Stormwater Runoff Water Quality Science/Engineering Newsletter
Devoted to Urban/Rural Stormwater Runoff
Water Quality Management Issues

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This issue of the Stormwater Runoff Water Quality Science/Engineering Newsletter is a double issue devoted to a review of **water quality issues in urban creeks associated with urban stormwater runoff**. In many areas, urban stormwater runoff occurs to a relatively small urban creek. There is considerable interest today in properly regulating the impacts of chemical constituents and pathogen indicator organisms in urban stormwater runoff as they may impact urban creek and lake water quality. This Newsletter consists of an approximately 50-page review of urban creek water quality issues. It integrates a number of the discussions on stormwater runoff water quality impact evaluation and management that have been presented in previous Newsletters.

The senior author (G. F. Lee) has been involved in a number of urban creek studies over the past 40 years, focusing on the impact of urban stormwater runoff on the water quality characteristics of the urban creek or lake, and he is familiar with some studies conducted by others on this same issue. This Newsletter reviews some of the issues that the author has experienced in assessing the impact of urban stormwater runoff on urban creek/lake water quality.

As discussed herein, the application of US EPA water quality criteria and state standards based on these criteria to regulating urban creek water quality is fraught with difficulty. This Newsletter reviews some of the issues that need to be considered in regulating urban stormwater runoff to protect the beneficial uses of urban creeks without significant unnecessary expenditures for control of stormwater runoff-associated constituents. It provides references to additional discussions of the issues summarized herein.

Urban Creek and Lake Water Quality Issues

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Abstract. – Urban creeks and lakes can be important habitats for a variety of aquatic life, as well as an aesthetic resource to communities. A key component of this resource is the quality of water in these waterbodies. This paper is devoted to a review of water quality problems in urban creeks and lakes associated with stormwater runoff and other urban sources of pollutants. A discussion is presented of the characteristics of urban stormwater runoff as they may impact the water quality-beneficial uses of urban creeks and lakes. Also, information is presented on

regulatory issues that need to be incorporated into cost-effectively controlling constituents that cause pollution – impairment of urban creek and lake water quality/beneficial uses. A review is presented of current information on some aspects of approaches (BMPs) for managing urban creek and lake water quality. The conclusion from this approximately 50-page review is that very little is known about the impacts of chemical constituents that are present in urban stormwater runoff on the beneficial uses of urban creeks and lakes. It is clear that exceedence of US EPA water quality criteria or state standards based on these criteria is likely a poor indicator of the impairment of beneficial uses of urban creeks and lakes.

As discussed, there is need for comprehensive studies on urban creeks and lakes to determine the impacts of residential and commercial area and street and highway stormwater runoff. These studies can lead to the development of wet weather standards that can be used to more appropriately regulate chemical constituents in urban area and highway stormwater runoff than is occurring today. These studies will also provide the information needed to develop appropriate runoff management practices to control the significant water quality beneficial use impairments that are occurring in urban creeks and lakes due to chemical constituents in the runoff.

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Introduction

In many areas, urban stormwater runoff occurs into a relatively small urban creek, which in turn discharges to a larger waterbody within or outside of the urban area. In some areas, urban creeks discharge to urban lakes, where the primary water entering the lake is urban stormwater drainage. Urban creeks and lakes are waters of the US, which means that US EPA water quality criteria/state water quality standards are applicable to urban creek and lake water, including the application of the US EPA worst-case-based national water quality criteria for protection of aquatic life propagation.

Many urban creeks' primary function is that of conveyance of stormwater to prevent flooding. They have often been channelized to assist in achieving rapid stormwater removal from an urban area. This channelization, coupled with the development (paving) of the urban creek watershed, is strongly contrary to providing high-quality aquatic life habitat. Urban creek flows can vary from a few cubic feet per second of groundwater-based flow to hundreds to a thousand or more cubic feet per second during flood flow conditions associated with major runoff events. The high flows are detrimental to developing/maintaining desirable aquatic life habitat. Urban creeks also are frequently receptacles for waste materials, litter and debris, including shopping carts, yard waste, etc.

At the same time, urban creeks and lakes can be important aesthetic amenities and provide, in some cases, a recreational fishery as well as a nursery area for aquatic life. The fisheries in urban creeks can range from a sustainable trout fishery, such as in Spring Creek in Fort Collins, Colorado (see Lee and Jones, 1981a), to carp- or minnow-dominated waters. Some urban lakes provide good warmwater sport fisheries for bass, bluegill, etc.

The senior author has been involved in a number of urban creek and lake studies over the past 44 years, focusing on the impact of urban stormwater runoff on creek/lake water quality characteristics. This paper reviews water quality issues the authors have experienced in assessing the impact of urban stormwater runoff on urban creek and lake water quality. Lee and Jones (1980) presented a review on water quality issues associated with stormwater runoff to urban lakes. Presented below is an updated overview discussion of the water quality problems in urban creeks and lakes. Consideration is given to heavy metals, aquatic life toxicity, dissolved oxygen, nutrients/excessive fertilization, pH, ammonia, sanitary quality, total organic carbon, excessive bioaccumulation of hazardous chemicals in edible aquatic organisms, PAHs, oil and grease, unrecognized hazardous/deleterious organic chemicals, suspended sediment/turbidity, trash and aquatic life habitat. Further information on these topics is available in the references provided. The experience that the authors have gained in studies of the creeks and sloughs associated with the city of Stockton, California, as well as work that they have done in other urban areas, is used as a basis for discussion of some urban creek and lake water quality issues.

Reference is made in these discussions to the *Stormwater Runoff Water Quality Science/Engineering Newsletter* (Jones-Lee, 2004). This Newsletter has been published through the Internet for the past seven and a half years. It contains expanded discussions of many of the topics reviewed herein. Copies of past Newsletters are available at www.gfredlee.com.

In this discussion reference is made to information derived from a Center for Watershed Protection report (CWP, 2003), "Impacts of Impervious Cover on Aquatic Systems." This report can be purchased from CWP for 25 dollars and downloaded from the following website: http://centerforwatershedprotection.goemerchant7.com/index.cgi

The CWP (2003) report is an expansion/update of earlier work by Schueler (1994) on the impact of urbanization (paving) of an area on the waterbodies receiving the runoff from the area. This report provides summaries of several reviews on the characteristics of urban stormwater runoff. While the Foreword to the CWP (2003) report states that it synthesizes emerging research within the topic area and provides information on the scientific basis behind the relationship between impervious cover and the health of aquatic ecosystems, a review of the report shows that it does not necessarily contain current information on many important water quality aspects of stormwater runoff, such as those that have been discussed in the *Stormwater Runoff Water Quality Science/Engineering Newsletter* (Jones-Lee, 2004) over the past seven and a half years. While the CWP report acknowledges that the aquatic chemistry of urban stormwater runoff-associated chemical constituents can influence aquatic life impacts, it does not provide a discussion of these issues. Some of these issues are reviewed below.

Burton and Pitt (2002) developed a Stormwater Effects Handbook, which provides background information on the water quality problems associated with stormwater runoff from urban and, to a lesser extent, rural areas. They discuss impacts on receiving water uses and sources of stormwater pollutants. The majority of the over-900-page handbook is devoted to a discussion of approaches for assessing the characteristics of stormwater runoff and its impacts on receiving water quality. The handbook provides background information to some of the methodologies discussed herein.

Evaluation of Water Quality Impacts of Stormwater Runoff

Throughout the CWP (2003) report, the chemical constituents found in urban streams that have been derived from urban stormwater runoff are characterized as "pollutants." As discussed herein, in the *Stormwater Runoff Water Quality Science/Engineering Newsletter* (Jones-Lee, 2004) over the past seven and a half years and in the authors' papers and reports devoted to this topic over the last 15 years (see www.gfredlee.com, in the Surface Water Quality, Urban Stormwater Runoff section), a pollutant, by tradition and legal definition, is a constituent that adversely impacts the designated beneficial uses of a waterbody. Further, and most importantly, the US EPA (1990) regulatory requirements for control of urban stormwater runoff water quality impacts are to be directed to controlling pollution to the maximum extent practicable using best management practices (BMPs). It would be more appropriate to change the word "pollutant" throughout the CWP (2003) document to "chemical constituent" or "pathogen indicator organism," with the understanding that some of these constituents or parts thereof, under certain conditions, can be a cause of water pollution – impairment of beneficial uses.

It is well-understood that many of the chemical constituents present in urban streams and lakes are in nontoxic, non-available forms and therefore are not pollutants. While there has been considerable work on the chemical characteristics of urban stormwater runoff, little of this work has been devoted to water quality impacts. It is, therefore, important to properly assess whether a chemical constituent derived from stormwater runoff that is present in an urban stream or lake is in a chemical form that is toxic or bioavailable – i.e., can cause pollution. Failure to make this evaluation can lead to expenditure of large amounts of public funds in the development and installation of so-called BMPs which have little or no impact on the beneficial uses of an urban stream or lake or other waterbody receiving the stormwater runoff. The discussions presented herein cover some of the aquatic chemistry/toxicology/bioassessment issues that need to be considered in properly evaluating data on the concentrations of chemical constituents derived from urban stormwater runoff that are present in urban streams and lakes, with respect to their impacts on the beneficial uses of these waterbodies.

Throughout the CWP (2003) report and the stormwater runoff water quality literature, there is discussion about stormwater pollutant loads. These discussions fail to adequately consider the fact that many of the constituents in stormwater runoff from paved areas are in nontoxic/non-available forms and, therefore, are not adverse to the beneficial uses of a waterbody. CWP (2003) and some others who work on water quality aspects of urban stormwater runoff persist with the technically invalid approach of attempting to discuss water quality impacts of urban stormwater runoff on urban streams in terms of event mean concentrations (EMCs). The event mean concentration approach for characterizing the concentrations of chemical constituents in stormwater runoff arose out of the US EPA (1983) Nationwide Urban Runoff Program (NURP) conducted in the early 1980s. While EMCs are potentially of value, when combined with reliable flow measurements, to estimate the loads of chemical constituents (both pollutants and non-pollutants) in urban stormwater runoff to waterbodies or in a waterbody on downstream waterbodies, as discussed below EMCs are not reliable for estimating water quality impacts of chemical constituents within an urban stream.

The authors of the CWP (2003) report repeatedly comment on how there appears to be little or no relationship between "pollutant" event mean concentrations and the water quality characteristics of urban streams receiving appreciable loads of constituents associated with urban stormwater runoff. This is not surprising, since many of the constituents (potential pollutants) in urban stormwater runoff are in nontoxic, non-available forms.

Urban Creek/Lake Water Quality Issues

The quality of water in urban creeks at times is dominated by urban stormwater runoff-associated constituents. In the late 1970s/early 1980s, the US EPA conducted a Nationwide Urban Runoff Program (NURP) in 28 communities across the US. The NURP studies provided information on concentrations and loads of a variety of potential pollutants in urban stormwater runoff. Pitt and Field (1990) summarized the results of the NURP studies. A summary of these results is also presented in WEF/ASCE (1998). While the US EPA NURP studies provided data on the concentrations and loads of a variety of potential pollutants in urban stormwater runoff, these studies failed to address true water quality issues – i.e., the impacts of the potential pollutants on the beneficial uses of the receiving waters for the runoff.

Lee and Jones (1981b) criticized the NURP studies during their development and implementation, for failing to determine the impacts of the urban stormwater runoff-associated constituents, such as the potential toxicity of heavy metals, on the beneficial uses of the receiving waters for the runoff. While at the time that the NURP studies were conducted it was well-known through the National Academies of Science and Engineering "Blue Book" of <u>Water</u>

Quality Criteria 1972 (NAS/NAE, 1973) that measurements of the total concentrations of heavy metals could not be used to predict heavy metal toxicity, this issue was ignored by the US EPA in developing and conducting the NURP studies. Specifically, those in the US EPA responsible for NURP failed to include the recommended toxicity testing to determine if the heavy metals and other constituents in urban stormwater runoff were in toxic available forms. They specifically prohibited the City and County of Denver, Colorado, from using NURP funds to determine if the urban runoff from this area was toxic to aquatic life. As discussed below, with respect to heavy metals, it was known in the 1960s that at least some of the heavy metals, such as lead, that occur in stormwater runoff were in nontoxic forms. These issues are discussed further below.

Heavy Metals. In the fall of 1998 the California Storm Water Quality Task Force conducted a review of the constituents that are present in urban area and highway stormwater runoff at sufficient concentrations to cause violations of US EPA water quality criteria and/or California Toxics Rule criteria which were developed by the US EPA (2000a) for the State. As presented in Newsletter 1-5 (Jones-Lee, 2004), copper, lead and zinc were found in almost all urban street and highway stormwater runoff at concentrations which would violate US EPA worst-case-based water quality criteria and state standards based on these criteria. Sometimes cadmium and mercury were also present above these criteria/standards. This finding indicates that there is a potential for certain heavy metals in urban stormwater runoff to be toxic to aquatic life in urban creeks.

CWP (2003) has summarized the results of several studies of the heavy metal concentrations in urban stormwater runoff from various municipalities in the US. They report that the event mean concentrations of copper ranged from 1.4 to 60 µg/L, lead ranged from 8.5 to 330 µg/L, and zinc ranged from 55 to 540 µg/L. CWP (2003) reported that the range of heavy metal concentrations found in various parts of the US is related to frequency of rainfall.

Lee, *et al.* (2001a) conducted a study of heavy metal concentrations and aquatic life toxicity in 10 different Upper Newport Bay (Orange County, California) watersheds during 1999-2000. Lee and Taylor (2001a) presented the results of the heavy metals part of this study. Several of these watersheds had predominantly urban land use. Lee and Taylor found several heavy metals, such as copper, zinc and lead, at concentrations above water quality criteria/standards. Through toxicity investigation evaluation (TIE) studies, Lee and Taylor (2001b) found, as have others, that heavy metals in urban residential area and highway stormwater runoff are in nontoxic forms. The statement with respect to the lack of toxicity of heavy metals associated with urban area street and highway stormwater runoff does not necessarily apply to heavy metal discharges in industrial stormwater runoff. There are a number of examples where heavy metals such as zinc from galvanized roofs or copper from copper roofs can be present in industrial stormwater runoff in sufficient concentrations and forms to be toxic to aquatic life.

Taylor and Lee (2000), in a study of stormwater runoff from the Eastern Transportation Corridor (ETC), a toll road in Orange County, found, in addition to copper, zinc and lead, measurable concentrations of palladium (estimated to be 0.17 µg/L) in highway stormwater runoff. Palladium is one of the substances used in catalytic mufflers. The ETC stormwater runoff samples were also examined for platinum, another catalytic muffler substance. Total platinum was found at a concentration of 0.006 µg/L. No information is available on the toxicity of palladium and platinum to aquatic life.

Chromium. One of the heavy metals of concern in urban stormwater runoff is chromium. Lee and Jones-Lee (1997a; 1998a,b) have discussed some of the issues that should be considered in regulating chromium in ambient waters. There are two oxidation states of chromium of concern, III and VI. Chromium-III has low toxicity to aquatic life. It is formed under anoxic conditions and tends to strongly sorb to sediments. The urban creek sediments that are not subject to scour during high flow can be reservoirs of chromium. Chromium-VI is highly toxic to aquatic life and has low sorption tendencies.

Prior to about 1970, the city of Madison, Wisconsin, allowed cooling tower operators to discharge chromium-VI, which was used as a corrosion inhibitor, in "blowdown" to Madison creeks in order to avoid toxicity problems in the City's domestic wastewater treatment plant. This was a common practice across the country, which was stopped in Madison by 1970, although in some areas of the US discharges of chromium in cooling tower blowdown continued for a decade or more. Schroeder and Lee (1975) conducted a study on the fate of chromium in Madison, Wisconsin, urban creeks. Schroeder and Lee found that Madison, Wisconsin, urban creeks in the 1960s had elevated levels of chromium, and that chromium-III, which was produced when chromium-VI from cooling tower blowdown was in contact with anoxic sediments, was slowly oxidized to chromium-VI in oxygen-containing waters. This could lead to toxicity in the water column during the time that the waterbody sediments are scoured and the chromium-III is oxidized.

Lee and Jones-Lee (1998a,b) have discussed the potential under-regulation of chromium-VI that is being allowed by the US EPA (2002a) and the states in adopting the chromium-VI water quality criterion/standard. This chronic criterion, since the mid-1980s, has been set at 11 µg/L. However, a review of the US EPA (1987) Gold Book chromium criterion document, the US EPA (1985) "Ambient Water Quality Criteria for Chromium" and Environment Canada (1994) show that chromium-VI is toxic to a few common zooplankton at a few tenths of a microgram per liter. These results indicate that the US EPA criterion for chromium-VI is not protective of zooplankton. This represents an inconsistent approach on the part of the US EPA in developing criteria, where the chromium-VI criterion does not protect zooplankton, yet, as discussed below, the US EPA's approach for regulating the OP pesticides diazinon and chlorpyrifos focuses on protecting zooplankton.

Lead. Another heavy metal of concern in urban stormwater runoff is lead. The former use of lead as an additive in gasoline as an anti-knock agent caused urban and highway stormwater runoff to contain greatly elevated concentrations of lead. The addition of lead to gasoline was terminated across the country by the mid-1980s. Peterson (1973) conducted his PhD dissertation in Water Chemistry at the University of Wisconsin, Madison, under the supervision of Dr. G. F. Lee, on the occurrence of lead in waterbody sediments. His dissertation included measurements of lead in Madison, Wisconsin, stormwater runoff during the late 1960s. He found concentrations of lead up to 2,200 µg/L in urban area street and highway stormwater runoff, as well as high concentrations in the surface layers of urban and nearby lake sediments. It was found, however, that the lead in the runoff and in the sediments was in a form that was nontoxic to aquatic life.

Lee and Jones (1992), Lee and Jones-Lee (1997b) and Lee and Taylor (1998) have reviewed the water quality significance of lead in urban area street and highway stormwater runoff and in the surface soils near the highways/streets. Much of the lead added to gasoline that was discharged in automobile exhaust settled on the highways/streets and on nearby soils. When lead was added to gasoline the concentration in gasoline was about 250 mg/L. Lee and Taylor report that, while lead is no longer used as an additive in gasoline, the naturally occurring lead in gasoline, which, for some gasolines, can be on the order of 15 mg/L, still causes urban area street and highway stormwater runoff to contain sufficient concentrations of lead to violate water quality standards based on total lead, and, in some cases, soluble lead content. As reported by Lee and Taylor (1998), the concentrations of lead in soils near highways and streets can be sufficient to cause these soils to be considered a "hazardous waste" in California (i.e., total lead greater than 1,000 mg/kg) if the soils are excavated, and thereby require their disposal in a hazardous waste landfill.

