high stormwater flows that frequently occur from urban areas, as well as the cost of operating the treatment plants to achieve water quality standards at the edge of the mixing zone for the treatment plant discharge. It is clear that meeting water quality standards at the edge of the mixing zone is not an economically viable option. It also is clear that the water quality standards that the US EPA has developed for point source discharges would tend to significantly over-regulate stormwater dischargers, especially if applied to the edge of a mixing zone for a storm sewer outfall. As discussed herein, there is obvious need to change the regulatory approach for urban area and highway stormwater runoff from that followed in regulating municipal and industrial wastewater discharges. This situation in 1985 led to urban stormwater dischargers to work with Congress to develop appropriate sufficient funding as part of the reauthorization of the Clean Water Act to develop wet weather criteria/standards that could be used to regulate real water quality problems associated with stormwater runoff from urban areas. Since the Clean Water Act was not reauthorized at that time, there is need when the Act is finally reauthorized to address the significant problems in regulating urban area and highway stormwater runoff so the funds spent for constituent control are used cost-effectively to manage real water quality use impairments of significance to the public.

The US EPA, as part of its ANPRM (US EPA, 1996i), proposed an alternative approach for addressing the problems associated with exceedance of water quality standards in the receiving waters caused by urban area and highway stormwater runoff-derived constituents. Rather than develop wet weather water quality standards that more appropriately consider toxic/available forms of constituents and duration of exposure issues in urban area and highway stormwater runoff, the Agency has proposed to consider adopting temporary exemptions from meeting water quality standards in the receiving waters for stormwater runoff where the exceedance is due to stormwater runoff-derived constituents. While the details of this proposed approach are not yet available, it would be important that the Agency, as part of implementing this approach, allow stormwater dischargers to demonstrate on a site-specific basis whether any residual exceedances of water quality standards following the cessation of a stormwater runoff event are causing real water quality use impairments in the receiving waters for the stormwater runoff.

The Agency is proposing as part of the same ANPRM to modify its current Independent Applicability Policy which requires that chemically-based water quality standards be met in the receiving waters, even if properly conducted studies show that the exceedance of a water quality standard, such as occurs in San Francisco Bay due to copper, is not adverse to the beneficial uses of the waterbody. As discussed by Lee and Jones-Lee (1995b,c), the US EPA's Independent Applicability Policy is technically invalid and should be abandoned. Wastewater and stormwater dischargers should be provided with the opportunity to work with the regulatory agencies and the public to determine on a site-specific basis whether the exceedance of a US EPA water quality criterion/state standard in ambient waters that represents a potential threat to the beneficial uses of the waters represents a real use impairment. The Evaluation Monitoring approach provides a technical basis for making this type of evaluation.

While Agency staff at the July 1996 Denver, Colorado US EPA multi-regional meeting on water quality criteria and standards indicated that the Agency was considering as part of the ANPRM modifying the Independent Applicability Policy, it appears that the Agency's proposed modifications may not be adequate to eliminate the significant over-regulation of stormwater runoff-associated constituents, such as is occurring for copper in San Francisco Bay. The Agency staff stated at the Denver meeting that finding that the copper in Bay waters is non-toxic to highly sensitive forms of aquatic life using the same organisms and procedures as were used to develop the copper water quality criterion would not be adequate justification to wave the Independent Applicability requirement. According to the Agency's representative, those concerned about the over-regulation associated with the Independent Applicability of chemically-based criteria would also have to show that the numbers, types and characteristics of aquatic organisms in the receiving waters for the stormwater runoff or wastewater discharge are not adversely impacted by the runoff or discharge. The Agency's proposed approach could involve conducting large-scale, expensive study programs to collect aquatic organism assemblage data on the receiving waters, such as San Francisco Bay. While aquatic organism assemblage data can be a reliable tool if appropriately used for assessing the impacts of a particular discharge to a small stream or to benthic organisms in a waterbody, it is not possible to readily develop information of this type for water column organisms in large waterbodies, such as rivers, lakes, estuaries and marine waters. Far too many factors influence the numbers, types and characteristics of water column organisms in a waterbody to enable with reasonable cost the development and use of aquatic organism assemblage data to discern under most conditions whether the exceedance of a water quality criterion, such as for copper in San Francisco Bay, is, in fact, adverse to the aquatic organisms in the Bay. As discussed herein, rather than trying to directly measure the subtle impacts of potentially toxic chemicals, such as copper in San Francisco Bay, through determining the numbers types and characteristics of Bay water column organisms, the approach that should be used is that adopted in the Evaluation Monitoring approach of assessing whether the toxicity associated with a constituent is present for sufficient time and areal extent within the waterbody to be potentially adverse to aquatic organisms. This indirect toxicity impact assessment approach is readily implementable and, in most cases, reliable.