Copper. There is concern about the concentrations of copper in urban area stormwater runoff. Total and dissolved copper concentrations in this runoff can exceed water quality standards. Copper in highway and street stormwater runoff is derived in part from its use in automobile brake pads for some types of automobiles. This has led to some environmental groups calling for a ban on the use of copper in automobile brake pads. However, as discussed by Lee (1994) and Lee and Jones-Lee (1993, 1997c), copper, like lead, in urban area and highway stormwater runoff is in a nontoxic form. Further, should it become toxic, through dissolution in low-alkalinity acidic waters (which is unlikely), it will in most situations be complexed with organics and rendered nontoxic.

Mercury. The concentrations of mercury in urban area and highway stormwater runoff have been found to exceed the US EPA (1987) Gold Book water quality criterion of 12 ng/L for total recoverable mercury. Mercury is of concern because of its conversion to methylmercury in waterbody sediments, which can lead to food web accumulation into higher-trophic-level fish tissue which would cause the edible fish to be hazardous to fetuses and young children. As part of developing the California Toxics Rule, the US EPA (2000a) changed the mercury criterion to 50 ng/L total recoverable mercury. This change did not reflect a change in the significance of mercury as a human health threat, but reflected a change in how the Agency computes water quality criteria for bioaccumulatable chemicals. According to Woods (2000) of the US EPA Region 9, a worst-case-based total recoverable water column mercury criterion could be set at about 5 ng/L.

Lee and Jones-Lee (1997d) discuss the problems of trying to reliably regulate mercury based on a water quality criterion/standard. They recommend that mercury and other bioaccumulatable chemicals should be regulated based on aquatic organism tissue levels that are considered hazardous to human health. The US EPA (2001a,b) has indicated that this is the approach that the Agency will be adopting for regulating mercury. The Agency has indicated that it plans to regulate mercury based on the methylmercury content of edible fish tissue, with a criterion of 0.3 mg methylmercury/kg (wet weight) in fish tissue which should not be exceeded, in order to protect the health of consumers of noncommercial freshwater/estuarine fish. Lee (2003a) has recently reviewed the current and pending approaches for regulating mercury in the water column and sediments.

Dissolved vs. Particulate Heavy Metals. Heavy metals present in urban stormwater runoff are largely in particulate forms, which are not regulated in urban streams by water quality standards, since the US EPA (1995) criteria and state standards regulate dissolved forms of metals that do not bioaccumulate. However, particulate heavy metals can accumulate in sediments and could cause urban stream and lake sediments to contain concentrations of heavy metals which exceed co-occurrence-based sediment quality guidelines, such as those developed by Long and Morgan. However, as discussed by Lee and Jones-Lee (2002a, 2003a), such exceedances do not mean that there is a water quality problem which would impair the beneficial uses of the water. They are more likely related to the inappropriateness of using total concentrations of heavy metals (or, for that matter, other constituents in sediments) to attempt to determine the water quality impacts of these constituents on aquatic-life-related beneficial uses of the waterbody in which the sediments are located. Lee and Jones-Lee (2002a, 2003a, 2004a) recommend that a best professional judgment triad weight of evidence approach be used to evaluate the water quality significance of heavy metals and other constituents in aquatic sediments. This approach involves an integrated use of aquatic life toxicity/aquatic food web bioaccumulation information, altered organism assemblages compared to habitat characteristics, and TIE information devoted to discerning the cause of aquatic life toxicity and bioavailability of potential pollutants associated with aquatic sediments.

Aquatic Life Toxicity. There are several constituents normally present in urban area stormwater runoff which could cause aquatic life toxicity. The constituents of greatest concern are the heavy metals, such as copper, zinc, lead, and occasionally cadmium. There have been a number of studies conducted in several areas of California to determine whether the heavy metals present in urban stormwater runoff are in toxic forms. See Lee, *et al*. (2001a) and Lee and Taylor (2001a,b) for a review. Toxicity measurements of urban stormwater runoff from a number of areas have shown that, while urban residential and commercial runoff is toxic to *Ceriodaphnia* (a US EPA standard freshwater zooplankton test organism), this toxicity is not due to heavy metals. Toxicity investigation evaluations (TIEs) have shown that the toxicity is due to the organophosphorus (OP) pesticides diazinon and/or chlorpyrifos. The OP pesticides are of concern because of their toxicity to a few types of zooplankton. They are not toxic to fish or algae at the concentrations found in urban runoff.

Pesticide-Caused Toxicity. OP-pesticide-caused toxicity has been reviewed by Lee, *et al.* (2001a,b) and Lee and Jones-Lee (2002b). This issue has also been reviewed in the *Stormwater Runoff Water Quality Science/Engineering Newsletter* (Jones-Lee, 2004), Newsletters NL 1-5, 2-1, 3-5, 6-3. As discussed in these Newsletters, while diazinon and chlorpyrifos have been or are soon to be phased out of urban use by the US EPA due to their potential toxicity to children, other pesticides, especially the pyrethroid pesticides, are being used in urban areas as replacements for the OP pesticides. Chlorpyrifos can no longer be sold for use as a pesticide in urban areas. The US EPA and the registrants have agreed that it will no longer be legal to sell diazinon for urban use after December 2004. The replacement pesticides for the OP pesticides are not evaluated by the US EPA Office of Pesticide Programs for their potential to cause aquatic life toxicity in stormwater runoff from their point of application. A number of them are more toxic to fish and zooplankton than the OP pesticides. Many of the pyrethroid pesticides tend to sorb strongly to soil particles and, therefore, will be transported in particulate form and accumulate in sediments. Weston (2002) and Weston et al. (2004) have reported finding that some sediment-sorbed pyrethroid-based pesticides are bioavailable to some benthic organisms. It is unclear whether this bioavailability leads to toxicity. It could, however, cause toxicity in urban streams and lakes and their sediments.

The California Central Valley Regional Water Quality Control Board (CVRWQCB) and the DeltaKeeper monitored aquatic life toxicity in city of Stockton sloughs and creeks for the period 1994 through 2000. Lee and Jones-Lee (2001) have presented and discussed these data. It has been found that, associated with each stormwater runoff event, the creeks and sloughs became toxic to *Ceriodaphnia*, with a TUa (acute toxic units) of 1 to 2 units. Generally, all of this toxicity could be attributed to diazinon and chlorpyrifos. The toxicities of diazinon and chlorpyrifos are additive when normalized based on the LC_{50}s for the test organisms (zooplankton). The creek and slough waters were nontoxic between runoff events. These waters were also generally not toxic to fathead minnow larvae or the alga *Selenastrum*. This situation has led to the CVRWQCB listing several of the city of Stockton creeks and sloughs as Clean Water Act 303(d) impaired, which requires that a total maximum daily load (TMDL) be developed to control this toxicity. Lee and Jones-Lee (2002b) have provided guidance on the development of a TMDL to control the OP-pesticide-caused toxicity in the city of Stockton creeks and sloughs.

Lee, *et al.* (2001a,b) reported finding from 5 to 10 TUa of *Ceriodaphnia* toxicity in stormwater runoff in the Upper Newport Bay watershed in Orange County, California. About half of this toxicity could be accounted for based on the diazinon and chlorpyrifos concentrations. The other half was due to unknown causes that were not identified, even though extensive TIEs were conducted on the samples. There was an indication, however, through the use of piperonyl butoxide (PBO) that pyrethroid-based pesticides, which were extensively used in the Upper Newport Bay watershed in urban areas, were responsible for part of the unknown-caused toxicity. This situation is likely to become more common in other areas as the OP pesticides are phased out of use and the pyrethroid pesticides take their place.

One of the issues of concern with respect to OP-pesticide-caused aquatic life toxicity is the water quality significance of this toxicity – i.e., whether the finding of OP-pesticide-caused toxicity in the US EPA standard toxicity test means that there is a significant impairment of the aquatic-life-related beneficial uses of the waterbody. This issue is of particular significance with respect to stormwater runoff-associated urban stream aquatic life toxicity. As discussed by Lee, *et al.* (2000), based on their studies on Upper Newport Bay tributaries and within the Bay, there are significant questions as to whether the laboratory-based toxicity translates to field toxicity that is of significance to water column aquatic-life-related beneficial uses. With respect to San Diego Creek, which is the primary tributary to Upper Newport Bay, there is only an eight-hour travel time between the headwaters of the Creek and the Bay during a stormwater runoff event. Therefore, the maximum exposure of a zooplankter would be eight hours, before entering the Bay. Toxicity results that are based on tests that are carried out for several days have little or no relevance to toxic exposure that zooplankton could receive during the runoff event. Further, zooplankters present in San Diego Creek that are carried into the Bay during the runoff event would likely be killed due to the high salinity of the Bay waters. A similar situation with respect to short-term exposure exists in the city of Sacramento, where Arcade Creek is toxic to *Ceriodaphnia* during stormwater runoff events; however, the Creek discharges to the Sacramento River where the OP pesticides are quickly diluted below toxic levels.

While there may not be sufficient exposure time in an urban creek to be adverse to zooplankton that move with the water in the creek, there could be adverse effects to the benthic organism population. Some benthic organisms are more sensitive to OP pesticide toxicity than *Ceriodaphnia*, such as the freshwater amphipod *Gammarus fasciatus* (Menconi and Cox, 1994). The benthic organism population may be a key part of larval fish food. Studies on the impact of pulses of aquatic life toxicity in urban creeks need to be conducted to determine if the toxic pulses affect the benthic organism population, and, if so, whether this translates to an adverse impact on fish larvae and other aquatic life.

One of the major problems with the approach that was used by the US EPA and its contractors in presenting the results of the NURP studies was the use of an event mean concentration to describe potential water quality impacts. This approach is, unfortunately, widely used today by those who do not understand water quality issues. The water quality impacts of a constituent are not dependent on the mean concentration of the constituent over a runoff event. Chemicals that cause aquatic life toxicity impact aquatic life through a concentration of available forms duration of exposure relationship. As discussed below, short-term exposures of high concentrations can have a significant adverse impact on aquatic life, which is not reflected in the event mean concentration of the toxicant.

Failure to find toxicity in a standard toxicity test does not mean that no toxicity exists. For example, diazinon has an LC_{50} for *Ceriodaphnia* of about 450 ng/L. This means that half of the test organisms will be killed in the standard 48-hour test with diazinon at this concentration. To get to a no-kill level of diazinon, it would be necessary to have diazinon concentrations on the order of 100 to 200 ng/L. There still could be toxicity below that concentration. The acute one-hour water quality criterion concentration for diazinon, based on the US EPA criteria development approach, is 80 ng/L (Menconi and Cox, 1994). This criterion, however, is based on a somewhat arbitrary approach adopted by the US EPA of assuming that acute toxicity would be manifested in a one-hour exposure. That situation does not necessarily apply to all forms of aquatic life. In fact, it is the authors' experience that it does not apply to most forms of aquatic life.

Dissolved Oxygen. Stormwater runoff events can cause significant dissolved oxygen (DO) depletion in urban streams and other nearby waterbodies. Recently the authors have been involved in evaluating the impact of stormwater runoff from the city of Stockton, California, on the dissolved oxygen resources of the City's creeks, rivers and sloughs. The city of Stockton has a number of creeks and sloughs which are connected to the Sacramento-San Joaquin River Delta. These creeks are freshwater tidal systems that are the drainage ways for much of Stockton's stormwater runoff.

Lee and Jones-Lee (2003b) and Lee (2003b) have presented the results of studies of the dissolved oxygen content of several of these creeks/sloughs following stormwater runoff events. A stormwater runoff event in November 2002, and another in August 2003, which were the first major runoff events of the summer/fall, led to large fish kills in half a dozen or so of these waterbodies. Measurements by the DeltaKeeper (2002) of dissolved oxygen in the waterbodies just prior to, during and following the runoff event showed that the DO prior to the event was adequate for maintenance of aquatic life – i.e., above about 5 mg/L. Shortly after initiation of the event, the DO in some of the waterbodies dropped to less than 1 mg/L. It stayed depressed for several days.

Further, at the same time, the San Joaquin River Deep Water Ship Channel, which is the recipient for the stormwater runoff from the city of Stockton, experienced a significant decrease in the dissolved oxygen in the Channel, with DO concentrations, in some instances, less than 3 mg/L. Several of the city of Stockton waterbodies receive runoff from watersheds upstream of the City. The DO measured in these waterbodies coming into the City was not depressed before or following the runoff event. Based on the City's stormwater runoff monitoring data, the average five-day biochemical oxygen demand (BOD_5) for the City's stormwater runoff is about 14 mg/L (Stockton, 1998). Considering the area of the City, the November 2002 stormwater runoff event amounted to several tens of thousands of pounds of BOD added to the City creeks, sloughs and rivers and to the Deep Water Ship Channel.

CWP (2003) reported that the $BOD_{5?}$ event mean concentrations in urban stormwater runoff in about a dozen cities located across the US ranged from 11 to 112 mg/L. While urban stormwater runoff can have appreciable concentrations of BOD_5, ordinarily little of this BOD would be exerted in the urban creek, because of the relatively short time typically associated with urban creek flow through the urban area during a stormwater runoff event and the slow rate of exertion of the biochemical oxygen demand. Typically, about five days is required for about 75 percent of the BOD to be exerted. Therefore, the oxygen demand associated with the urban runoff is likely manifested in waterbodies downstream of the City.

In addition, a significant source of oxygen demand for the creeks, sloughs, etc., was likely the suspension of the waterbody sediments, where the accumulated ferrous iron and sulfides, upon suspension into the water column and contact with dissolved oxygen, were rapidly abiotically oxidized to ferric iron and sulfate. In addition to the waterbody sediments being a source of oxygen demand upon suspension into the water column, stormwater runoff events can add oxygen demand through scour of sediments that have accumulated in storm sewers. The storm sewer sediments can contain biochemically oxidizable organics, ammonia and organic nitrogen, all of which can exert oxygen demand. The net result is that there can be an appreciable oxygen demand associated with urban stormwater runoff that can have significant adverse impacts on the receiving water oxygen resources immediately following and for several days to a week or more after the event. These events can lead to significant adverse impacts on the aquatic life resources of an urban creek.

The low-DO situation following a stormwater runoff event that has been found in Stockton creeks and sloughs is not atypical of situations that occur in urban and rural creeks across the country following a stormwater runoff event. Similar situations have been observed in

San Diego Creek in the Upper Newport Bay watershed in Orange County, California (Lee, *et al*., 2001a) and in the Trinity River just downstream of Dallas, Texas.

Urban lakes can also have low-DO problems associated with stormwater runoff events. The DeltaKeeper (2002) found that Yosemite Lake, which receives stormwater runoff from the city of Stockton, California, and is the upper end of Smith Canal (one of Stockton's sloughs), experienced low DO and a fish kill associated with the November 2002 stormwater runoff event.

Photosynthetic and respiratory activity in urban creeks and lakes can lead to early morning DO below the water quality objective (typically 5 mg/L). These DO concentrations below the objective are violations of the objective in some areas where averaging of DO during the day to account for photosynthesis is not allowed. Such averaging is allowed by the US EPA. Some states, such as California, do not allow this. From the information available, it appears that short-term DO excursions below the 5 mg/L water quality objective do not represent significant adverse impacts to a waterbody's fisheries.

Nutrients. Urban stormwater runoff contains elevated concentrations of various nutrients (nitrogen and phosphorus compounds) that can lead to excessive fertilization of urban creeks, lakes and downstream waterbodies. Nutrients, especially nitrate, in addition to being derived from stormwater runoff, can also be present in groundwater flow to urban creeks and lakes. This can be an important source of nitrate. CWP (2003) reported event mean total nitrogen concentrations in urban stormwater runoff in about a dozen municipalities across the US ranging from 1.7 to 4.6 mg/L, and total phosphorus ranging from about 0.3 to about 0.8 mg/L, with soluble P ranging from 0.04 to about 0.5 mg/L P. These concentrations, if in algal available forms, could readily lead to excessive growths of aquatic plants. CWP (2003) has provided some information on sources and source areas of nutrients, providing information on the total nitrogen and total phosphorus concentrations in runoff from various types of urban land use, including commercial parking lots, streets, rooftops, residential lawns, etc. CWP's discussion of these issues should be consulted for further details.

Some waterbodies, such as Five Mile Slough in the city of Stockton, can become completely choked with water hyacinth and duckweed. Others can experience prolific attached algal growth. Five Mile Slough is treated with aquatic herbicides in an attempt to control excessive growths of aquatic weeds. As discussed by Lee and Jones-Lee (2003c, 2004b) and Lee (2004), since, at least thus far, the regulation of aquatic herbicides is not adequate to protect non-target organisms, the control of aquatic weeds with herbicides can have direct and secondary adverse impacts on the beneficial uses of the waterbody. The direct effects are related to the toxicity of the herbicide and other chemicals added with it, as well as interactions with other chemicals within the water. The secondary effects can be related to the killing of dense growths of aquatic weeds which in turn exert a large oxygen demand, causing low-DO in treated areas that have limited mixing with other areas of the waterbody.

In order to control excessive fertilization in waterbodies, several years ago the US EPA (2001c) initiated an effort to develop numeric chemical-specific nutrient criteria and standards. As initially proposed, the exceedance of these standards would require that the discharger, such as an urban stormwater management agency, control nutrient inputs to the waterbody so that exceedances of the standard do not occur by any amount more than once every three years.

While the US EPA has been attempting to develop chemical-specific nutrient criteria for a number of years, it appears now that the Agency has met with such large-scale opposition, to cause it to delay its original timetable of the states' having to have chemical-specific nutrient standards in place by 2004, or the Agency would impose default nutrient criteria. Lee and Jones-Lee (2002c, 2004c) and Jones-Lee (2004 – NL4-3/4) have discussed the unreliability of the US EPA's approach for developing default nutrient criteria, pointing out the importance of conducting site-specific evaluations of the impacts of nutrients on the beneficial uses of the waterbodies into which they are discharged. As they discuss, it is not possible to develop reliable generic chemical-specific nutrient criteria, since such criteria would not adequately consider the relationship between available forms of nutrients added to a waterbody and their impact on excessive aquatic plant growth in the waterbody.

The effects of nutrients added to a waterbody on the waterbody's fisheries should be considered in establishing a waterbody's allowable nutrient loads. Lee and Jones (1991a) have discussed the role of aquatic plant nutrients in influencing the fish biomass in a waterbody. They have reported that for many waterbodies there is a direct relationship between the normalized phosphorus load to the waterbody and fish production. Significantly decreasing the nutrient loads to waterbodies could be adverse to the waterbodies' fisheries. Properly developed site-specific nutrient criteria can be established which represent the balance between desired fisheries and the water quality impacts of excessive growths of aquatic plants.

Lee and Jones (1980) presented an approach for assessing the impact of nutrients added to urban lakes from stormwater runoff and other sources on excessive fertilization of the waterbody. They recommended that consideration be given to the use of the results of the US Organization for Economic Cooperation and Development (OECD) studies to relate nutrient loads to urban lakes to their excessive fertility as measured by planktonic algal chlorophyll. This approach has been updated by Jones and Lee (1986) and Lee and Jones-Lee (2002c). As they discuss, it is important in evaluating nutrient loads to urban lakes and streams to focus on the loads of nutrients that are available to support aquatic plant growth. As discussed below, for some waterbodies, especially those receiving substantial amounts of particulate phosphorus derived from urban stormwater runoff or agricultural land runoff, most of the particulate phosphorus is not available to support algal growth.

There is confusion about the potential benefits of aerating waterbodies, such as urban lakes, to control excessive planktonic algal growth. Of particular concern is the development of planktonic algae which at times causes the waterbody to be a "pea soup" green. With blue-green algae, a floating scum with a metallic blue-green sheen occurs, which can be sufficiently thick at times to allow turtles, ducks, etc., to walk on the surface. The decay of this scum leads to severe odor problems.

Mixing/aeration is often advocated as a control approach for excessive algal growth in waterbodies; however, mixing of the water by aeration or other means may, in fact, produce more algae -- not less. In the late 1970s/early 1980s the senior author (G. F. Lee) was a member of (and then chaired for a period of four years) the American Water Works Association national committee on Quality Control in Reservoirs. This committee conducted a comprehensive study on the impacts of aeration on algal-related water quality problems at a number of reservoirs across the US. Rather than decreasing algae, as claimed by aeration proponents, aeration stimulated the growth of algae. This is because it mixes nutrients from the lower parts of the water column into the surface waters, where they are available for algal uptake and growth, and it provides a greater number of algae with the opportunity to gain some exposure to sunlight. Algae only need a little light once in a while to stay alive and grow. Mixing of blue-green algal blooms that form a scum, if done adequately, can dissipate the scum. This does not, however, eliminate the green water.

While for many ponded waterbodies (lakes) the relationship between nutrient loads and planktonic algal growth in the waterbody is fairly well defined based on the waterbody's morphology and hydrology, this relationship is poorly understood for streams and rivers. There is a variety of morphological, hydrological and physical factors that influence the growth of algae (planktonic and attached) and various types of water weeds in streams and rivers. These factors influence how the available concentrations of nutrients in these waterbodies impact aquatic plant growth. The development of appropriate nutrient criteria for streams and rivers will require detailed site-specific studies. The results of these studies will likely have limited transferability to other waterbodies.

Studies conducted in the 1960s by Lee and his graduate students at the University of Wisconsin, Madison, have shown that substantial parts of the particulate phosphorus in urban stormwater runoff are not available to support algal growth and do not convert to an available form. Cowen and Lee (1973) reported that part of the algal available P in urban stormwater runoff was derived from the leaching of tree leaves and flowers. This finding provides additional impetus to require that urban dwellers not deposit their leaves, grass clippings and yard trimmings uncontainerized in the gutter of the street, where they could be leached by rainfall or fugitive irrigation waters. All leaves, grass clippings, yard trimmings, etc., should be containerized if there is potential for leaching prior to their pickup. This would tend to reduce the amount of nutrients present in stormwater runoff. It would also be of value in reducing the oxygen demand load of urban stormwater runoff. The city of Stockton, California, has recently adopted a regulation that prohibits placing uncontainerized grass and yard clippings in the street.

Kluesener and Lee (1974) determined the total nutrient loads in city of Madison, Wisconsin, urban stormwater runoff. Rast and Lee (1983/1984) summarized information on the amounts of nitrogen and phosphorus present in urban stormwater runoff. They reported the results in terms of nutrient export coefficients in the mass of N or P contributed per watershed unit area per unit time, such as grams of N or P per square meter per year. They reported that urban stormwater drainage typically contributes about twice as much phosphorus per unit area per unit time as agricultural stormwater drainage. This difference relates primarily to the increased runoff that occurs from urban areas due to paving, compared to agricultural areas where more of the precipitation infiltrates into the groundwater system.

Rast and Lee (1983/1984) reported that urban stormwater runoff typically contains about 0.1 g P per square meter of urban area per year, while agricultural drainage contains about 0.05 g

P per square meter per year. For nitrogen, urban drainage and agricultural drainage both contained about 0.5 g N per square meter per year for locations east of the Mississippi. In the western US, 0.2 to 0.25 g N per square meter per year was found in urban and agricultural stormwater drainage. The difference in nitrogen export between the eastern and western US relates to the higher concentrations of nitrate in rainfall in the Midwest and eastern US. These values apply to lands not receiving animal manure. Manured lands can have nutrient export coefficients much higher than this, depending on rates and methods of application, and depending on whether the soils become frozen during the winter, thereby preventing infiltration of precipitation.

Cowen and Lee (1976) conducted studies in a number of urban areas of the algal available phosphorus in urban stormwater runoff. Lee et al. (1980) summarized the results of these studies and presented the results of studies by others on algal available P in urban and agricultural runoff. In general it has been found that the algal available P in stormwater runoff from urban and agricultural areas is equal to the sum of the soluble orthophosphate plus about 20 percent of the particulate phosphorus. Therefore, 80 percent of the particulate phosphorus (which can be most of the phosphorus load) does not support algal growth. As discussed by Lee and Jones-Lee (2002c), the US EPA is making a significant error in proposing to regulate phosphorus based on total phosphorus, rather than algal available phosphorus.

Cowen et al. (1976) investigated the algal availability of nitrogen in urban runoff. They reported that nitrate and ammonia are available to support algal growth, as well as part of the organic nitrogen. The fraction of the organic nitrogen that was available depended on the age of the organic nitrogen, with older organic nitrogen tending to be more refractory. On the average about 70 percent of the organic nitrogen was convertible to algal available forms.

The excessive fertilization of urban creeks and lakes can lead to the need to attempt to control the aquatic weed growth through the use of herbicides and/or mechanical harvesting. An example of this type of situation occurs in Five Mile Slough in the city of Stockton, where the San Joaquin Area Flood Control Agency (SJAFCA, 2003) has recently proposed to use a combination of herbicides to control the excessive growths of water hyacinth and duckweed in this waterbody. Lee (2003c) has discussed the inappropriateness of the SJAFCA failing to develop an Environmental Impact Report on this proposed aquatic weed control program. The issue of primary concern is the potential for the herbicides proposed to be used in this project and their associated chemicals as well as possible interaction with chemicals present in the water to be toxic to non-target organisms.

Lee (2003d) has discussed a similar situation with respect to the use of glyphosate-based herbicides for the control of *Spartina* in selected areas of San Francisco Bay. Lee and Jones-Lee (2003c, 2004b) and Lee (2004) have provided guidance on the development of a water quality monitoring program that should be conducted as part of an aquatic weed control program in order to determine if there is toxicity to non-target organisms in the water column and/or sediments and/or other adverse impacts. They recommend that the monitoring program focus on worst-case conditions in order to determine if there is a potential for the use of the herbicides and other chemicals to impair the beneficial uses of the waterbody.

pH. There can be sufficient primary productivity in urban creeks and lakes to cause significant diel (night to day) changes in pH and dissolved oxygen. This will be especially true for those urban streams that have limited reaches of extensive canopy from trees along the bank. While the US EPA (1987) Gold Book water quality criterion limits the pH of waters to 9, the state of California Central Valley Regional Water Quality Control Board limits the maximum pH to 8.5. As currently regulated, any pH above 8.5 at any time represents a violation of the Basin Plan objective. It is not unusual for the pH of waterbodies to exceed this value in the late afternoon, associated with photosynthetic activity, while in early morning the pH can be several units lower.

The CVRWQCB does not allow diel averaging of pH to account for photosynthetic activity. However, the CVRWQCB allows water quality managers to demonstrate that the exceedance of the pH 8.5 standard (objective) is due to photosynthesis, and thereby eliminate the need to control nutrients to a sufficient degree to eliminate the photosynthesis that causes the pH violations. It is the authors' experience that a pH above 9 or so is not significantly detrimental to a waterbody's fisheries. Many highly eutrophic waterbodies have outstanding warmwater fisheries and routinely have a pH of 9.5 or 10 in the late afternoon.

Ammonia. It is possible that the ammonia concentrations in urban creeks could be sufficient to violate ammonia water quality criteria based on potential toxicity to aquatic life in the urban stream or lake, especially if there is a significant storm sewer discharge that contains sludge scoured during a runoff event, or scour of stream sediments, which would tend to have high ammonia concentrations. This is especially true in those urban streams and lakes which are highly productive that tend to have an elevated pH in mid-afternoon due to photosynthetic activity. The likelihood of violations of the ammonia water quality criteria for aquatic life toxicity changed significantly when the US EPA (1999) changed the ammonia criteria to include a 30-day averaging period. It is important to evaluate whether the ammonia concentrations, coupled with pH and temperature, are such that ammonia could be toxic to aquatic life in an urban stream environment. Again, as with toxicity, it is important to focus on the duration of exposure that an organism could receive in a stream.

Sanitary Quality. Urban stormwater runoff and, in some situations, drainage ways such as creeks in urban areas, during dry weather flow, often have greatly elevated concentrations of total coliforms, fecal coliforms and *E. coli*. CWP (2003) reported that the NURP national event mean concentration for fecal coliforms was about 15,000 MPN (most probable number) per 100 ml. CWP (2003) has indicated that other studies have reported mean urban area stormwater runoff fecal coliform concentrations ranging from a low of 4,500 to a high of 78,000 MPN per 100 ml. According to CWP (2003), for fecal streptococci the NURP national event mean concentration was about 35,000 MPN per 100 ml. CWP reported that various studies have shown mean fecal streptococci concentrations ranging from about 6,000 to 56,000 MPN per 100 ml.

There are significant questions about the reliability of total coliforms as a measure of human health hazards associated with contact recreation (swimming, wading, water skiing, etc.), since a number of studies have shown that total coliforms and, for that matter, fecal coliforms are not reliable indicators of human health hazards associated with contact recreation (Cabelli et al., 1982; Dufour, 1984; US EPA, 1986). The sanitary quality of urban creeks is of importance, since children often play in creek waters and are therefore exposed to pathogens that are carried by the creeks. Schroeder et al. (2002) have reviewed issues pertinent to the management of pathogens associated with urban area and highway stormwater discharges. They discuss the fact that there is considerable uncertainty about the relationship between pathogen-indicator organism concentrations, such as *E. coli*, and diseases contracted through contact recreation. An issue of particular concern is the finding by Byappanahalli et al. (2003) that *E. coli* can reproduce in warm soils.

The US EPA (1998) announced that it was going to require that states adopt a revised contact recreation criterion for fresh water based on the measurement of *E. coli*. As discussed by Lee and Jones-Lee (2002d), *E. coli* has become the standard recommended organism for assessing the sanitary quality of a water with respect to contact recreation. It is also a useful indicator of potential pathogens for domestic water supplies. On July 1, 2004, the US EPA (2004a) announced that it was implementing the US EPA's (1986) criteria for bacteria in states bordering Great Lakes or ocean waters that had not adopted these criteria by April 2004.

In many communities, the design of the sanitary sewerage (collection) system is such that there can be discharges of raw sewage to urban waterways, associated with pump station power failure, blockage of the sewer, and other factors. Further, sanitary sewerage systems are sometimes poorly maintained, with the result that there can be discharges of raw sewage on an ongoing basis through leaks in the sewerage system, to nearby watercourses. In addition, animals, especially birds, can contribute significant amounts of fecal coliforms and *E. coli* to stormwater runoff, which in turn causes urban creeks to be of poor sanitary quality.

Lee and Winkler (1984) conducted a study of the sanitary quality of the Yellowhouse Canyon Lakes in the city of Lubbock, Texas. Lubbock created a series of small lakes as part of a recreational area within the City. There were questions about the sanitary quality of the water in these lakes with respect to contact recreation. The Lee and Winkler studies showed that in general the sanitary quality of the water in these lakes was good except for following a stormwater runoff event. For a period of a week to two weeks after a stormwater runoff event, depending on the time of year and the magnitude of the event, the sanitary quality of these lakes was poor. Since the flow through the lakes was generally low during non-runoff events, the eventual improvement in water quality was associated with the settling of the pathogen-indicator organisms and their death. The pathogen indicators were derived from the streets and overflow of sanitary sewers during runoff events. Additional information on these studies is provided in Lee and Jones (1991b).

With increased emphasis on managing the water quality impact of urban stormwater runoff in some parts of the country, such as in Southern California (especially in the Santa Monica Bay watershed, because of the adverse impacts on Santa Monica Bay beaches), efforts are being made to control *E. coli* and other pathogen indicators in the stormwater runoff as well as dry weather flow in separate storm sewers. Ultimately, through comprehensive studies that are now being developed in the Los Angeles Basin and elsewhere, information will be gained on the specific sources of *E. coli* and the potential for their control. The California Central Valley Regional Water Quality Control Board, as part of reviewing the city of Stockton's NPDES permit for storm sewer discharges, has recently required that the City develop a sanitary quality management plan for the City's storm sewer discharges. This plan is designed to attempt to control the violations of the sanitary quality indicator organisms water quality criteria in Stockton's storm sewer discharges through studies on the specific sources of indicator organisms that cause these violations.

There is need for additional studies of the type conducted by Cabelli et al. (1982) and Dufour (1984) to relate contact-recreation-acquired diseases to pathogen-indicator organism concentrations. Studies on the sources of pathogens and pathogen-indicator organisms could lead to improved sanitary quality for urban creeks.

Total Organic Carbon (TOC). Based on US EPA regulations, domestic water supplies across the country that have a total organic carbon (TOC) concentration above about 2 mg/L may be required to treat the water to remove the total organic carbon to this level, in order to reduce the potential for trihalomethane (THM) formation during the disinfection of the water supply. This situation raises the question as to whether urban stormwater runoff could be a significant contributor of TOC to urban creeks and ultimately to downstream waterbodies that are used for domestic water supply purposes.

Lee and Jones-Lee (2003d) have recently developed a review of TOC/THM issues as they relate to water quality management in the Sacramento-San Joaquin River Delta and its watershed, which includes an assessment of the potential for urban stormwater runoff to be a significant source of TOC. Based on the data for the city of Stockton, California (Stockton, 1998), the average TOC in stormwater runoff is about 12 mg/L. CWP (2003) reported that the mean of the event mean concentrations for total organic carbon in stormwater runoff from urban areas across the country ranged from 17 to 32 mg/L, with a median of 15.2 mg/L. Because of the large volume of stormwater runoff that can occur from urban areas during a runoff event, there could be an appreciable slug of TOC in the receiving waters, which could be adverse to downstream water utilities that must achieve the US EPA TOC limit, although the US EPA allows long-term averaging of the TOC to determine if violations are occurring.

Lee and Jones-Lee, in their 2003 TOC review, have introduced the concept of refractory TOC and labile TOC. They point out that, for some sources of TOC, appreciable parts of it can be in a labile (degradable) form. An example of this situation occurs in the city of Stockton, California, where the five-day biochemical oxygen demand (BOD_5) in the stormwater runoff from the City averages about 14 mg/L. CWP (2003) reported that the mean of the event mean concentrations found by various investigators from several locations across the US ranged from about 10 to about 14 mg/L $BOD_{5?}$. Multiplying by 2.5 to convert BOD_5 to BOD_u (ultimate), and converting oxygen to equivalent carbon, it is found that a substantial part of the TOC in Stockton stormwater runoff is in a labile form, which means that, if a week or several weeks (depending on temperature and other conditions) elapse between the discharge of TOC and when it would enter a domestic water supply intake, an appreciable part of the TOC would be degraded through biochemical reactions. If, however, the water supply intake is near the stormwater runoff from the City, with the result that there is not enough time for degradation of the labile part of the TOC (BOD), then the total TOC, both refractory and labile, would be of concern to the water utility.

Except for the water supply THM issue, TOC in urban stormwater runoff to an urban creek is not necessarily adverse to the creek's water quality, and it could be beneficial in terms of providing complexing agents which would tend to detoxify toxic forms of metals through complexation.

Many urban stormwater runoff monitoring programs include the measurement of chemical oxygen demand (COD). According to CWP (2003), the mean of the event mean concentrations for COD in urban stormwater runoff ranges from about 53 to about 66 mg/L. While COD can be a useful parameter for quick estimates of BOD in a domestic wastewater during the treatment process and some other waste streams where information is needed for control of the operation of the treatment works, it may not be reliable for estimating BOD in urban stormwater runoff. Since it would be rare that quick estimates of BOD would be needed in urban stormwater runoff monitoring programs, and since COD does not measure a well-defined characteristic of stormwater runoff that is translatable to a water quality impact, it is suggested that TOC and BOD be measured in stormwater runoff, and that there is little value in measuring COD.

Excessive Bioaccumulation of Hazardous Chemicals in Edible Aquatic Organisms. Fish and other edible aquatic life taken from some urban streams have been found to contain excessive concentrations of legacy pesticides such as DDT, dieldrin and chlordane, which are associated with the former use of these pesticides in urban areas, as well as current runoff from agricultural areas that have been converted to urban areas. In addition, urban stream fish and other aquatic life can contain excessive concentrations of PCBs and dioxins/furans. As discussed by Lee and Jones-Lee (2002a), dioxins are known to be present in urban area and highway stormwater runoff and, therefore, can be present in urban streams and lakes, especially in the sediments. PCBs are sometimes found in urban stream fish due to spills of electrical transformer PCBs that have occurred in the urban stream watershed or illegal discharges of PCBs from industrial sources to the storm sewer system.