For many waterbodies, such as San Francisco Bay, there is increasing understanding that biological pollution by invading organisms can have a significant adverse impact on the waterbody's ecosystem. A prime example of this situation is occurring in San Francisco Bay today where a number of invading species, such as the mitten crab and the Asian clam, have established themselves as dominant organisms in parts of the San Francisco Bay estuary. Several papers presented at the Third Biennial State of the Estuary Conference (San Francisco Estuary Project, *et al*., 1996) discussed the highly significant changes in the Bay aquatic organism assemblages caused by invading species. It certainly will not be possible in situations of this type to rely on aquatic organism assemblage data to determine whether the exceedance of the site-specific water quality criterion for copper that occurs routinely in Bay waters is causing adverse impacts on the aquatic life-related beneficial uses of the Bay.

The concerns about the over-regulation of urban area stormwater runoff expressed by municipalities across the US have caused the US EPA to initiate several advisory committee activities, including the development of an Urban Wet Weather Flows Watershed Framework, an Interim Permitting Approach for Water Quality-Based Effluent Limitations in Storm Water Permits and Recommendations on Monitoring Requirements for Watershed Monitoring Programs. The Agency and the Agency advisory committees have released several draft documents that discuss the Agency's proposed approaches for addressing the over-regulation of urban area stormwater runoff that arises from requiring urban area and highway stormwater dischargers to meet water quality standards in the receiving waters for the runoff. The approaches presented in the various draft documents are supportive of the Evaluation Monitoring approach of focusing water quality management for stormwater runoff on identifying and controlling real water quality problems in the receiving waters for the runoff.

Basically, these draft documents recognize the overly-protective nature of US EPA water quality criteria when applied to urban area and highway stormwater runoff. They also recognize the inability of end-of-the-outfall-pipe/edge-of-the-pavement monitoring in providing reliable and useful information on water quality impacts of stormwater runoff-associated constituents.

One of the important issues that the Agency has formally addressed as part of its current activities in the stormwater runoff water quality management field is whether urban area and highway NPDES-permitted stormwater runoff permit holders would be in violation of their permit due to the exceedance of water quality standards in the receiving waters for the permit. While at this time the Agency, as part of implementing Clean Water Act requirements, must require that water quality standards be met in receiving waters by NPDES dischargers, in June 1996 the Agency announced its Interim Policy which sets forth the approach that exceedance of a water quality standard in urban area and highway stormwater runoff does not represent a violation of the stormwater dischargers' NPDES permit. This then-proposed policy was formally adopted by the Agency in August 1996 (Perciasepe, 1996). In accord with its 1990 federal national stormwater runoff management approach, the Agency adopted the requirements that stormwater NPDES permit holders must use BMPs to try to achieve water quality standards in the receiving waters to the maximum extent practicable. While this approach is more appropriate than an absolute mandate to meet water quality standards in receiving waters for urban area and highway stormwater runoff, it still sets as a goal achieving chemically-based water quality standards. As long as the Agency's Independent Applicability Policy stands, this could cause stormwater dischargers to have to implement BMPs designed to achieve inappropriate, overly-protective water quality standards for stormwater runoff. Lee and Jones-Lee (1997b,f) have discussed the importance of the Agency ultimately associated with reauthorization of the Clean Water Act where appropriate consideration is given to managing water quality impacts associated with urban area and highway stormwater runoff developing appropriate policy and goals which will enable public and private funds spent for stormwater runoff water quality management to be focused on controlling real, significant water quality use impairments in the receiving waters for the runoff. The key to future regulatory activities in the urban area and highway stormwater runoff water quality management field will be the incorporation of concepts that are evolving out of the US EPA's Wet Weather Flows Advisory Committee's activities into the Clean Water Act when it is finally reauthorized by Congress.