An example of this type of situation occurred in Smith Canal in the city of Stockton, California, where some of the edible fish taken from this canal in 1998 were found to contain concentrations of PCBs well above those that are considered hazardous for consumption due to the increased risk of cancer. Lee et al. (2002) conducted a study on Smith Canal sediments to determine the total concentrations of PCBs in the sediments and the bioavailable forms, through the use of the US EPA (1994a) standard sediment bioavailability test procedure using *Lumbriculus variegatus*. It was found that, while the sediments had high TOC which would tend to make the PCBs less bioavailable, there still was significant uptake of the PCBs from the sediments by *Lumbriculus*, indicating that these organisms would be a food-web source of the excessive PCBs that are found in higher-trophic-level edible fish taken from parts of Smith Canal.

Some measurements of mercury in urban stormwater runoff have shown that the concentrations are sufficient to potentially lead to excessive bioaccumulation of mercury in edible fish tissue. Fish taken from the urban stream or lake of interest should be examined to determine if they have excessive bioaccumulation of mercury. Lee and Jones-Lee (2002d) and

Lee (2003a) have provided guidance on the approaches that should be followed to evaluate excessive mercury bioaccumulation, involving examination of edible fish tissue.

PAHs, Oil and Grease and Unrecognized Hazardous/Deleterious Organic Chemicals. There are a number of organic compounds that are of potential concern in urban stormwater runoff that are not pesticides or organochlorine bioaccumulatable chemicals. These include oil and grease, PAHs, etc. CWP (2003) provides a summary of information on hydrocarbons, PAHs and oil and grease in urban stormwater runoff. Some of the PAHs (polycyclic aromatic hydrocarbons) are human carcinogens and are toxic to aquatic life. CWP (2003) reported mean event mean PAH concentrations in stormwater runoff of about 3 to 13 µg/L. CWP (2003) also reported oil and grease mean event mean concentrations in stormwater runoff ranging from about 2 to 13 mg/L. The impacts of the PAHs and/or oil and grease on urban stream water quality have not been adequately investigated.

Within the oil and grease fraction and TOC present in urban stormwater runoff can be thousands of unregulated organic chemicals that are a threat to be toxic to aquatic life and/or to bioaccumulate in edible aquatic life to be a threat to higher trophic-level organisms, including humans. Lee (in Jones-Lee, 2004, NL7-3) has discussed the large number of unrecognized pollutants that can be in stormwater runoff. For example, Silva (2003) of the Santa Clara Valley Water District has reported that flares used at highway accidents, after burning, can still contaminate 726,000 gallons of drinking water with perchlorate above the California Department of Health Services action level of 4 µg/L. McDonald (2003) has reported that,

> *"Approximately 75 million pounds of PBDEs are used each year in the U.S. as flame retardant additives for plastics in computers, televisions, appliances, building materials and vehicle parts; and foams for furniture. PBDEs migrate out of these products and into the environment, where they bioaccumulate. PBDEs are now ubiquitous in the environment and have been measured in indoor and outdoor air, house dust, food, streams and lakes, terrestrial and aquatic biota, and human tissues."*

Daughton (2004) has indicated that there are over 22 million organic and inorganic substances, with nearly 6 million commercially available. The current water quality regulatory approach addresses less than 200 of these chemicals, where in general pharmaceuticals and personal care products (PPCPs) are not regulated. According to Daughton, *"Regulated pollutants compose but a very small piece of the universe of chemical stressors to which organisms can be exposed on a continual basis."* Additional information on PPCPs is available at www.epa.gov/ nerlesd1/chemistry/pharma/index.htm.

Suspended Sediment/Turbidity. If the urban creek watershed has areas of new construction and/or if the urban creek watershed and the creek have readily erosible soils, there can be significant increases in suspended solids/turbidity in the creek during runoff events. CWP (2003) reported mean event mean concentrations in stormwater runoff for total suspended solids (TSS) ranging from 78 to 174 mg/L. The TSS impacts the turbidity of the stream water. CWP (2003) reported mean event mean concentrations for turbidity of 53 NTU.

The typical approach that is used (straw bales, silt curtains) to attempt to control runoff/erosion from construction sites sometimes is little more than cosmetic in terms of controlling the amount of suspended solids that actually enter the creek from the developed area. The problem is that the straw bales, etc., are often poorly maintained. This situation then leads to a pulse of inorganic turbidity during the runoff event. Ordinarily these pulses are not significantly adverse to water column fish; however, they may be adverse to fish habitat in those areas where the erosional materials settle. One of the primary concerns of TSS is the potential for deposition in ecologically sensitive areas, such as those used for fish spawning. Such deposition can also affect the numbers and types of benthic macroinvertebrates that are an important part of a waterbody's food web.

One of the issues of particular concern with respect to TSS in urban stormwater runoff is that a number of potential pollutants, such as heavy metals, many organics, etc., tend to become associated with suspended solids, which accumulate in the receiving waters for the runoff in areas of TSS deposition. As discussed in Newsletter NL7-2 (Jones-Lee, 2004), there is considerable confusion and unreliability in regulating potential pollutants associated with bedded sediments.

Trash. Urban creeks are notorious for accumulating discards of people, including grocery carts, tires, paper, Christmas trees and shrubbery and lawn trimmings. Some of these items, while inhibiting flow which can lead to flooding, provide habitat for aquatic organisms in the creek. The primary adverse impact of trash is on the aesthetic quality of the waterbody. Some creeks receive large amounts of trash. This is evident by the "creek days" that environmental/public groups conduct, when debris of various types is removed from the creek. With increased emphasis being placed on controlling trash in stormwater runoff in the Los Angeles area, where a TMDL has been issued to control trash in urban stormwater runoff (LARWQCB, 2003), there could be a reduction in the total amount of trash that is dumped into Los Angeles area urban creeks.

Aquatic Life Habitat. The US EPA, as part of its Water Quality Criteria and Standards Plan (US EPA, 1998), specifically delineated urban stormwater runoff as a cause of deteriorated aquatic life habitat. The habitat degradation is a result of a variety of factors including channelization and increased urban stream flow due to paved development in the watershed.

The CWP (2003) report contains an extensive discussion of the impact of urbanization and the associated increase in the impervious cover of an urban stream's watershed on the hydrological and morphological characteristics of urban streams. The key message from the CWP (2003) report is that when the percentage of impervious cover in an urban stream's watershed exceeds about 10 percent, the stream's characteristics are impacted. When the impervious cover exceeds about 25 percent, there are severe impacts on the waterbody's characteristics.

CWP (2003) has been a pioneer in developing information on the impacts of impervious area in an urban stream's watershed on the stream's water quality characteristics. CWP (2003) indicates that increased impervious area in a stream's watershed will increase runoff volume, increase peak discharge, and potentially increase frequency of bankful flow and stream channel enlargement. It will also increase channel modification, lead to the decline of stream habitat quality, change pool/riffle structure, decrease streambed quality, increase stream temperature, lead to violations of bacterial sanitary quality, lead to the decline of aquatic insect diversity and fish diversity, the loss of coldwater fish species, reduced fish spawning and a decline in the amphibian community. CWP (2003) indicates that there is considerable variability in the response of urban streams to the percentage of impervious cover in the stream's watershed.

The US EPA, as part of the implementation of its Water Quality Criteria and Standards Plan (US EPA, 1998), indicated that it plans to pursue the use of bioassessment methodology to determine the degree of degradation caused by urban stormwater runoff that would need to be corrected to develop desirable aquatic life habitat in urban streams and other waterbodies that receive urban stormwater runoff. Thus far the US EPA and state water pollution control agencies seem to have made little progress in achieving this goal. Information on the US EPA's current program in this area is presented at
http://www.epa.gov/ebtpages/watewaterbioassessment.html

Groundwater Sources of Pollutants

In some urban areas the groundwater table is near the soil surface, with the result that there can be groundwater recharge of urban streams and lakes. This can be both advantageous and deleterious to the water quality of these waterbodies. Situations like that in Fort Collins, Colorado – where the upper part of Fort Collins' Spring Creek receives groundwater input, and the groundwater is of high quality with substantial DO content – can lead to an urban creek in which a trout population can be maintained. However, there are many situations where the shallow groundwater in urban areas has low DO and is polluted by municipal, industrial and recreational sources. With respect to the latter, several years ago, the authors were involved in reviewing information on the pollution of Lake Tahoe. There, as a result of low lake levels, it was evident that there was groundwater discharge below what would have ordinarily been the surface of the lake from onshore property owners' lawns and golf courses. The point where the groundwaters discharged during low lake levels was rich in nutrients, as evidenced by prolific growth of attached algae at those locations.

In some cities, like Stockton, California, the urban streams (creeks and sloughs) are isolated from the city through large dykes designed to prevent flooding. This, coupled with high groundwater, leads to the situation where the city is pumping groundwater from the storm sewer system into a number of the creeks year-round. This groundwater has been found by the DeltaKeeper to be toxic to aquatic life. The cause of the toxicity is not known, although it could be ammonia arising from the decay of debris that has collected in the storm sewer system.

Another source of pollutants in groundwaters that could impact urban streams and lakes is the pollution of the groundwaters that occurred by septic tank disposal systems before a sanitary sewerage system was constructed. Streams draining the developed valley on the northwest side of Lake Tahoe are an example of this type of situation, where for many years the dwellings in the valley used septic tank systems for sewage disposal. This polluted the shallow groundwater. The shallow groundwater flows to the lake. Therefore, there is a nutrient-rich front of polluted water migrating from the residential areas that formerly used septic tanks, to the lake. In years with normal lake water level, the nutrient-rich waters would be discharged below the lake surface. However, during years of low lake water level, these discharges would occur as springs along the high water level shore of the lake.

Another source of pollution of groundwaters in urban areas is landfills. Many urban areas have closed landfills located in the city. These landfills are often located near waterways on what were at one time relatively inexpensive lands. These landfills typically are polluting groundwaters with landfill leachate; therefore, if there is a shallow groundwater table and migration of the groundwaters to the nearby water courses, there can be pollution of the water course by municipal solid waste leachate. An example of this type of situation occurred in Madison, Wisconsin, in the 1960s, where one of the city's landfills was generating leachate that was polluting groundwaters, which were then being discharged to one of the urban lakes in Madison.

The authors were involved in this type of situation in connection with the Ferry Point Landfill in the Bronx, New York (Lee, 2000a). Because of the highly concentrated nature of municipal solid waste landfill leachate, small amounts of pollution of surface waters by leachate-polluted groundwaters can have a significant adverse impact on the waterbody's water quality. In conducting studies of urban creeks and lakes, it is important to assess groundwater hydrology and the position of the water table, with particular reference to whether there is discharge of groundwaters to urban waterbodies.

One of the management practices that is sometimes advocated for urban stormwater runoff is infiltration of the stormwater into the groundwater system. As Lee et al. (1998) and Taylor and Lee (1998) discuss, it is important to be certain that the infiltration system does not lead to pollution of groundwaters that would be a threat to their use for domestic and other purposes, as well as, for shallow groundwater systems, the potential for pollution of surface waters through stormwater infiltration. In their review of stormwater infiltration management practices, Lee and Taylor discuss that the best infiltration systems are those with sand and gravel aquifer systems that can readily accept substantial amounts of stormwater infiltration. However, these systems also are the ones that have the least ability to control pollutant transport because of the low sorption capacity of the aquifer materials.

Urban wetlands can also be a source of pollutants for urban streams and lakes. Lee, Bentley and Amundson (1975) conducted studies in the 1960s on the water quality characteristics of freshwater wetlands discharges. They found, as expected, that discharges from wetlands, especially under moderate to high flow, can be of quite poor quality – rich in nutrients, low in DO and high in total organic carbon.

Monitoring Urban Creek/Lake Water Quality

There is controversy concerning the appropriate approach to follow in monitoring the impacts of stormwater runoff on urban stream water quality. There are some urban stormwater runoff water quality managers in California who have been monitoring urban stormwater runoff characteristics for over a decade, where a suite of parameters such as those discussed above have been monitored at a couple of locations for a couple of storms each year. This approach has shown that there are a number of potential pollutants in urban stormwater runoff that exceed numeric and potentially exceed narrative water quality standards/objectives. However, no information is provided in this monitoring approach on the beneficial use impairments of the receiving waters for the runoff that are caused by constituents that occur at concentrations that exceed water quality standards or by other unmeasured constituents present in the runoff.

The appropriate approach to follow in regulating urban stormwater runoff with respect to compliance with water quality standards is to first determine if the water quality standard is an appropriate standard to protect the designated beneficial uses of the urban stream or other receiving waters without unnecessary expenditures in implementing management practices to achieve compliance with the standard at the point of discharge. Lee and Jones-Lee (1995/1996) discussed the importance of understanding how the US EPA national water quality criteria were developed, which leads to the national criteria being based on worst-case (i.e., most toxic) conditions (100 percent available, and extended duration of exposure) for assessing the concentrations that could be toxic. They recommend that exceedance of a US EPA national water quality criterion be considered as an indicator of the need to do a site-specific evaluation of the appropriate criteria for a particular discharge and receiving water. The US EPA's Water Quality Standards Handbook (US EPA, 1994b) provides guidance on some aspects of site-specific adjustment of water quality standards to account for the impact of constituents in the water on the toxicity of a potential pollutant. In order to adjust the water quality standard for the site-specific conditions associated with the forms of the constituents in urban stormwater runoff and their toxicity/availability to impact receiving water beneficial uses, it is necessary that a significantly different type of monitoring program be implemented than the conventional runoff monitoring that is being practiced today.

Lee and Jones-Lee (2002d) recommend that a water quality monitoring program consist of two components: first, the potential problem definition, which is accomplished to some extent by current monitoring approaches, where samples of the runoff are collected for a couple of storms per year; and second, the proper evaluation of the water quality significance of the violations of numeric and/or narrative water quality standards. Accomplishing the second phase requires the use of an Evaluation Monitoring approach of the type described by Jones-Lee and Lee (1998a), in which the focus of the monitoring is on discerning beneficial use impairments, as opposed to chemical constituent concentration assessment.

The focus of the Evaluation Monitoring approach is to critically examine the receiving waters of a discharge, such as stormwater runoff to an urban creek or lake, for adverse impacts of discharge-associated constituents on the beneficial uses of the receiving waters of the discharge. For example, is the receiving water toxic? If so, are the toxicity measurements appropriate for the duration of exposure that can occur in the urban stream or lake situation? If it is toxic, then through TIEs and forensic studies of sources, it may be possible to determine the cause of the toxicity and its source within the watershed. For example, rather than measuring copper, zinc or lead in the stormwater runoff and then trying to extrapolate to aquatic life toxicity of significance in the receiving waters for the stormwater runoff, measurements are made of toxicity, and, if toxicity is found, then determinations are made as to whether the toxicity is due to the copper, zinc or lead, or some other constituent, such as pesticides. If toxicity is found, an evaluation needs to be made as to whether it is of water quality significance. It should not be assumed that finding toxicity in a standard laboratory test automatically means that this toxicity is significantly adverse to aquatic life in the receiving waters for the runoff.

A key component of the Jones-Lee and Lee (1998a) Evaluation Monitoring approach is the provision that the dischargers and the regulatory agencies/public, to the extent possible, fund ongoing studies to specifically look for new water quality problems in the receiving waters for the urban stormwater runoff. An examination for new, unknown problems would be conducted by an independent study group under the supervision of a representative panel of experts.

It has been the authors' experience that urban stormwater runoff water quality managers have largely failed to properly implement the second phase of a credible stormwater runoff water quality monitoring program, with the result that the managers' constituency – i.e., those whom they are serving – are being driven to ultimately spending far more funds in the BMP (best management practices) ratcheting-down process than is necessary to properly protect the beneficial uses of the receiving waters for urban stormwater runoff-associated constituents. Lee and Jones-Lee (2002e) have reviewed the approach that should be used for developing and evaluating management practices for stormwater runoff-associated constituents. In order to comply with US EPA (1990) regulatory requirements for urban stormwater runoff, urban stormwater runoff water quality managers should be working with regulatory agencies to shift funds from routine runoff monitoring, where there is already a substantial database on the existence of some – if not most – of the water quality standards violations associated with urban stormwater runoff, to using these funds in a properly developed water quality impact assessment. Such studies would, in the long term, advance the current state of science/engineering of urban stormwater runoff water quality management from the state of affairs that existed in the early 1990s when the regulations were first adopted, to one where the BMP ratcheting-down process is implemented in a technically valid, cost-effective manner in support of the public's interests.

One of the issues of concern to regulatory agencies, environmental groups, etc., is the progress being made toward implementation of effective management practices (BMPs) for potential pollutants in urban stormwater runoff. ASCE (2000, 2002) and CASQA (2003) BMP guidance provide information on across-the-BMP removal of constituents. However, the approach of measuring decreases in concentrations of a heavy metal, pesticide or nutrient in the discharge of a BMP to an urban stream or lake is not a valid approach for evaluating the impact of the implementation of the BMP. The focus of evaluating the efficacy of a management practice, such as a so-called BMP, must be on how well it controls the beneficial use impairment of the urban stream or lake or downstream waterbody. For example, increasing the efficacy of a BMP from 30 to 60 percent removal of pathogen indicators in a treatment works for urban stormwater runoff may superficially seem to reflect a significant improvement in controlling a water quality problem. However, the real issue is how well the management practice affects the beach closures of concern to the public.

In evaluating urban creek water quality it is important to consider whether the urban creek has an upstream watershed outside of the city where agricultural input of nutrients, fertilizers, TOC and other constituents of concern adds to the urban contribution. In some situations it will be important to control the upstream agricultural sources of pollutants, in order to realize a significant improvement in the water quality of the urban creek.

Burton and Pitt (2002), in their Stormwater Effects Handbook, provide information on developing a stormwater runoff monitoring program. This handbook includes guidance on various sampling and assessment methodologies that can be used to characterize stormwater runoff water quality impacts.

Urban stormwater runoff should be monitored for at least four representative runoff events per year – i.e., one for each season – in those areas where rainfall runoff events occur year-round. In California and some of the more arid areas, the monitoring should be conducted in the fall, winter and spring. Monitoring parameters should include the suite of heavy metals (Cu, Zn, Ni, Cd, Pb, Cr, As), nutrients (N and P compounds), TDS/EC, TSS, turbidity, Priority Pollutants, oil and grease, BOD, TOC, DOC, water column aquatic life toxicity to US EPA freshwater standard three species (fathead minnow larvae, the zooplankton *Ceriodaphnia* and the alga *Selenastrum*) (US EPA, 2002b), sediment toxicity using US EPA (1994a) standard procedure with *Hyalella azteca* as the test organism, *E. coli*, total and fecal coliforms, pH, alkalinity, hardness, temperature, dissolved oxygen, and scans for organophosphate pesticides and carbamate pesticides.

The list of parameters that are monitored can be reduced as data are obtained on the characteristics of the urban creek, although some parameters such as aquatic life toxicity in the water column and sediments should continue to be measured since the types of pesticides used in urban areas are changing. As discussed above, Lee (2004) has recently discussed the approach that should be followed to develop reliable aquatic life toxicity monitoring for chemicals that are added to waters, such as aquatic herbicides. The same issues apply to monitoring aquatic life toxicity caused by chemicals in water that are derived from urban stormwater runoff, as well as other sources.

Since pyrethroid-based pesticides are now being used in urban areas as a substitute for the organophosphorus pesticides diazinon and chlorpyrifos, the receiving water sediments should be analyzed for aquatic life toxicity, since the pyrethroid-based pesticides are strongly sorbed by particulates and are now known (Weston, 2002; Weston et al., 2004) to be bioavailable to some benthic organisms. As analytical methods become available for measuring low levels of pyrethroid-based pesticides, the analyses should focus on those pyrethroid-based pesticides that are being predominantly sold in the hardware and garden supply stores in the area, as well as those used by commercial applicators for treating residential and commercial properties.

The US EPA Office of Pesticide Programs (OPP) and some state pesticide regulatory programs (such as the California Department of Pesticide Regulation) permit the use of pesticides in urban and agricultural areas in accordance with the label restrictions, which are highly toxic to some non-target forms of aquatic life. This leads to the situation that stormwater runoff from the pesticide application areas can cause aquatic life toxicity in the receiving waters for the runoff. This approach leads to violations of narrative federal water quality criteria and state water quality standards that prohibit the discharge of toxic chemicals in toxic amounts – i.e., cause toxicity in the receiving waters for the discharge.

The part of the US EPA that implements the Clean Water Act requirements has the responsibility of developing water quality standards for pesticides and other chemicals.

However, the US Congress does not fund the US EPA to a sufficient degree to enable it to develop water quality criteria that can be developed into state water quality standards for many (if not most) of the pesticides that are permitted to be used in urban and agricultural areas by the US EPA OPP. Therefore, there is a major disconnect between the requirements of the Clean Water Act for controlling toxicity in the nation's waters caused by pesticides and the US EPA OPP's approach for registering of pesticides. Basically, the US EPA OPP allows the permitted use of pesticides without evaluating whether stormwater runoff or fugitive/deliberate irrigation water discharges contribute pesticides to the receiving waters at concentrations that are toxic to aquatic life. Under the US EPA OPP regulatory approach, the Agency can determine that aquatic life toxicity in stormwater runoff is an allowable consequence of pesticide use.

The current situation, where the organophosphorus (OP) pesticides diazinon and chlorpyrifos are being phased out of urban residential use because of their toxicity to children, has led to the pyrethroid-based pesticides being used in urban areas by residential and commercial applicators. While it is known that some pyrethroid-based pesticides are as toxic (if not more toxic) to some forms of zooplankton than the organophosphorus pesticides and are more toxic to fish than the OP pesticides, there are no restrictions on their use in urban areas other than those associated with the US EPA OPP labels.

The current deficiencies in the regulatory approaches that are used to control toxicity to aquatic life in urban and agricultural stormwater runoff have led Jones-Lee and Lee (2000) and Lee (2001) to recommend a Proactive Approach that would have to be implemented at the state and local level to protect aquatic life from toxicity caused by pesticides. This approach involves the state and local regulatory agencies conducting studies specifically directed to determining whether stormwater runoff from areas where pesticides have been applied causes toxicity in the receiving waters. If toxicity is found, then the state water pollution control agency can impose restrictions on pesticide use to prevent the runoff of the pesticides at toxic amounts. An important component of the Proactive Approach is that, before a pesticide is allowed to be used in an area, the manufacturer/user should work with the water quality regulatory agencies to conduct studies associated with the initial use of the pesticide that would determine whether stormwater runoff or irrigation water discharges from the area of proposed use will cause aquatic life toxicity in the receiving waters for the runoff/discharges associated with the first runoff event from the area.

Another significant deficiency in the US EPA OPP and state agencies' registration of pesticides is the failure to require that the manufacturer of a pesticide develop analytical methods that can be used to determine the pesticide in aquatic systems (water and sediments) at potentially toxic concentrations. As discussed below, analytical methods with sufficient sensitivity are an important component of being able to estimate the potential toxicity of a pesticide that is present in stormwater runoff from an area where it has been applied.

Lee (2004) has pointed out that failure to find aquatic life toxicity in a waterbody that contains a pesticide does not mean that the pesticide is not causing toxicity to aquatic life. The basic problem is that the standard toxicity tests that are used do not have sufficient sensitivity to detect chronic toxicity – i.e., toxicity that occurs over an extended period of time. Lee has recommended that possible inference on potential aquatic life toxicity from pesticides can be gained by examining the US EPA OPP Ecotoxicity Database (US EPA, 2002c). As part of registering pesticides, the registrant must provide data on the toxicity of a pesticide to several forms of aquatic and terrestrial life. Typically, these data are provided in the form of an LC50 – i.e., the concentration that will be lethal to half the organisms during the test period. It has been found that chronic toxicity caused by pesticides to some forms of aquatic life will occur at concentrations that are 10 to 100 times less than that which causes acute toxicity. Therefore, if it is found that a pesticide applied to urban or agricultural areas is present at more than about 100 times less than its LC50, there is need for concern (evaluation) of its potential to cause chronic toxicity to aquatic life.

Concentrations of potentially toxic chemicals below the water quality standard (objective) or less than 0.05 times the LC50 for the most sensitive organisms tested in registering the pesticide can still, through additive or synergistic effects of the added pesticides with each other or with other chemicals in the water, cause adverse impacts to aquatic life. The additive/synergistic effects of pesticides with each other or with other chemicals is becoming recognized as a potentially important issue that needs to be addressed as part of protecting waterbodies from pesticide-caused aquatic life toxicity.

There are urban stream situations where the pesticide or other chemical's toxicity should only be evaluated based on acute toxicity since there is insufficient time in the urban stream for chronic toxicity to be manifested before the urban stream mixes with other waterbodies that do not have the toxicity. An example of this situation occurred in the San Diego Creek watershed of Upper Newport Bay in Orange County, California. As discussed above and by Lee et al. (2000), there is only a few hours' travel time within the urban area before the pesticide and other chemical-caused toxicity is diluted out by mixing with Upper Newport Bay. However, chronic toxicity could be important in those situations where the urban stormwater runoff is discharged to an urban lake and is one of the primary sources of water for the lake. Under these conditions it is necessary to evaluate whether chronic toxicity is occurring.

As part of a stormwater runoff water quality impact monitoring program, fish tissue samples should be analyzed for the suite of organochlorine legacy pesticides (including DDT, chlordane, dieldrin, etc.), PCBs, dioxins and mercury. Planktonic algal chlorophyll *a* and pheophytin *a* should be measured. Also, the areal extent of the waterbody near the sampling locations that is covered with floating macrophytes, such as water hyacinth or duckweed, as well as the extent of the profuse attached algae and other waterweed growth should be estimated. Estimates of the flow and the velocity of the water should be made at the time of sampling.

The measurement of COD in urban stormwater runoff is unnecessary, since it does not provide a meaningful assessment of a water quality parameter that can be properly interpreted with respect to impacts. TOC is a much more meaningful measurement that is related to potential water quality impacts on domestic water supplies.

The approach that has been and continues to be used of measuring pesticide concentrations without measuring aquatic life toxicity is not a valid approach and can readily lead to erroneous conclusions on the water quality significance of the pesticides and the cause of aquatic life toxicity in an urban creek or lake. This is one of the major deficiencies in the

USGS's National Water-Quality Assessment (NAWQA) program, where pesticide concentrations in urban and rural streams and rivers have been measured without concomitant measurements of aquatic life toxicity and excessive bioaccumulation. The focus of a credible water quality evaluation program should be on aquatic life toxicity, with the chemical measurements used to identify its cause, through appropriately conducted TIEs.

The measurements of aquatic life toxicity should include measuring the total toxicity and, through a dilution series, the total acute toxic units (TUa) for the test organism. Efforts should be made to determine, through TIEs, the amount of the toxicity that is due to chemically measured pesticides or other toxicants. For example, the addition of piperonyl butoxide (PBO), which interacts with the OP pesticides preventing them from being toxic to *Ceriodaphnia*, is a useful, simple TIE approach to identify how much of the toxicity was due to OP pesticides. PBO is also useful to help identify pyrethroid-based toxicity, since it causes these types of pesticides to be more toxic. Lee (1999) provided guidance on the overall monitoring approach that should be used for aquatic life toxicity in urban stormwater runoff. Since this guidance focuses on OP pesticides and since they are being phased out for urban use, similar guidance needs to be developed for the pesticides that are being used as replacements for the OP pesticides. Lee (2004) has discussed the importance of not assuming that measuring the total concentrations of a pyrethroid pesticide and toxicity on a sediment sample is a reliable approach to assessing whether the pyrethroid-based pesticide is a cause of the sediment toxicity, if any. He recommends the use of a standard additions approach, in which incrementally increasing amounts of the pyrethroid-based pesticides of interest are added to the sediment sample and an assessment is made as to whether the measured toxicity increases proportional to the added pesticides.

Biological assessment of benthic and epibenthic organism assemblages should be conducted to determine the numbers and types of organisms present at selected locations along the course of urban streams, with particular reference to whether urban stormwater runoff adversely impacts the organism assemblages. The California Department of Fish and Game (Harrington and Born, 1999; DFG, 2003) and the US EPA (Barbour et al., 1999) have reported on bioassessment methodology that can be used to assess whether chemicals in waterbodies are adversely affecting the biological characteristics of the waterbody. Burton and Pitt (2002) have provided information on biological assessment methodologies. The US EPA (2004b) has presented a review of "Biological Indicators of Watershed Health" that contains information pertinent to evaluating the potential for stormwater runoff to be adverse to aquatic organisms. Lee and Jones (1982) discussed how the Department of Interior Instream Flow Methodology, which includes bioassessment measurements relative to habitat characteristics, could be used to evaluate point-source discharge impacts on aquatic communities. This same approach can be used to evaluate the impact of chemical additions associated with urban stormwater runoff. It will be important to distinguish between the effects of stormwater runoff flow on organism assemblages and those of chemicals in the runoff.

Also, the fish populations should be assessed as part of assessing the numbers and types of aquatic organisms present in the urban stream or lake. The US EPA (2000b) has provided guidance on stressor identification that can be used to determine whether aquatic organism populations are being impacted by habitat or chemicals. This information can be useful to identify situations where physical factors or chemical discharges are adverse to the benthic community. Unfortunately, the information provided in this guidance on the use of total concentrations of potential pollutants in the water column or sediments is unreliable, since the total concentration of many potential pollutants is not related to their water quality impacts. A best professional judgment triad weight of evidence approach of the type described by Lee and Jones-Lee (2002a; 2003a, 2004a) should be used to assess the health of an urban stream or lake.

An approach that has the potential of detecting the impacts of chemicals associated with urban stormwater runoff events on aquatic life is the use of caged organism toxicity tests. Newbry and Lee (1984) described the development of some simple, inexpensive cages constructed of plastic pipe that have been used to assess toxicity to fathead minnow relative to the discharge of domestic wastewaters to urban streams. These cages were used in studies (Heinemann et al., 1983; Newbry et al., 1983) of the toxicity of domestic wastewater discharges from several Colorado wastewater treatment plants (Fort Collins, Loveland, Colorado Springs and Pueblo) to several Front Range streams (Cache la Poudre River, Big Thompson River, Fountain Creek and Arkansas River). The caged fish upstream of the discharge did not show toxicity during urban stormwater runoff events or at other times; however, toxicity due to chlorine used for wastewater disinfection was found near the point of discharge of the domestic wastewaters to the urban stream. Fathead minnow caged upstream of the Fort Collins wastewater discharge, but influenced by stormwater runoff from Fort Collins, lived for over a year in the cages without supplemental feeding. Eventually the upstream cage was lost, due to very high flow that dislodged the cage anchor.

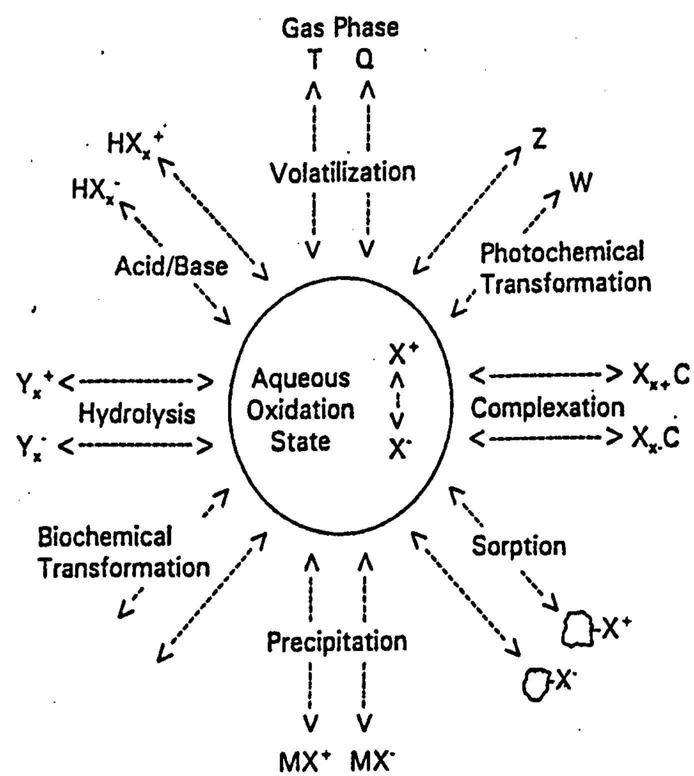
Stormwater Runoff Water Quality Modeling

A review of the stormwater runoff literature shows that there are a number of papers, reports, short courses, etc., which purport to address stormwater runoff water quality modeling. A critical review of these models, however (such as the US EPA's SWMM – US EPA, 2004c), shows that they are basically hydraulic modeling, in which there is a routing of the stormwater runoff through the urban area. These hydraulic models may include the transport of chemical constituents in the water to yield a concentration-time profile at particular locations. This is what is called by the modelers, "water quality." However, those familiar with true water quality issues know that, in order for a model to properly describe water quality impacts, it is necessary that the model include aquatic chemistry of the constituents and toxicity/toxicology to aquatic organisms.

Figure 1 presents the aquatic chemistry "wheel" originally developed by Lee and Jones in the early 1980s, which shows the types of chemical reactions that can influence the impact of a chemical on aquatic life through toxicity or excessive bioaccumulation. There are eight types of reactions that can influence whether a particular potential pollutant remains in a waterbody in a toxic available form or converts to this form in the receiving waters for stormwater runoff. The "hub" of the wheel contains the unreacted chemical species that are potentially present in stormwater runoff and in the receiving waters. For example, copper can be present in stormwater runoff as metallic copper, copper-1 (cupric), and copper-2 (cuprous). Each of these oxidation states of copper enters into the eight types of reactions shown in Figure 1, to varying degrees. The forms of a chemical, as represented by the products of the reactions at the "rim" of the wheel, are controlled by the reaction's kinetics (rates) and thermodynamics (positions of equilibrium). One of the more important types of reactions of concern with regard to the

Figure 1

Aquatic Chemistry of Chemical Constituents

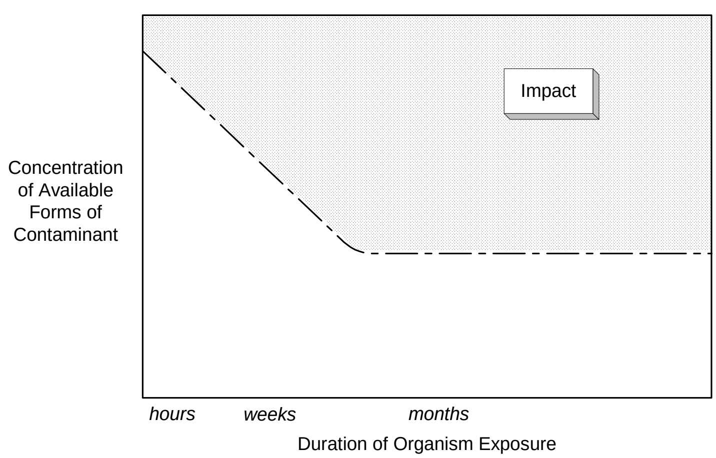


- Distribution among Species Depends on Kinetics & Thermodynamics of Reactions in the Particular Aquatic System
- Each Chemical Species Has Its Own Toxicity Characteristics
  - Many Forms Are Non-Toxic

potential impacts of heavy metals in urban stormwater runoff is complexation. Complexation of a metal, such as copper, can form a soluble or particulate chemical. Strongly "complexed" metals are generally nontoxic. In order to reliably model water quality – impairment of beneficial uses, it is necessary to model the kinetics and thermodynamics of the reactions that lead to the distribution of chemical species that affect aquatic organisms or other beneficial uses of waterbodies – i.e., those at the rim of the aquatic chemistry wheel.

Another important aspect of evaluating the impact of potential pollutants in stormwater runoff is the duration of exposure to a toxic chemical that an organism can receive during and following a stormwater runoff event. Figure 2 (from Lee et al., 1982) shows the relationship between the duration of exposure and toxicity for toxic chemicals. If the duration of exposure concentration of a toxic available form of a chemical is above the "no impact" line – i.e., in the stippled area – then there will be an adverse impact on aquatic life. This impact can range from acute toxicity, leading to death of the organism in a short period of time, to chronic toxicity, where there is impairment of reproduction, abnormal growth, greater susceptibility to disease, predation, etc. As shown, much higher concentrations of a toxicant can be present if the duration of exposure is short. This is why the acute criterion is typically a factor of two to ten times higher than the chronic criterion. This has important implications for evaluation of stormwater runoff water quality impacts. Those runoff situations which only show elevated concentrations near the point of stormwater discharge during the discharge event could have much higher concentrations in the discharge without adverse impacts.