Summary and Conclusions

There is widespread agreement among professionals in the urban area street and highway stormwater runoff evaluation and management field that the approaches being used today to monitor the water quality characteristics and impacts of chemical constituents and pathogenic organism indicators in stormwater runoff is inadequate and unreliable. There is also growing recognition that the standard

BMPs, such as detention basins and filters, that are often used for urban area street and highway stormwater runoff are largely ineffective in controlling the concentrations of chemical constituents in the runoff waters that could be adverse to the designated beneficial uses of the receiving waters. There is need to change the standard practice for urban area street and highway stormwater runoff impact evaluation and management so the resources available are more appropriately directed toward identifying real, significant water quality use impairments of the receiving waters for the runoff and, where found, implement technically valid, cost-effective control programs to the maximum extent practicable using site-specific developed BMPs. The BMPs that will likely be used to address real water quality problems will almost certainly be significantly different from the standard practice BMPs that are used today.

The Evaluation Monitoring approach described in this report provides an alternative approach that specifically focuses the resources available on identifying significant water quality use impairments in the receiving waters for the stormwater runoff, determining their cause and the source of the constituents responsible for the use impairment, and developing control programs that conform to current regulatory requirements of controlling pollution of the receiving waters for the runoff caused by the runoff-associated constituents to the MEP using BMPs. Table 1 presents a summary of the components of an Evaluation Monitoring program and provides a brief overview of key issues that need to be considered in its implementation. Additional information on each of the components in this Table are provided in this report.

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Since the authors plan to periodically update the discussion of the application of Evaluation Monitoring to various situations, they would appreciate receiving comments from those who review the authors' discussion of these topics as well as information on experience that others may have devoted to the application of Evaluation Monitoring to their particular areas of concern.

Table 2
Issues that Should be Considered in the
Development of an Evaluation Monitoring Program

Organize an Evaluation Monitoring program development team.

Team should have expertise in aquatic chemistry, analytical chemistry as applied to water and wastewater analysis, aquatic toxicology, aquatic biology, hydrology/hydraulics, public health and water quality.

Technical representatives of all stakeholders for the waterbody's water quality and watershed should be involved in the Evaluation Monitoring program development and implementation.

Select the waterbody(s) of concern.

For the waterbody of concern determine its watershed.

Determine the potential stakeholders in the watershed and for the waterbody.

- Potential sources of constituent dischargers
  - Point sources
    - Municipal and industrial wastewater discharges
  - Non-point sources
    - Surface water inputs
      - Base flow in streams
        - Groundwater input to tributary streams, direct subsurface groundwater input
      - Dry weather runoff
        - Fugitive water-watering of lawns, etc., irrigation return flow
      - Stormwater runoff
        - Urban - Residential, commercial, industrial
        - Rural - commercial establishments, Industry
          - Agriculture - Irrigated lands, pastures
          - Non-developed - Forests, grasslands, wetlands
    - Atmosphere - Local and longer distance sources

Determine potentially impacted and interested parties for the waterbody of concern

- Users of the waterbody
  - Water supply - Surface and groundwater with recharge
    - Municipal, industrial/commercial, agriculture
  - Recreation - Contact and non-contact
  - Fishing - Fish and shellfish
  - Boating, canoeing
  - Walking, bird watching, wildlife habitat, nature preserve
- Regulatory Agencies

Federal, state, county and local

Water quality, air quality, department of health, pesticide use, etc.