Figure 2
Concentration Duration of Exposure Relationship



From Lee et al., 1982

The aquatic chemistry component of a true stormwater runoff water quality model could, as an example, include the US EPA MINTEQA2 model (US EPA, 2004d), which describes the distribution of chemical species as a function of the characteristics of the water. The toxicology information would include modeling, for various types of organisms, to determine if there are critical concentrations of toxic available forms of the constituent of concern during the duration of exposure which the organisms experience during and following a runoff event. For those chemicals present in stormwater runoff that are of concern because they bioaccumulate through the food web, a true stormwater runoff water quality model would need to include the bioaccumulation component that leads to excessive concentrations of a chemical in higher-trophic-level organisms. An example of this type of modeling would be the US EPA's BASS model (US EPA, 2004e).

While there are aquatic chemistry models such as MINTEQA2 and BASS, at this time, the incorporation of these models into a reliable stormwater runoff water quality model, which relates the presence of toxic available forms to the duration of exposure that various types of aquatic life can receive during a runoff event, have not been developed. Because of the inability to develop the information needed to properly model these issues, it is likely to be many years before such models will be available.

Regulating Urban Stormwater Runoff Water Quality Impacts

The US EPA (1990) urban stormwater regulations require that "pollution" be controlled through the use of "best management practices" (BMPs) to the "maximum extent practicable" (MEP). Neither "BMPs" nor "MEP" was defined, and they still have not been defined. It is important to understand that the word "pollution" is defined in the Clean Water Act as an impairment of beneficial uses. As discussed above, while there is a variety of potential pollutants in urban stormwater runoff, there is limited understanding of the real, significant pollution (impairment of beneficial uses) associated with runoff-derived constituents.

In 1987 the US Congress, in developing the updated Clean Water Act, established that urban stormwater runoff will be regulated under National Pollutant Discharge Elimination System (NPDES) permits. Since NPDES-permitted discharges must not cause violations of water quality standards, there is need for the US EPA to develop a regulatory program that would include urban stormwater runoff's compliance with water quality standards. Under the current regulatory approach, the US EPA has the option of determining when NPDES-permitted urban stormwater dischargers must control the concentrations of constituents in the runoff so that they do not cause or contribute to violations of water quality standards. Since, in general, urban stormwater runoff is not granted a mixing zone, compliance with water quality standards means that the runoff must meet the standard with no more than one exceedance by any amount in a three-year period.

As discussed in the *Stormwater Runoff Water Quality Science/Engineering Newsletter* (Jones-Lee, 2004, NL 2-2, 5-3), a Ninth Circuit Court decision supports the position that NPDES-permitted urban stormwater runoff must ultimately comply with water quality standards in a timeframe to be established by the US EPA. Currently, the regulation of NPDES-permitted discharges for cities with populations over 100,000 (MS-4s) must participate in a BMP ratcheting-down process, where as violations of water quality standards occur in the stormwater runoff, ever more effective BMPs are to be implemented in the direction of controlling the magnitude of these violations. The US EPA Environmental Appeals Board (US EPA, 2002d) has determined that stormwater runoff water quality managers are required to demonstrate that the BMPs being implemented are more effective in controlling water quality standards violations than those that existed at the time of the violation.

In 1999 the US EPA (2000c), as part of developing its so-called "Phase II" regulations that are applicable to stormwater runoff from urban areas with populations less than 100,000 (small MS-4s), has established regulatory requirements where the Agency still maintains that stormwater runoff from these communities also must ultimately not cause violations of water quality standards. However, the Agency has defined six actions that these communities can take that will represent satisfactory progress toward compliance with water quality standards. These include

- Public Education and Outreach
- Public Participation/Involvement
- Illicit Discharge Detection and Elimination
- Construction Site Runoff Control
- Post-Construction Runoff Control
- Pollution Prevention/Good Housekeeping.

A critical review of these actions, however, shows that, in general, they will not significantly impact the magnitude of the water quality standards violations that occur in urban stormwater runoff. The Agency does not require that the Phase II communities conduct any water quality monitoring of their stormwater runoff. It appears that the Agency developed this approach in order to avoid having to cause smaller communities to participate in the BMP ratcheting-down process. The state pollution control agencies have the option of requiring more effective Phase II stormwater runoff management programs; however, states are reluctant to implement such programs because of the cost to the communities.

A review of the literature on so-called "best management practices" (more properly called "management practices") for urban area and highway stormwater runoff shows that there is a variety of conventional BMPs (such as grassy swales, detention basins, infiltration basins) that are advocated as treatment technologies for urban area and highway stormwater runoff. However, as discussed by Taylor (2000) and Lee and Jones-Lee (2002e), these conventional BMPs will not achieve the removal of potential pollutants from urban area and highway stormwater runoff to a sufficient degree to achieve compliance with water quality standards. As Jones-Lee and Lee (1998b) discussed, these BMPs were developed based on hydraulic considerations, rather than on consideration of removal of constituents of potential concern. Unfortunately, some organizations, such as the Water Environment Federation (WEF) and the American Society of Civil Engineers (ASCE) in their Urban Runoff Quality Management manual (WEF/ASCE, 1998) do not provide reliable information on true water quality issues associated with urban area and highway stormwater runoff and the ability of the management practices (BMPs) discussed in their manual to achieve compliance with water quality standards.

There are several lists of so-called BMPs for treating urban stormwater runoff-associated potential pollutants. The term "BMP" is a misnomer in that the treatment approach, such as a detention basin, grassy swale, vegetative strip, etc., is an approach that will remove some of the potential pollutants under certain conditions. The so-called BMPs should be more properly called management practices that may have some potential to remove some of a chemical constituent that is a potential pollutant. These lists of BMPs are sometimes used in a mechanical way in which the stormwater runoff water quality manager selects one or more BMPs from a BMP handbook or list without properly evaluating whether the management practice will have a significant impact on receiving water quality. This approach can lead to spending public funds just to be able to claim that stormwater runoff is being "treated" to some degree and thereby satisfy the current requirements of the BMP ratcheting-down process.

Conventional so-called BMPs such as detention basins, grassy swales, etc., on a retrofit basis in established areas, can cost $1 to $2 per person per day for the population served by the storm sewer system. A significant problem with the current conventional BMPs is that they primarily remove particulate nontoxic, non-available forms of chemical constituents. While a detention basin may show 50 percent or so removal of lead in stormwater runoff, the lead that is being removed is nontoxic – i.e., not a pollutant. It is important that stormwater managers and the public not be lulled into believing that they are doing something useful by installing conventional BMPs in terms of improving water quality in the receiving waters for the stormwater runoff, when in fact the conventional BMPs may be having little or no impact on the constituents of importance in influencing receiving water quality.

The US EPA and state regulatory agencies adopted the BMP ratcheting-down process, which, if fully implemented, ultimately should achieve compliance with water quality standards; however, the cost of achieving water quality standards in urban stormwater runoff for established urban areas is estimated to be on the order of $5 to $10 per person per day for the population served by the storm sewer system. These costs are based on the cost of developed land acquisition for the stormwater collection system and for the treatment works, and construction, operation and maintenance of the treatment works.

As discussed by Jones-Lee and Lee (1998b), the treatment works necessary to achieve compliance with water quality standards in urban stormwater runoff will need to be based on advanced water and wastewater treatment processes. One of the major costs of treating urban stormwater runoff to achieve compliance with water quality standards is associated with the large volumes of water that must be treated during a runoff event, or stored for subsequent treatment. It has been estimated that 50 storage facilities the size of the Oakland Coliseum would need to be constructed to store all of the Alameda County urban stormwater runoff that discharges to San Francisco Bay. It is clear that treatment of urban stormwater runoff to achieve the same compliance with water quality standards as other NPDES-permitted discharges is not a viable option for managing the water quality impacts of urban area and highway stormwater runoff.

The Water Resources Council of the American Society of Civil Engineers (ASCE, 2000, 2002), under contract with the US EPA (2002e), has compiled a "National Stormwater Best Management Practices (BMP) Database." This database contains approximately 160 BMPs that are used to control constituents in urban stormwater runoff. It is available online from www.bmpdatabase.org. This database presents, in standardized format, information on BMP performance. The BMPs included within this database are detention basins, media filters, grass filters/swales, hydrodynamic devices, infiltration basins, nonstructural BMPs (e.g., street cleaning, maintenance), percolation trenches/dry wells, porous pavements, retention ponds, wetland basins, wetland channels, inlet filters/traps and others. The focus of the ASCE BMP compilation is on across-the-BMP-unit removal of a variety of potential pollutants (such as heavy metals, suspended solids, oil and grease and organics) and includes information on removal of nutrients.

The California Stormwater Quality Association (CASQA, 2003) (formerly the California Storm Water Quality Task Force) has recently updated the California State BMP Handbooks. There are four BMP Handbooks, covering New Development and Redevelopment, Construction, Industrial and Commercial, and Municipal. These Handbooks provide information on the development of stormwater runoff water quality management practices for each of these areas. They are available on the Internet, at http://www.cabmphandbooks.com.

While there are some constituents in urban stormwater runoff, such as pathogen indicators, that affect water quality in urban creeks and lakes resulting in contact recreation/ beach closures, generally there is a poor understanding of the relationship between the concentrations of constituents measured in urban stormwater runoff and urban creeks/lakes, and the impairment of the beneficial uses of these waterbodies. While conventional BMPs (such as detention basins, grassy swales, etc.) are being incorporated into new residential and commercial construction, limited progress is being made in developing management approaches for potential pollutants in stormwater runoff from already developed areas. As discussed by Lee (2000b) and Jones-Lee (2004, NL3-3), even for new development, there are significant questions about the benefits of conventional BMPs in controlling real, significant water quality problems associated with these areas when they are developed. CWP (2003) has discussed some of the issues involved in evaluating the effect of BMPs on receiving water beneficial uses.

One of the issues of major concern with respect to selecting management practices for urban area and highway stormwater runoff is that the current focus is largely on across-the-BMP-unit approach, as measured by a percent-removal of a constituent. As discussed by Jones-Lee and Lee (1998b), this approach is not a valid approach for selecting management practices (BMPs). The selection and evaluation of a management practice for urban stormwater runoff should be based on how well the management practice addresses the real, significant water quality problems in the receiving waters for the runoff – i.e., how well it controls pollution/impairment of beneficial uses of these waters by the stormwater runoff.

Caltrans Studies on BMPs

The California Department of Transportation (Caltrans, 2004) has recently completed a five-year, approximately $15-million study of the ability of various conventional BMPs to remove potential pollutants in runoff from highways in the San Diego area of California. This study was initiated as the result of a settlement agreement between Caltrans and the Natural Resources Defense Council (NRDC), the Santa Monica BayKeeper, the San Diego BayKeeper, and the US EPA, where these groups sued Caltrans for failing to implement BMPs to control constituents in highway runoff. Caltrans agreed to undertake this study as part of evaluating the ability of various BMPs to remove constituents of potential concern in highway stormwater runoff.

According to Taylor and Barrett (2004), the study evaluated 37 BMPs at 33 sites with nine types of technology, including

- Extended detention basin (EDB)
- Drain inlet insert
- Infiltration
- Oil/Water separator
- Media filter (MF)
- Multi-Chambered Treatment Train (MCTT)
- Biofilter
- Wet Basin
- Continuous Deflective Separator (CDS).

Table 1 presents a summary of the percent removal of various types of potential pollutants by the various BMP technologies examined in the Caltrans studies. The negative values represent release of the constituent in the BMP unit. According to Taylor (pers. comm., 2004), the results of the Caltrans studies are similar to the results that have been previously published for these types of BMPs (see Taylor, 2000). Information on various BMPs' ability to remove constituents in street and highway stormwater runoff is also available in CWP (2003) and Burton and Pitt (2002).

Table 1
Summary of Constituent Removal

	TSS	Nitrate	TKN	P
Wet Basin	93%	61%	27%	5%
MCTT	75%	-63%	18%	18%
Austin MF	90%	-71%	41%	39%
Delaware MF	81%	-55%	44%	44%
Bio Strip	83%	36%	47%	7%
Extended Det.	76%	35%	37%	53%
Bio Swale	77%	60%	69%	8%

Strips, Swales, EDBs are Load Reduction
From Taylor and Barrett (2004)

Table 2 presents the Design Storm Concentrations of selected constituents. According to Taylor (pers. comm., 2004), the data presented in Table 2 represent the typical concentrations found in the stormwater runoff from the highways studied by Caltrans in the San Diego, California, area. Examination of this table shows that several of the constituents such as the aquatic plant nutrients (N and P compounds) occur at concentrations that are a threat to cause water quality problems (excessive aquatic plant growth) in the receiving waters. However, in order to evaluate whether their removal will impact the beneficial uses of the receiving waters, site-specific studies of the receiving waters need to be conducted.

Taylor and Barrett (2004) also present information on the removal of dissolved copper by the various BMPs, which ranged from about 15 percent to about 75 percent removal depending on the BMP. While a couple of the BMPs investigated in the Caltrans studies were somewhat effective in removal of dissolved copper, the dissolved copper in the runoff waters or within the receiving waters for the runoff could interact with organics to form nontoxic copper complexes.

Table 2
Design Storm Concentrations

Constituent	Concentration*
TSS	114
Nitrate (as N)	0.97
Total Kjeldahl Nitrogen	2.36
Ortho-phosphorus	0.12
Particulate Phosphorus	0.26
Dissolved Copper	18
Dissolved Zinc	122
Dissolved Lead	8

*Concentration in mg/L except metals which are µg/L
From Taylor and Barrett (2004)

With the adoption of the copper ligand model being developed by the US EPA for adjusting the copper national water quality criterion (http://www.epa.gov/waterscience/criteria/copper/), it could be found that the occurrence of dissolved copper in stormwater runoff from urban areas and highways above worst-case-based water quality criteria/standards would not represent a violation of the water quality standard, as a result of copper complexation by the organics.

Caltrans (2004) reported that, for some of the BMPs (vegetated areas and ponds), some removal of constituents was accomplished through infiltration of the stormwater into the underlying groundwater system. Studies were not conducted, however, to determine if this infiltration resulted in pollution of the groundwaters. As discussed by Lee et al. (1998), the infiltration of urban area and highway stormwater runoff has the potential to cause groundwater pollution. Any BMP that has infiltration of stormwater runoff in the unit should be investigated to determine if this infiltration is leading to groundwater pollution.

One of the problems that was found in the Caltrans studies with the development of BMPs that have standing water was the potential for vector (mosquito) development. This issue is becoming of special significance with respect to the occurrence of West Nile disease.

The Taylor and Barrett (2004) presentation and the Caltrans (2004) report include information on construction costs and maintenance hours required for each of the BMPs investigated. This information is particularly useful for estimating the cost of constructing and operating various types of “conventional” BMPs. For more information on the results of the Caltrans study, see Caltrans (2004).

As discussed above, across-the-BMP-unit removal of constituents is not a reliable measure of the ability of a BMP unit to control real pollutants in the runoff waters that impact the beneficial uses of the receiving waters. Many of the BMPs investigated in the Caltrans as well as other BMP studies can show removal of particulate or complexed forms of pollutants; however, at least for heavy metals, the particulate heavy metals removed are not regulated in the water column of the receiving waters, since the US EPA (1995) water quality criteria and state standards based on these criteria are applicable to dissolved forms of these metals.

As part of an effort to address the issue of the potential water quality benefits of constructing a BMP to "treat" highway stormwater runoff, the senior author (G. F. Lee) proposed to Caltrans that studies be conducted to determine the impact of the BMP treatment on the receiving water beneficial uses. Caltrans management tentatively agreed to fund in excess of a one-million-dollar study of this issue; however, the NRDC attorneys informed Caltrans that it would be inappropriate to conduct such a study. Failure to conduct the proposed water quality impact studies is a significant deficiency in the Caltrans studies, since without the results of such studies, no information is available on the potential benefits of removal of various potential pollutants in highway stormwater runoff on the beneficial uses for the receiving waters for the runoff.

It is apparent that subjecting stormwater runoff from a section of a Caltrans highway to passage through one of the BMPs, while removing certain amounts of potential pollutants, would likely have little or no impact on the beneficial uses of the receiving waters for the runoff treated by the BMP. The same constituents of concern in highway stormwater runoff are also derived from stormwater runoff from area streets and other areas which are not subject to Caltrans control. The reduction in the total load of potential pollutants by subjecting highway stormwater runoff to passage through a BMP would, in general, have little or no impact on the beneficial uses of the receiving waters for the highway stormwater runoff.

Overall

It has become evident that there is need for high-quality water quality monitoring/evaluation programs to determine, for representative locations, the real, significant water quality use impairments that are occurring in urban lakes and streams (and, for that matter, downstream waters) associated with urban area and highway stormwater runoff. This monitoring/evaluation program should include defining the specific sources of the constituents that lead to the water quality use impairments. Once the water quality problems have been defined and the sources of the responsible pollutants identified, then a reliable evaluation can be made of the management practices that can be implemented to control the pollution of urban streams and lakes by urban area stormwater runoff-associated constituents. In general, because of the high cost of treatment, it is likely that the management practices will focus on source control, as opposed to treatment of the stormwater runoff.

The guidance provided by Lee and Jones-Lee (2002d) should be followed in conducting the urban stream/lake water quality monitoring and evaluation program. It will be important to reliably interpret the data from these studies in terms of impairment of beneficial uses. Lee and Jones (1979) have provided guidance on some of the issues that need to be considered in properly interpreting data collected in water quality evaluation programs. One of the issues that needs to be addressed as part of the monitoring and evaluation program is the development of an estimate of the improvement of beneficial uses realized as a result of spending funds to control the concentrations of a real pollutant. Without this evaluation, a situation can readily occur where large amounts of money could be spent controlling a particular constituent that causes potentially significant toxicity, yet little or no impact is realized on the aquatic-life-related beneficial uses of the urban stream or lake.

So long as the US Congress/US EPA continues to try to regulate urban stormwater runoff through NPDES permits, which ultimately requires controlling the constituents in the runoff so that they do not cause violations of water quality standards in the receiving waters, there is need to develop a different approach for regulating chemical constituents that are potential pollutants in urban area and highway stormwater runoff that are a threat to cause impairment of the beneficial uses of an urban stream, lake or other waterbody receiving the runoff. At this time the US EPA water quality management program focuses on a chemical concentration-based approach which does not adequately consider that chemicals can exist in a variety of forms, only some of which impact water quality. It has been recognized for many years (Lee and Jones, 1982) that an alternative approach for water quality regulation is needed which properly considers how chemicals impact the water-quality-related beneficial uses of waterbodies. This is especially true for regulating urban area and highway stormwater runoff water quality impacts, because of the high cost of implementing water pollution control programs based on achieving chemical concentrations in the runoff waters.

The alternative approach should focus on chemical impacts as opposed to chemical concentrations. The chemical concentration approach currently being used by the US EPA is one of the primary reasons why US EPA water quality criteria and state standards based on these criteria tend to significantly over-regulate chemical constituents in urban area and highway stormwater runoff. As discussed by Lee and Jones-Lee (1995/1995), the US EPA's independent applicability policy regarding requiring that chemical-based water quality criteria/standards be met even though biological information shows that the chemical-concentration-based assessment is not an appropriate indicator of water quality impacts needs to be terminated so that water quality impact control becomes the focus of water pollution control programs.

Lee and Jones-Lee (2000, 2003a) have suggested the development of "wet weather" water quality standards that would be applicable to stormwater runoff events. The development of wet weather standards for stormwater runoff has been discussed in Newsletter 6-8 as part of a review of the US EPA's announced "Strategy for Water Quality Standards and Criteria" (US EPA, 2003). These standards would more appropriately consider how chemical constituents in stormwater runoff impact the beneficial uses of receiving waters. They would likely include a weight of evidence evaluation of the relationship between the concentrations of toxic available forms of constituents in stormwater runoff and their impacts on aquatic-life-related resources in the waterbodies receiving the runoff.

References

ASCE, "National Stormwater Best Management Practices (BMP) Database," American Society of Civil Engineers/US Environmental Protection Agency (2000).
www.asce.org/peta/tech/nsbd01.html

ASCE, "National Stormwater BMP Database Doubles," Urban Water Resources Research Council of the American Society of Civil Engineers, *Stormwater* 3:62-63, May/June (2002).

Barbour, M. T.; Gerritsen, J.; Snyder, B. D.; and Stribling, J. B., "Rapid Bioassessment Protocols for Use in Streams and Wadeable Rivers: Periphyton, Benthic Macroinvertebrates and Fish," Second Edition, EPA 841-B-99-002, U.S. Environmental Protection Agency; Office of Water; Washington, D.C. (1999).

Burton, G. A., Jr. and Pitt, R. E., Stormwater Effects Handbook: A Toolbox for Watershed Managers, Scientists, and Engineers, Lewis Publishers, Boca Raton, FL (2002).

Byappanahalli, M. N.; Whitman, R. L.; Fujioka, R. S., "Growth Potential of Indicator Bacteria, *E. coli* and Enterococci, in Natural Temperate and Tropical Soils," Presented at the Fifth International Symposium on Sediment Quality Assessment (SQA5), "Aquatic Ecosystems and Public Health: Linking Chemical, Nutrient, Habitat and Pathogen Issues," Aquatic Ecosystems Health and Management Society, Burlington, Ontario, Canada (2003). (In press.)

Cabelli, V. J.; Dufour, A. P.; McCabe, L. J. and Levin, M. A., "Swimming-Associated Gastroenteritis and Water Quality," *American Journal of Epidemiology,* 115:606-616 (1982).

Caltrans, "BMP Retrofit Pilot Program – Final Report," Report ID CTSW-RT-01-050, Division of Environmental Analysis, California Department of Transportation, Sacramento, CA (2004). http://www.dot.ca.gov/hq/env/stormwater/index.htm

CASQA, "Stormwater Best Management Practice (BMP) Handbooks," California Stormwater Quality Association, Livermore, CA (2003). http://www.cabmphandbooks.com

Cowen, W. F. and Lee, G. F., "Leaves as a Source of Phosphorus," *Environ. Sci. & Technol.* 7:853-854 (1973).

Cowen, W. F. and Lee, G. F., "Phosphorus Availability in Particulate Materials Transported by Urban Runoff," *Journ. Water Pollut. Control Fed*. 48:580-591 (1976).

Cowen, W. F., Sirisinha, K., and Lee, G. F., "Nitrogen Availability in Urban Runoff," *Journ. Water Pollut. Control Fed*. 48:339-345 (1976).

CWP, "Impacts of Impervious Cover on Aquatic Systems," Watershed Protection Research Monograph No. 1, Center for Watershed Protection, Ellicott City, MD (2003). http://centerforwatershedprotection.goemerchant7.com/index.cgi

Daughton, C. G., "Pharmaceuticals and Personal Care Products (PPCPs) as Environmental Pollutants: Pollution from Personal Actions," Presentation at California Bay-Delta Authority Contaminant Stressors Workshop, US Environmental Protection Agency, Las Vegas, NV (2004). daughton.christian@epa.gov

DeltaKeeper, "Low Dissolved Oxygen Problems in the City of Stockton Waterways during November 2002," Presentation to the Central Valley Regional Water Quality Control Board, Sacramento, CA, December (2002).

DFG, "California Stream Bioassessment Procedure," California Department of Fish and Game Water Pollution Control Laboratory, Aquatic Bioassessment Laboratory, Sacramento, CA, December (2003). http://www.dfg.ca.gov/cabw/csbp_2003.pdf

Dufour, A. P., "Health Effects Criteria for Fresh Recreational Waters," Health Effects Research Laboratory, Office of Research and Development, US Environmental Protection Agency, EPA 600/1-84-004, Washington, D.C. (1984).

Environment Canada, "Priority Substances List Assessment Report: Chromium and its Compounds," Canadian Environmental Protection Act, Quebec, Canada (1994).

Harrington, J. and Born, M., Measuring the Health of California Streams and Rivers: A Methods Manual for Water Resource Professionals, Citizen Monitors, and Natural Resource Students, Second Edition, Sustainable Land Stewardship International Institute, Sacramento, CA (1999).

Heinemann, T. J., Lee, G. F., Jones, R. A. and Newbry, B. W., "Summary of Studies on Modeling Persistence of Domestic Wastewater Chlorine in Colorado Front Range Rivers," In: Water Chlorination-Environmental Impact and Health Effects, Vol. 4, Ann Arbor Science, Ann Arbor, MI, pp 97-112 (1983).

Jones, R. A. and Lee, G. F., "Eutrophication Modeling for Water Quality Management: An Update of the Vollenweider-OECD Model," World Health Organization's *Water Quality Bulletin* 11(2):67-74,118 (1986). http://www.gfredlee.com/voll_oecd.html

Jones-Lee, A. (ed.), *Stormwater Runoff Water Quality Science/Engineering Newsletter*, published by G. Fred Lee & Associates, El Macero, CA (2004).
http://www.gfredlee.com/newsindex.htm

Jones-Lee, A. and Lee, G. F., "Evaluation Monitoring as an Alternative to Conventional Water Quality Monitoring for Water Quality Characterization/Management," Proc. of the NWQMC National Conference "Monitoring: Critical Foundations to Protect Our Waters," US Environmental Protection Agency, Washington, D.C., pp. 499-512 (1998a).
http://www.gfredlee.com/wqchar_man.html

Jones-Lee, A. and Lee, G. F., "Stormwater Managers Beware of Snake-Oil BMPs for Water Quality Management," Report of G. Fred Lee and Associates, El Macero, CA, July (1998b).
http://www.gfredlee.com/snakeoil.html

Jones-Lee, A. and Lee, G. F. , "Proactive Approach for Managing Pesticide-Caused Aquatic Life Toxicity," Report of G. Fred Lee & Associates, El Macero, CA, October (2000).
http://www.gfredlee.com/proactivepest_1000.pdf

Kluesener, J. W. and Lee, G. F., "Nutrient Loading from a Separate Storm Sewer in Madison, Wisconsin," *Journ. Water Pollut. Control Fed*. 46:890-936 (1974).

LARWQCB, "Trash TMDL for Los Angeles River Watershed," Los Angeles Regional Water Quality Control Board, Los Angeles, CA (2003).
http://www.swrcb.ca.gov/rwqcb4/html/meetings/tmdl/tmdl_pollutant_trash.html

Lee, G. F., "Copper in San Francisco Bay: Where is the Problem?" Letter to State Water Resources Control Board, Sacramento, CA, May (1994).
http://www.gfredlee.com/pwwqual2.htm#sfbay

Lee, G. F., "Recommended Aquatic Life Toxicity Testing Program for Urban Stormwater Runoff," Comments submitted to E. Bromley, US EPA Region IX, San Francisco, CA, February (1999). http://www.gfredlee.com/recaqtox.pdf

Lee, G. F., "Affidavit of G. Fred Lee on Environmental Assessment dated September 30, 1999, prepared by TRC Environmental Corporation on behalf of Ferry Point Partners LLC," G. Fred Lee & Associates, November (2000a).

Lee, G. F., "Comments on the Petitions of the Cities of Bellflower, *et al*., the City of Arcadia, and Western States Petroleum Association (Review of January 26, 2000 Action of the Regional Board and Actions and Failures to Act by Both the Regional Board and its Executive Officer Pursuant to Order No. 96-054, Permit for Municipal Storm Water and Urban Run-Off Discharges within Los Angeles County), Comments Submitted to the State Water Resources Control Board, Sacramento, CA, June 6 (2000b).
http://www.gfredlee.com/wspa_comments.pdf

Lee, G. F., "Proactive Approach for Managing Pesticide-Caused Aquatic Life Toxicity," PowerPoint Presentation to the Sacramento River Watershed Program Toxics Subcommittee, Sacramento, CA, September 26 (2001). http://www.gfredlee.com/ProActivePest.pdf

Lee, G. F., "Regulating Mercury in the Water Column and Sediments," Report to Dredge Tailings Workgroup, by G. Fred Lee & Associates, El Macero, CA (2003a).
http://www.gfredlee.com/TotalMercuryandDissolvedMercuryStandards-rev.pdf

Lee, G. F., "Additional Studies on the Impact of City of Stockton Stormwater Runoff on Low DO in the SJR DWSC," Report of G. Fred Lee & Associates, El Macero, CA (2003b).
http://www.gfredlee.com/stockton-storm-sept03r.pdf

Lee, G. F., "Comments on Five Mile Slough Aquatic Weed Control Program CEQA Initial Study and Proposed Mitigated Negative Declaration, Prepared for the San Joaquin Area Flood Control Agency by Kleinschmidt Associates and the Huffman-Broadway Group, Inc., Dated May 2003," Comments submitted to the DeltaKeeper by G. Fred Lee & Associates, El Macero, CA (2003c).
http://www.gfredlee.com/Jennings_5milesloEIR.pdf

Lee, G. F., "Comments on Draft Programmatic Environmental Impact Statement/Environmental Impact Report; San Francisco Estuary Invasive Spartina Project: Spartina Control Program, Prepared for the California State Coastal Conservancy and the U.S. Fish and Wildlife Service,

Dated April 2003," Comments submitted to the BayKeeper/DeltaKeeper by G. Fred Lee & Associates, El Macero, CA (2003d).
http://www.gfredlee.com/FinalSpartinacomments6-4-03.pdf

Lee, G. F., "Developing a Reliable Program to Monitor Water Quality Impacts of Aquatic Pesticides," Report of G. Fred Lee & Associates, El Macero, CA (2004).
http://www.members.aol.com/duklee2307/Aq-Pest-MonPgm.pdf

Lee, G. F., Bentley, E. and Amundson, R., "Effect of Marshes on Water Quality," IN: Ecological Studies 10, Coupling of Land and Water Systems, Springer-Verlag, New York, NY, pp 105-127 (1975).

Lee, G. F. and Jones, R. A., "Interpretation of Chemical Water Quality Data," Aquatic Toxicology, ASTM STP 667, American Society for Testing and Materials, pp. 302-321 (1979). Available from http://www.gfredlee.com/pwwqual2.htm

Lee, G. F. and Jones, R. A., "An Approach for Assessing the Water Quality Significance of Chemical Contaminants in Urban Lakes," Proc. Urban Stormwater and Combined Sewer Overflow Impact on Receiving Water Bodies Symposium, EPA 600/9-80-056, US EPA-Cincinnati, OH, pp 32-57 (1980).

Lee, G. F. and Jones, R. A., "Influences of Urban Stormwater Drainage on Water Quality Characteristics of Spring Creek and Parkwood Lake, Fort Collins, Colorado," Occasional Paper No. 73, Department of Civil & Environmental Engineering, New Jersey Institute of Technology, Newark, NJ, December (1981a).

Lee, G. F. and Jones, R. A., "Will EPA's Nationwide Urban Runoff Study Achieve Useful Results?" *Civil Engineering* 51:86-87 (1981b).

Lee, G. F. and Jones, R. A., "An Approach for Evaluating the Potential Significance of Chemical Contaminants in Aquatic Habitat Assessment," Proc. of Symposium, "Acquisition and Utilization of Aquatic Habitat Inventory Information," American Fisheries Society, pp. 294-302 (1982).

Lee, G. F. and Jones, R. A., "Effects of Eutrophication on Fisheries," Reviews in Aquatic Sciences 5:287-305, CRC Press, Boca Raton, FL (1991a). http://www.gfredlee.com/fisheu.html

Lee, G. F. and Jones, R. A., "Indirect Reuse of Domestic Wastewater for Recreational Lakes: Evaluation of the Sanitary Quality of the Yellowhouse Canyon Lakes, Lubbock, Texas," Proc. American Water Resources Association Symposium: "Water Supply and Water Reuse: 1991 and Beyond," San Diego, CA, pp. 435-449, June (1991b).

Lee, G. F. and Jones, R. A., "Evaluation of the Public Health and Water Quality Significance of Lead Residues in Soil: The Need for Better Understanding of Biogeochemistry of Lead," American Chemical Society Symposium on Biogeochemistry of Terrestrial Systems, 1pp, April (1992).

Lee, G. F.; Jones, R. A. and Newbry, B. W., "Alternative Approach to Assessing Water Quality Impact of Wastewater Effluents," *Journal Water Pollution Control Federation* 54(2):165-174, (1982). Available upon request from gfredlee@aol.com.

Lee, G. F., Jones, R. A. and Rast, W., "Availability of Phosphorus to Phytoplankton and Its Implication for Phosphorus Management Strategies," In: Phosphorus Management Strategies for Lakes, Ann Arbor Press, Ann Arbor, MI, pp 259-308 (1980).
http://www.members.aol.com/duklee2307/Avail-P.pdf

Lee, G. F. and Jones-Lee, A., "Water Quality Issues for Copper in San Francisco Bay," Report of G. Fred Lee & Associates, El Macero, CA, 4pp, March (1993).

Lee, G. F. and Jones-Lee, A., "Appropriate Use of Numeric Chemical Water Quality Criteria," *Health and Ecological Risk Assessment*, 1:5-11 (1995). Letter to the Editor, Supplemental Discussion, 2:233-234 (1996). http://www.gfredlee.com/chemcri.htm

Lee, G. F. and Jones-Lee, A., "Independent Applicability of Chemical and Biological Criteria/Standards and Effluent Toxicity Testing," *The National Environmental Journal*, 5(1):60-63, (1995), Part II, "An Alternative Approach," 5(2):66-67 (1995).
http://www.gfredlee.com/tnej.html

Lee, G. F. and Jones-Lee, A. "Chromium Speciation: Key to Reliable Control of Chromium Toxicity to Aquatic Life," Presented at the American Chemical Society National Meeting poster session, San Francisco, CA, April (1997a).

Lee, G. F. and Jones-Lee, A., "Lead as a Stormwater Runoff Pollutant," Report to CA Department of Transportation (Caltrans) by G. Fred Lee & Associates, El Macero, CA, June (1997b).

Lee, G. F. and Jones-Lee, A., "Regulating Copper in San Francisco Bay: Importance of Appropriate Use of Aquatic Chemistry and Toxicology," Presented at the Fourth International Conference on the Biogeochemistry of Trace Elements, Berkeley, CA, June (1997c).

Lee, G. F. and Jones-Lee, A., "Development of Technically Valid, Cost-Effective Hg Control for Sacramento River Delta & Upper San Francisco Bay," Presented at Society of Environmental Toxicology & Chemistry 18th Annual Meeting, San Francisco, CA, November (1997d).

Lee, G. F. and Jones-Lee, A., "Under-Regulation of Chromium in Ambient Waters - Expanded Discussion," Report, G. Fred Lee & Associates, February (1998a).

Lee, G. F. and Jones-Lee, A., "Under-Regulation of Chromium in Ambient Waters," Learned Discourses: Timely Scientific Opinions, *SETAC News* 18(4):22 July (1998b).