Planning agencies

Political jurisdiction representatives

Environmental Groups

Hold a watershed stakeholders' meeting to discuss the nature of the Evaluation Monitoring program

(It will likely be desirable to meet individually with key stakeholders to gain their views and support for the development of the Evaluation Monitoring program prior to the general meeting of stakeholders.)

Appoint a stakeholder Technical Advisory Committee (TAC).

(For special problem areas which require high degrees of special expertise, an advisory panel covering the topic area(s)will likely be needed to advise the stakeholders' Technical Advisory Committee.)

The TAC should have individuals with expertise in the water quality aspects of aquatic toxicology, aquatic biological resources, hydrodynamics-hydraulics/hydrology and other areas pertinent to evaluating the impairment of the beneficial uses of the waterbody of concern.

Select a consultant who can develop the necessary materials for review by the TAC.

Collect the information available on the water quality characteristics of the waterbody(s) of concern.

Consider for each of the potential types of water quality problems listed below the adequacy of the current information to define a significant water quality use impairment and whether such an impairment exists at this time. If inadequate data are available on water quality characteristics of the waterbody to define whether water quality problems exist, develop programs to gather needed data-information.

Toxicity--Water Column

- Assess levels or toxicity in tributary water and in main body
- If found, determine its fate, persistence and water quality significance
- If judged significant, determine its cause through TIEs and through forensic analysis, sources of constituent(s) responsible for the toxicity
- Explore toxicity control approaches focusing on control at the source

Focus on control of toxicity rather than chemical constituents that in some locations are toxic. Do not assume that all chemical constituent forms are toxic/available. Use toxicity tests.

Toxicity--Sediments

- Assess the toxicity of sediments several times/year using several sensitive organisms at multiple reference sites
- If found, determine its water quality significance
- If judged significant, determine its cause through TIEs and through forensic studies the source of chemical constituents responsible for toxicity. Also, evaluate the need to remove/remediate the toxic sediments

Do not assume that all sources and chemicals found are toxic/available. Use a combination of toxicity tests, TIEs and selected chemical analyses to determine actual sources of chemicals that are toxic to aquatic organisms in the sediments.

Recognize that natural toxicity due to low DO, H_2S and NH_3 can be an important component of sediment toxicity.

Bioaccumulation

Measure the concentrations of mercury, lead and chlorinated hydrocarbon pesticides, PCBs and dioxins in edible aquatic organism tissue. Compare the concentrations found in tissue to US EPA human health-based guideline values based on a one meal/week (30 g/day) consumption rate.

As wildlife-based bioaccumulation "excessive" tissue residues in lower trophic level organisms that serve as important components of target organisms' food become available, use the criteria to evaluate "excessive" tissue residue in fish and other aquatic life.

In those situations where excessive bioaccumulation is found, determine through combined aquatic organism tissue and chemical analyses the specific sources of the constituents that are bioaccumulating to excessive levels to represent a use impairment.

Focus on actual tissue residues rather than chemical constituents that have the potential to bioaccumulate in some situations. The forensic studies must focus on determining the actual sources rather than assuming that all sources of a constituent are in available chemical forms.

Eutrophication--Excessive Fertilization

Through a public shareholders evaluation for a waterbody, determine if the waterbody or parts thereof are experiencing excessive aquatic plants (planktonic algae, attached algae, macrophytes and emergent water weeds). For freshwaters that are used as domestic water supply determine if a water utility is experiencing taste and odors, shortened filter runs , excessive total trihalomethanes, etc.

Determine the times of the year when excessive fertilization was occuring.

Where excessive fertilization is found, determine the nutrients (N or P) compounds responsible for controlling peak aquatic plant biomass.

Determine the sources of the available forms of the limiting nutrients (sol-o P, NO_3^-, and NH_3) and to some extent particulate N and P that control or could control peak aquatic plant biomass at the times when the public - water utilities experience water quality use use impairment due to aquatic plants.