Lee, G. F. and Jones-Lee, A., "Development of TMDL Goals and Wet Weather Standards for the Control of Heavy Metals in Urban Stormwater Runoff," Proc. Water Environment Federation nation 73rd Annual Conference, Anaheim, CA, October (2000). http://www.gfredlee.com/wef_heavymetal.pdf

Lee, G. F. and Jones-Lee, A., "Review of the City of Stockton Urban Stormwater Runoff Aquatic Life Toxicity Studies Conducted by the CVRWQCB, DeltaKeeper and the University of California, Davis, Aquatic Toxicology Laboratory between 1994 and 2000," Report to the Central Valley Regional Water Quality Control Board, G. Fred Lee & Associates, El Macero, CA, October (2001). http://www.gfredlee.com/stockton-txt_0401.pdf

Lee, G. F. and Jones-Lee, A., "Organochlorine Pesticide, PCB and Dioxin/Furan Excessive Bioaccumulation Management Guidance," California Water Institute Report TP 02-06 to the California Water Resources Control Board/Central Valley Regional Water Quality Control Board, 170 pp, California State University Fresno, Fresno, CA, December (2002a). http://www.gfredlee.com/OClTMDLRpt12-11-02.pdf

Lee, G. F. and Jones-Lee, A., "City of Stockton Mosher Slough and Five Mile Slough Diazinon and Chlorpyrifos Aquatic Life Toxicity Management Report," California Water Institute Report TP 02-08 to the California State Water Resources Control Board/Central Valley Regional Water Quality Control Board, 44 pp, California State University Fresno, Fresno, CA, December (2002b). http://www.gfredlee.com/StockDiaTMDL12-14-02.pdf

Lee, G. F. and Jones-Lee, A., "Developing Nutrient Criteria/TMDLs to Manage Excessive Fertilization of Waterbodies," Proceedings Water Environment Federation TMDL 2002 Conference, Phoenix, AZ, November (2002c). http://www.gfredlee.com/WEFN.Criteria.pdf

Lee, G. F. and Jones-Lee, A., "Issues in Developing a Water Quality Monitoring Program for Evaluation of the Water Quality - Beneficial Use Impacts of Stormwater Runoff and Irrigation Water Discharges from Irrigated Agriculture in the Central Valley, CA," California Water Institute Report TP 02-07 to the California Water Resources Control Board/ Central Valley Regional Water Quality Control Board, 157 pp, California State University Fresno, Fresno, CA, December (2002d). http://www.gfredlee.com/Agwaivermonitoring-dec.pdf

Lee, G. F. and Jones-Lee, A., "Review of Management Practices for Controlling the Water Quality Impacts of Potential Pollutants in Irrigated Agriculture Stormwater Runoff and Tailwater Discharges," California Water Institute Report TP 02-05 to California Water Resources Control Board/Central Valley Regional Water Quality Control Board, 128 pp, California State University Fresno, Fresno, CA, December (2002e). http://www.gfredlee.com/BMP_Rpt.pdf

Lee, G. F. and Jones-Lee, A, "Regulating Water Quality Impacts of Port and Harbor Stormwater Runoff," Proc. International Symposium on Prevention of Pollution from Ships, Shipyards, Drydocks, Ports, and Harbors, New Orleans, LA, November (2003a). Available on CD ROM from www.ATRP.com. http://www.members.aol.com/duklee2307/PHStormwater-papfinal.pdf

Lee, G. F. and Jones-Lee, A., "Synthesis and Discussion of Findings on the Causes and Factors Influencing Low DO in the San Joaquin River Deep Water Ship Channel Near Stockton, CA: Including 2002 Data," Report Submitted to SJR DO TMDL Steering Committee and CALFED Bay-Delta Program, G. Fred Lee & Associates, El Macero, CA, March (2003b). http://www.gfredlee.com/SynthesisRpt3-21-03.pdf

Lee, G. F. and Jones-Lee, A., "Developing Water Quality Monitoring Programs Associated with the Use of Herbicides in the Control of Aquatic Weeds," Report of G. Fred Lee & Associates, El Macero, CA (2003c). http://www.gfredlee.com/AqWeed_Cont_Mon.pdf

Lee, G. F. and Jones-Lee, A., "Issues that Need to Be Considered in Evaluating the Sources and Potential Control of TOC that Leads to THMs for Water Utilities that Use Delta Water as a Water Supply Source," Report of G. Fred Lee & Associates, El Macero, CA, May 27 (2003d). http://www.gfredlee.com/TOC_update.pdf

Lee, G. F. and Jones-Lee, A., "Appropriate Incorporation of Chemical Information in a Best Professional Judgment 'Triad' Weight of Evidence Evaluation of Sediment Quality," Presented at the 2002 Fifth International Symposium on Sediment Quality Assessment (SQA5), In: Munawar, M. (Ed.), *Aquatic Ecosystem Health and Management* 7(3):351-356 (2004a). http://www.gfredlee.com/BPJWOEpaper-pdf

Lee, G. F. and Jones-Lee, A., "Inadequate Regulation of Potential Water Quality Impacts of Aquatic Pesticides," Report of G. Fred Lee & Associates, El Macero, CA, June (2004b). http://www.members.aol.com/apple27298/InadequateRegAqPest.pdf

Lee, G. F. and Jones-Lee, A., "Assessing the Water Quality Impacts of Phosphorus in Runoff from Agricultural Lands," In: Hall, W. L. and Robarge, W. P., ed., Environmental Impact of Fertilizer on Soil and Water, American Chemical Society Symposium Series 872, Oxford University Press, Cary, NC, pp. 207-219 (2004c). http://www.gfredlee.com/ag_p-1_012002.pdf

Lee, G. F., Jones-Lee, A., and Ogle, R. S., "Preliminary Assessment of the Bioaccumulation of PCBs and Organochlorine Pesticides in *Lumbriculus variegatus* from City of Stockton Smith Canal Sediments, and Toxicity of City of Stockton Smith Canal Sediments to *Hyalella azteca*," Report to the DeltaKeeper and the Central Valley Regional Water Quality Control Board, G. Fred Lee & Associates, El Macero, CA, July (2002). http://www.gfredlee.com/SmithCanalReport.pdf

Lee, G. F., Jones-Lee, A. and Taylor, S., "Developing of Appropriate Stormwater Infiltration BMPs: Part I Potential Water Quality Impacts, Monitoring and Efficacy Evaluation," Proc. of Ground Water Protection Council's 98 Annual Forum, Sacramento, CA, pp. 55-72, Sept (1998).

Lee, G. F., Jones-Lee, A. and Taylor, S., "Evaluation of the Water Quality Significance of OP Pesticide Toxicity in Tributaries of Upper Newport Bay, Orange County, CA," Ninth Symposium on Environmental Toxicology and Risk Assessment: Recent Achievements in Environmental Fate and Transport, ASTM STP 1381, pp 35-51 (2000).

Lee, G. F. and Taylor, S., "Proposed Soil Lead Management Criteria as Part of Caltrans Highway Construction and Maintenance," Report of California Department of Transportation (Caltrans), Sacramento, CA, June (1998). http://www.gfredlee.com/soillead_mgmt.pdf

Lee, G. F. and Taylor, S., "Results of Heavy Metal Analysis Conducted During 2000 in the Upper Newport Bay Orange County, CA Watershed," Report of G. Fred Lee & Associates, El Macero, CA (2001a). http://www.members.aol.com/apple27298/Heavy-metals-319h.pdf

Lee, G. F. and Taylor, S., "Results of Aquatic Toxicity Testing Conducted During 1997-2000 within the Upper Newport Bay Orange County, CA Watershed," Report of G. Fred Lee & Associates, El Macero, CA (2001b). http://www.members.aol.com/apple27298/295-319-tox-paper.pdf

Lee, G. F., Taylor, S., and County of Orange Public Facilities and Resources Department, "Upper Newport Bay Water Quality Enhancement Project, Final Report," Agreement Nos. 8-023-258-0 and 8-174-250-0, submitted to State Water Resources Control Board, Santa Ana Regional Water Quality Control Board and Orange County Public Facilities and Resources Department to meet the requirements of the US EPA 319(h) Project, G. Fred Lee & Associates, El Macero, CA and RBF Consulting, Irvine, CA, May (2001a).

Lee, G. F., Taylor, S., and County of Orange Public Facilities and Resources Department, "Upper Newport Bay/San Diego Creek Watershed 205(j) Water Quality Planning Grant, Final Report," Agreement No. 7-037-250-0, US EPA 205(j) Project, May (2001b).

Lee, G. F. and Winkler, B. A., "Evaluation of the Sanitary Quality of the Yellowhouse Canyon Lakes," Report to city of Lubbock, TX, Buffalo Springs Lake Water Control and Improvement District No. 1, and Village of Ransom Canyon, TX, Department of Civil & Environmental Engineering, New Jersey Institute of Technology, Newark, NJ, May (1984).

McDonald, T. A., "The Risk Posed by the PBDEs, A Class of Flame Retardants," In: 6th Bienniel State of the Estuary Conference, "The San Francisco Bay-Delta Estuary: Changes and Challenges," San Francisco Estuary Project, Oakland, CA (2003).

Menconi, M. and Cox, C., "Hazard Assessment of the Insecticide Diazinon to Aquatic Organisms in the Sacramento-San Joaquin River System," Administrative Report 94-2, California Department of Fish and Game, Environmental Services Division, Pesticide Investigations Unit, Rancho Cordova, CA (1994).

NAS/NAE, Water Quality Criteria 1972, Ecological Research Series, National Academy of Sciences/National Academy of Engineering, EPA-R3-73-033, US Environmental Protection Agency, Washington, D.C., March (1973).

Newbry, B. W. and Lee, G. F., "A Simple Apparatus for Conducting In-Stream Toxicity Tests," ASTM *Journ. of Testing and Evaluation*, 12:51-53 (1984).

Newbry, B. W., Lee, G. F., Jones, R. A. and Heinemann, T. J., "Studies on the Water Quality Hazard of Chlorine in Domestic Wastewater Treatment Plant Effluents," In: Water Chlorination-Environmental Impact and Health Effects, Vol. 4, Ann Arbor Science, Ann Arbor, MI, pp 1423-1436 (1983).

Peterson, J. O., "A Study of Lead in Lake Sediments," Thesis Submitted to the Graduate School of the University of Wisconsin in Partial Fulfillment of the Requirements for the Degree of Doctor of Philosophy, Madison, WI, August (1973).

Pitt, R. E. and Field, R., "Hazardous and Toxic Wastes Associated with Urban Stormwater Runoff," Proc. of the Sixteenth Annual BREL Hazardous Waste Research Symposium, US EPA Office of Research and Development, EPA/600/9-90 037, pp. 274-289 (1990).

Rast, W. and Lee, G. F., "Nutrient Loading Estimates for Lakes," *J. Environ. Engr. Div. ISCHIA* 109:502-517 (1983). See also closure discussion, "Nutrient Estimates for Lakes," *Journ. Environ. Engrg*. 110:722-724 (1984).

Schroeder, D. C. and Lee, G. F., "Potential Transformations of Chromium in Natural Waters," *Water, Air, Soil Pollut*. 4:355-365 (1975).

Schroeder, E. D.; Stallard, M.; Thompson, D. E.; Loge, F. J.; Deshussess, M. A.; Cox, H. H. J., "Management of Pathogens Associated with Storm Drain Discharge: Results of Investigations of the Presence of Human Pathogens in Urban Storm Drains," CTSW-RT-02-025, Report Prepared for the Division of Environmental Analysis, California Department of Transportation, Interagency Agreement No. 43A0073, by the Center for Environmental and Water Resources Engineering, Department of Civil & Environmental Engineering, University of California, Davis, CA, May (2002).

Schueler, T., "The Importance of Imperviousness," *Watershed Protection Techniques* 2(4):100-111 (1994).

Silva, M. A., "Safety Flares Threaten Water Quality with Perchlorate," Report of Santa Clara Valley Water District (2003).
http://www.valleywater.org/Water/Water_Quality/Protecting_your_water/_Lustop/Perchlorate.shtm

SJAFCA, "Five Mile Slough Aquatic Weed Control Program (AWCP) CEQA Initial Study and Proposed Mitigated Negative Declaration," Prepared for the San Joaquin Area Flood Control Agency by Kleinschmidt Associates & The Huffman-Broadway Group, Inc., Stockton, CA (2003).

Stockton, "City of Stockton 1997-1998 Storm Water Monitoring Program," Report prepared for the City of Stockton Department of Municipal Utilities by Kinnetic Laboratories, Inc., Stockton, CA, August (1998).

Taylor, S., “Overview of conventional Stormwater Runoff Water Quality BMP Characteristics and Performance,” In: Jones-Lee (ed.), *Stormwater Runoff Water Quality Science/Engineering Newsletter* 3(2): 1-8 (2000). http://www.gfredlee.com/news/swnews32.pdf

Taylor, S. and Barrett, M., “Caltrans BMP Retrofit Pilot Program,” Presentation at Caltrans BMP Workshop, RBF Consulting, Irvine, CA (2004).

Taylor, S. and Lee, G. F., “Developing of Appropriate Stormwater Infiltration BMPs: Part II Design of Infiltration BMPs,” Proc. of Ground Water Protection Council’s 98 Annual Forum, Sacramento, CA, pp. 73-80, Sept (1998).

Taylor, S. and Lee, G. F., “Evaluation Monitoring Demonstration Project Phase IV,” Eastern Transportation Corridor Drainage Report, submitted to Orange County Transportation Corridor Agency, Silverado Constructors, Irvine CA, December (2000).

US EPA, “Final Report for the Nationwide Urban Runoff Program,” Water Planning Division, US Environmental Protection Agency, Washington, D.C., December (1983).

US EPA, “Ambient Water Quality Criteria for Chromium - 1984,” EPA 440/5-84-029, US Environmental Protection Agency, Washington, D.C., January (1985).

US EPA, “Ambient Water Quality Criteria for Bacteria,” US Environmental Protection Agency, Office of Water Regulations and Standards, Criteria and Standards Division, EPA 440/5-84-002, Washington, D.C., January (1986).

US EPA, “Quality Criteria for Water 1986,” EPA 440/5-86-001, US Environmental Protection Agency, Washington, D. C. (1987).

US EPA, “National Pollutant Discharge Elimination System Permit Application Regulations for Storm Water Discharges; Final Rule,” *Federal Register* 55(222):47990-48091, November 16 (1990).

US EPA, “Methods for Measuring the Toxicity and Bioaccumulation of Sediment-Associated Contaminants with Freshwater Invertebrates,” US Environmental Protection Agency, EPA/600/R-94/024, Washington, D.C., June (1994a).

US EPA, “Water Quality Standards Handbook: Second Edition Appendixes,” EPA-823-B-94-005b, US Environmental Protection Agency, Washington, D.C. (1994b).

US EPA, “Stay of Federal Water Quality Criteria for Metals; Water Quality Standards; Establishment of Numeric Criteria for Priority Toxic Pollutants; States’ Compliance—Revision of Metals Criteria; Final Rules,” US Environmental Protection Agency, *Federal Register*, 60(86):22228-22237 (1995).

US EPA, “Water Quality Criteria and Standards Plan – Priorities for the Future,” EPA 822-R-98-003, US Environmental Protection Agency, Office of Water, Washington, D.C., June (1998).

US EPA, “1999 Update of Ambient Water Quality Criteria for Ammonia,” EPA-822-R-99-014, US Environmental Protection Agency, Washington, D.C., December (1999).

US EPA, “Water Quality Standards; Establishment of Numeric Criteria for Priority Toxic Pollutants for the State of California; Rule,” US Environmental Protection Agency, Region 9, *Federal Register* 40 CFR Part 131, Vol. 65, No. 97, [FRL-6587-9], RIN 2040-AC44, San Francisco, CA (2000a).

US EPA, “Stressor Identification Guidance Document,” EPA/822/B-00/025, US Environmental Protection Agency, Washington, D.C., December (2000b).

US EPA, “Storm Water Phase II Final Rule: Small MS4 Storm Water Program Overview,” EPA 833-F-00-002, Office of Water (4203), US Environmental Protection Agency, Washington, D.C., January (2000c). http://cfpub1.epa.gov/npdes/stormwater/phase2.cfm?program_id=6

US EPA, “Water Quality Criteria for the Protection of Human Health: Methylmercury,” EPA-833-F-01-001, US Environmental Protection Agency, Office of Water, Washington, D.C. (2001a).

US EPA, “Water Quality Criteria: Notice of Availability of Water Quality Criterion for the Protection of Human Health: Methylmercury,” US Environmental Protection Agency, *Federal Register*, 66(5):1344-1359 (2001b).

US EPA, “Nutrient Criteria Development; Notice of Ecoregional Nutrient Criteria,” US Environmental Protection Agency, *Federal Register,* 66(6):1671-1674 (2001c). http://www.epa.gov/fedrgstr/EPA-WATER/2001/January/Day-09/w569.htm

US EPA, “National Recommended Water Quality Criteria: 2002,” EPA-822-R-02-047, US Environmental Protection Agency, Washington, D.C., November (2002a).

US EPA, “Methods for Measuring the Acute Toxicity of Effluents and Receiving Waters to Freshwater and Marine Organisms,” Fifth Edition, US Environmental Protection Agency, Office of Water, Washington, D.C. (2002b). http://www.epa.gov/OST/WET/disk2/

US EPA, Ecotoxicity Database, US Environmental Protection Agency, Office of Pesticide Programs, Washington, D.C. (2002c).

US EPA, “Order Denying Review in Part and Remanding in Part,” NPDES Appeal Nos. 00-14 & 01-09, In re: Government of the District of Columbia Municipal Separate Storm Sewer System NPDES Permit No. DC 0000221, Environmental Appeals Board, US Environmental Protection Agency, Washington, D.C., February 20 (2002d).

US EPA, “Urban Stormwater BMP Performance Monitoring: A Guidance Manual for Meeting the National Stormwater BMP Database Requirements,” US Environmental Protection Agency, EPA-821-C-02-005, Washington D.C. (2002e).

US EPA, “Strategy for Water Quality Standards and Criteria: Setting Priorities to Strengthen the Foundation for Protecting and Restoring the Nation’s Waters,” US Environmental Protection Agency, Washington, D.C. (2003).
http://www.epa.gov/waterscience/standards/strategy/final.pdf

US EPA, “EPA Proposes Federal Water Quality Standards for Beaches,” US Environmental Protection Agency, Washington, D.C. (2004a). http://www.epa.gov/beaches/

US EPA, “Biological Indicators of Watershed Health,” US Environmental Protection Agency (2004b). http://www.epa.gov/bioindicators/html/table_contents.html

US EPA, “Storm Water Management Model (SWMM), US Environmental Protection Agency (2004c). http://www.epa.gov/ceampubl/swater/swmm/

US EPA, “MINTEQA2,” US Environmental Protection Agency (2004d).
http://www.epa.gov/ceampubl/mmedia/minteq/index.htm

US EPA, “Bioaccumulation and Aquatic System Simulator (BASS),” National Exposure Research Laboratory, Ecosystems Research Division, Office of Research and Development, US Environmental Protection Agency, Athens, GA (2004e).
(Contact Craig Barber: 706-355-8110, barber.craig@epa.gov)

WEF/ASCE, Urban Runoff Quality Management, Water Environment Federation Manual of Practice No. 23 and American Society of Civil Engineers Manual and Report on Engineering Practice No. 87, Water Environment Federation, Alexandria, VA, and American Society of Civil Engineers, Reston, VA (1998).

Weston, D. P., “Toxicological Implications of Changing Pesticide Use in the Central Valley, *Norcal SETAC News* 13(1):15-16, March (2002).

Weston, D. P.; You, J. and Lydy, M. J., “Distribution and Toxicity of Sediment-Associated Pesticides in Agriculture-Dominated Water Bodies of California’s Central Valley,” *Environmental Science & Technology* 38(10): 2752-2759 (2004).

Woods, P., pers. comm., US Environmental Protection Agency, Region 9, San Francisco, CA (2000).