Develop control strategy for the key limiting nutrient(s) at the source.

Focus on controlling water use impacts due to excessive fertilization, rather than total N and P inputs to a waterbody.

Assessing water quality significance of potential water quality impacts

Based on a watershed-based, stakeholder-driven, consensus-building process, develop an approach for determining what constitutes a significant water quality use impairment.

Implement this approach for the waterbody.

Focus on defining real water quality use impairments of importance to the public rather than achieving water quality standards for specific regulated chemical constituents.

For toxicity, a technical advisory panel of experts should develop a consensus-based approach to determine the magnitude, persistence, frequency and spectrum of impacted organisms.

Apply this approach to the waterbody and parts thereof to develop an expert panel based consensus, best professional judgement, weight-of-evidence to determine the areas of the waterbody that have sufficient toxicity to cause significant water quality use impairment that should be controlled to manage the problems in those parts of the waterbody where the toxicity is found.

Sanitary Quality

Work with local health agencies and waterbody stakeholders to define water quality use impairments due to excessive concentrations of total and fecal coliforms. Consider impacts on domestic water supply, contact recreation and shellfish harvesting.

Consider the potential for enteric viral and protozoan pathogens to cause disease to those using the waters for a water supply, contact recreation or shellfish harvesting. If there is a potential for waters of concern to have runoff containing animal wastes such as from dairies and feedlots and conventionally treated domestic wastewaters, establish a monitoring program for *Cryptosporidium*.

Focus sanitary quality problem evaluation on excessive concentrations of fecal indicator organisms and the potential for human pathogenic viruses and protozoans to cause disease in those who utilize the waters of concern.

Sediment Impacts

Evaluate the impacts of suspended sediments on aquatic life through turbidity, including photosynthesis, aesthetic quality and abrasion.

Also evaluate when the sediment accumulation is adverse to aquatic life habitat such as spawning beds, coral and shellfish beds as well as shoaling that interferes with navigation and aquatic plant habitat.

Where adverse sediment impacts are defined, determine the sources of the sediment and control erosion at the source.

Focus the sediment impact evaluation on finding real, significant water quality use impacts of importance to the public's use of the waterbody.

Oil and Grease and Litter Accumulation

Examine the receiving waters for areas where oil and grease and litter accumulation is occurring.

Where such areas are found, determine source of the oil and grease and/or litter accumulation and develop control programs.

Dissolved Oxygen Depletion

Examine the waterbody to determine if low dissolved oxygen conditions exist which significantly impact the beneficial uses of the waterbody.

If low DO conditions are found, determine the cause, i.e. scoured sediments, Fe^{2+}, H_2S, BOD, photosynthetic activity, etc.

Focus a DO depletion evaluation on determining whether the DO depletions are of sufficient magnitude, duration and frequency to significantly adverse impact aquatic life resources.

Water Supply Water Quality

Examine the water quality characteristics of the raw and treated waters and the treatment processes used to determine the raw water quality characteristics that cause increased treatment costs and the adequacy of finished water quality.

The sources of constituents that either cause increased costs of treatment or deteriorated finished water quality should be controlled at source.

For groundwater-based water supply, define the constituents in recharged surface waters that cause deteriorated groundwater quality that influences the use of the groundwater's domestic and other uses.

Focus water supply water quality on the increased cost of water treatment.

Plan for On-Going Evaluation Monitoring Program Implementation and Funding

> Each of the potential areas of water quality concern should be re-examined at least once every five years, i.e. NPDES permitting cycle to determine if new water quality problems have developed or are now discernible.

Development of BMPs

> For each significant water quality problem found, work with the stakeholders to develop technically valid, cost-effective best management practices that will control pollution of the receiving waters by stormwater runoff-associated constituents to the maximum extent practicable.
> Evaluate the efficacy of the BMPs by an on-going monitoring program that focuses on assessing the changes in the beneficial uses of the waterbody that the BMP is supposed to address.

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